

Doctoral Thesis

An analysis of Chiang Mai city's transport system and its path towards sustainability, with a focus on the role of the motorcycle and the shared-taxi

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Dipl.-Ing. Peraphan Jittrapirom M Eng
Matrikelnummer 0928527
Fasangasse 39-41/4/11
1030 Wien

Erstbegutachter: Em. O. Univ. Prof. DI Dr. techn.
Hermann Knoflacher
Institut für Verkehrswissenschaften,
Technische Universität Wien
Gusshausstraße 30/230
1040 Wien

Zweitbegutachter: Univ.-Prof. Dipl.-Ing. Dr. techn.
Markus Mailer
Institut für Infrastruktur, Universität Innsbruck
Technikerstraße 13,
A-6020 Innsbruck

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Abstract

This thesis addresses the challenge of developing and implementing sustainable transport policies to mitigate negative environmental impacts caused by rapid growth of urbanised city areas within Southeast Asia.

The recent trend towards urbanisation in Southeast Asia has seen many cities grow at a phenomenal rate as people have moved away from rural areas in search of employment. Resulting pressure on city transport systems has increased traffic congestion, air pollution, and the number of traffic accidents, with correspondingly detrimental effects on the quality of life.

Acknowledging the challenging nature of attaining a sustainable transport system, this research investigates the potential of the motorcycle and the shared-taxi to improve sustainability within an urban transport system. Chiang Mai was chosen as the case study; it is the biggest city in Northern Thailand and, in recent years, has experienced rapid population growth, which has resulted in worsening transport problems. Motorcycles currently outnumber cars and are the preferred means of transport for local city residents. In addition, a form of shared-taxi service, which uses converted pick-up trucks, has operated within the city and the surrounding locality for over 50 years.

The study begins with (a) a review of relevant past literature on these two modes of transport, (b) an analysis of previous studies of the city's transport system, and (c) a comparison of MARS (Metropolitan Activity Relocation Simulator) with five other sustainable transport planning models.

The comparison indicated MARS was suitable for analysing the city's transport system; it operates at an urban level and has a track record of transferability for use in cities across different continents. Modifications to MARS were made to reflect the dominance of motorcycle transport and further changes accommodated analysis of the shared-taxi. The result is the Chiang Mai Metropolitan Activity Relocation Simulator (CNX-MARS). The System Dynamics (SD) model in CNX-MARS and Systems Thinking are the primary analytical tools used in this study.

By tracing the development timeline of the city's transport system, the current context of its inherent problems was established. The timeline demonstrates the speed at which Chiang Mai has transformed from a "walking" city to a highly motorized city,

plagued by traffic congestion and near-gridlock conditions in some central areas during peak travel times.

A survey of 2,319 households was carried out to gather empirical data about the mobility behaviour of the city's residents. This data is used, in combination with data from other secondary sources, to uncover the underlying trends and attributes of the city's transport system. For example, an in-depth trip distribution analysis of the primary data revealed the dominance of motorcycle usage whereas shared-taxis are used for only 1% of all trips made by local residents.

The complexity of the transport system and the difficulties faced in formulating suitable measures to resolve the issues were examined next, using a tailored Causal Loop Diagram (CLD) to simulate the interactions between different entities, such as the effect on the environment of preferred extensive use of privately owned vehicles when compared with public transport.

This qualitative model is also used to review the effects of solutions offered by local decision makers responsible for Chiang Mai's transport policy and its implementation. The assessment shows a wide gap between the perceived best fit solutions preferred by decision makers and the forecast results of these measures when implemented within the transport system.

The solutions suggested by the decision makers are combined with other proposals to form 16 alternative transport policies for the city. An assessment framework is created to evaluate these policies quantitatively. The framework is based on the policy makers' vision for the sustainability of the city and the results accessed from CNX-MARS.

The qualitative and quantitative policy assessments reveal a number of interesting points. They show that the promotion of motorcycle ownership and usage will yield localised enhancements, but worsen the overall condition of the system in the long term. However, if a form of parking management is implemented in tandem with this measure, such as restricting on-road car parking and increasing motorcycle parking space, an overall improvement of the system can be achieved. The assessment also shows that improvement to the shared-taxi service, without changing its organisational structure, brings limited benefit.

Moreover, the assessments revealed that despite the high commitment to solve the city's transport problems, the decision makers are likely to deploy measures that improve one aspect of transportation but detrimentally affect the system as a whole. This finding points toward the need for a transport planning tool that aids decision makers' understanding of the complex interaction between different entities within the transport system.

In summary, the results of this research contribute towards solving the persistent transport problems of Chiang Mai by:

1. Demonstrating the application of System Dynamics in CNX-MARS, assessing its transferability in the context of Asian cities and making incremental improvements to the functionality of the model
2. Showing the importance of understanding the context of the transport system and how its component parts interact.
3. Collecting empirical mobility data from 2,319 households, which, for the first time in transport-related research studies about Chiang Mai, included walking time to and from embarkation/disembarkation points. Understanding the effect of walking time on trip mode choice provides city transport planners with additional information to be considered when formulating sustainable transport policy.
4. Analysing the attributes of motorcycle and shared-taxi trips within the context of the transport system. Contrary to expectations, the analysis reveals that promotion of the motorcycle provides only short-term benefits and, despite its high visibility in the city, the shared taxi is currently the least used transport mode by local residents. The study also shows that without radically changing its organisational structure, suggested improvements to the shared taxi service will bring limited benefits to the system.
5. Providing a suite of qualitative and quantitative tools, including the creation of an assessment framework, to support future city transport decisions. With modifications, these tools are transferable for use in other Southeast Asian cities which have similar characteristics to Chiang Mai's transport system.

Although a definitive solution to the city's transport problems has not been reached, the study provides a robust and transferable methodology to test and analyse the sustainability of proposed transport policies. The study also demonstrates that it is possible for the city's transport system to improve its sustainability by significantly lowering its fuel consumption and CO₂ emissions.

This can only be achieved, however, by resolutely shifting gear; there needs to be significant change at the strategic level of formulating transport policy and at the personal level of persuading residents to move away from their dependence on privately owned vehicles.

The linchpin is strong government and political commitment to implement measures that may initially prove unpopular, such as road closures and parking management, but which will eventually improve the overall condition of the transport system.

The methodologies used and the results obtained within this study are evidence that their adoption can contribute to changing the current *status quo* to bring about much needed improvements to the system.

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Abbreviation list

AADT	Annual average daily traffic
CBD	Central Business District
CM-DLT	Chiang Mai's Department of Land and Transport
CLD	Causal Loop Diagram
CM-LTSS	Chiang Mai Province Land Transport System Management Subcommittee
CM-MTS	Chiang Mai mobility and travel survey
CMPC	Chiang Mai Principle City Area
CNX-MARS	Chiang Mai Metropolitan Activity Relocation Simulator model
CO ₂	Carbon dioxide
CTC	Chiang Mai Transport Co-operative
DOH	Department of Highway
DOPA	Department of Provincial Administration
DPT	Department of Public work and Town and country Planning
DRR	Department of Rural Roads
EXAT	Department of Express Way
FSM	Four-stage modelling
GPP	Gross Provincial Product
HCM	Highway Capacity Manual
HWH	Home-work-home tour rate
ICM	Climate Change and Infrastructure Research Unit
IEA	International Energy Agency
ITS	Intelligent transportation system
IVV	Research Centre of Transport Planning and Traffic Engineering
JICA	Japan International Cooperation Agency
LPG	Liquefied petroleum gas
LTC	Lanna Transportation Co-operative
LTSC	National Land Transport System Management Committee
LUTI	Land use and Transport Interaction
MARS	Metropolitan Activity Relocation Simulator
NESDB	National Economic and Social Development Board
NESDP	National Economic and Social Development plan
NHCL	National Highway Construction Legislation
NMT	Non-motorised transport (i.e. walking cycling)
NSO	National Statistic Office
OCMLT	Office of the Commission for the Management of Land Traffic
OTP	Office of Transport and Traffic Policy and planning
PATA	Pan Asia Travel Association)
PT	Public Transport
PTW	powered two-wheeler
SD	System Dynamics
ST	Sustainable transport
SRT	State Railway of Thailand MRTA Mass Rapid Transit Authority
STC	Sankampang Transport Co-operative
TTB	Travel Time Budget
VKT	Vehicle-kilometre travel

Table of Contents

Abstract	i
Acknowledgement.....	v
Abbreviation list	vii
Table of Contents.....	i
Figures.....	vi
Graph.....	viii
Tables.....	ix
Tables of equations	xi
Tables of boxes	xi
1. Introduction.....	1
1.1. Sustainability in urban transport system	1
1.2. The unsustainable nature of Thailand's transport system.....	2
1.3. Chiang Mai urban transport system	5
1.4. Objectives and research questions	6
1.5. Scope and methodology of the study	7
1.6. Introducing Sustainable transport (ST), System Approach, and System Dynamics (SD) 10	
1.6.1. Sustainable Transport (ST).....	10
1.6.2. Systems Approach and System Dynamics (SD).....	12
2. Literature reviews.....	14
2.1. Introduction.....	14
2.2. Background of Chiang Mai city	14
2.3. Literature related to the motorcycle.....	16
2.3.1. Motorcycle safety	17
2.3.2. The motorcycle in traffic engineering.....	17
2.3.3. Motorcycle ownership and usage	18
2.3.4. The motorcycle, sustainability, and its effects on land use	19
2.4. Literature related to Shared-taxi as a form of paratransit.....	21
2.5. Position of MARS in sustainable transport planning	22
2.6. Literature review findings on Chiang Mai transport problems.....	25
3. The Development of Chiang Mai City, its Transport System and Land Use	29
3.1. Introduction.....	29
3.2. The founding of Chiang Mai city	29
3.3. Development of the city's transport system	36
3.3.1. The Non-motorisation period (1296 – 1900)	36
3.3.2. The Motorised period (1901-present)	41
3.3.3. Development of road infrastructures	55
3.4. Development of the city's land use.....	58
3.5. Factors that influence transport and land use development.....	64
3.6. Chapter findings and discussion.....	67
4. Urban socio-demographics and transport indicators	72
4.1. Introduction.....	72
4.2. Socio-demographic trends.....	72
4.2.1. Population and household	72

4.3.	Mobility trends.....	76
4.3.1.	Vehicle ownership and number of motorised vehicles	76
4.3.2.	Ratio between Car and The motorcycle ownership	81
4.3.3.	Trip purpose.....	83
4.3.4.	Mode share.....	83
4.3.1.	Trip origin.....	85
4.3.2.	Annual Average Daily Traffic (AADT).....	85
4.3.3.	Daily trip rate.....	86
4.3.4.	Average travel time and distance	87
4.3.5.	Transport infrastructure in the municipality	88
4.4.	Household expenditure	89
4.5.	Informal observations made during the CM-MTS.....	91
4.6.	Chapter findings and discussion.....	99
5.	Mobility analysis.....	103
5.1.	Introduction.....	103
5.2.	Limitation and validation of the data set	103
5.3.	Trip distribution analyses.....	105
5.3.1.	Trip purpose.....	105
5.3.2.	Trip modes	109
5.3.3.	Sex.....	114
5.3.4.	Registration status.....	117
5.3.5.	Household location.....	120
5.3.6.	Household monthly income	123
5.4.	Walking time to/from embarkation points	131
5.5.	Mobility and Urban sprawl.....	133
5.5.1.	Urban sprawl and the richer household	133
5.5.2.	Relationship between urban sprawl, vehicle ownership, and vehicle use	136
5.5.3.	Urban sprawl in the motorcycle dominated city	138
5.6.	Analyses findings and discussions	140
6.	Understanding Chiang Mai city's transport problems	144
6.1.	Introduction.....	144
6.2.	Conventional definitions of urban transport problem.....	144
6.2.1.	Transport problems catalogue.....	146
6.2.2.	Interconnectedness between transport problems.....	147
6.3.	Validation of the CLD using Chiang Mai city data	150
6.4.	Perspectives of the decision makers.....	155
6.4.1.	Methodology.....	156
6.4.2.	Content categorisation.....	159
6.4.3.	Theme consistency analysis.....	166
6.4.4.	Priority analysis.....	170
6.4.5.	Causal analysis	171
6.5.	Results	176
7.	Vision for Chiang Mai city transport system.....	178
7.1.	Introduction.....	178
7.2.	Sustainable transport vision for Chiang Mai city	178
7.2.1.	Sustainable transport visions.....	179
7.2.2.	Sustainable transport objectives.....	180

7.2.1.	Sustainable transport indicators and background variables.....	181
8.	Chiang Mai city MARS model.....	184
8.1.	Transferability of MARS and possible improvements	184
8.1.1.	Travel Time Budget (TTB).....	184
8.1.2.	Subjective valuation of friction factor.....	188
8.1.3.	Area speed flow relationship.....	189
8.1.4.	PT overcrowding.....	191
8.1.5.	Accessibility	191
8.1.6.	Modes of transport.....	192
8.1.7.	Vehicle availability	192
8.1.8.	Tour rates.....	194
8.1.9.	Frequency of household relocation.....	198
8.1.10.	The quality of life indicator.....	199
8.1.11.	Update zonal demographic characteristic	200
8.1.12.	Update emission and fuel consumption module.....	200
8.1.13.	Selecting improvements and conclusion	200
8.2.	Development of the model.....	202
8.2.1.	Principle assumptions of the data used	203
8.2.2.	Quality of life indicators.....	210
8.2.3.	Homogenous use of land within each zone	210
8.2.4.	Calibration and testing of the model	211
8.3.	Chapter conclusion.....	211
9.	Scenario assessments	213
9.1.	Modelling scenarios	213
9.2.	Scenarios set A1-3: Baseline with different vehicle growth rates	215
9.2.1.	Scenario A1: Business as Usual (BAU)	216
9.2.2.	Scenario A2: High car growth	216
9.2.3.	Scenario A3: High motorcycle growth	216
9.2.4.	Discussion of results	216
9.2.5.	Summary of results	220
9.3.	Scenario set B: Motorised transport development.....	223
9.3.1.	Scenario B1: Increase in road capacity.....	223
9.3.2.	Scenario B2: Promotion of motorcycle	223
9.3.3.	Scenario B3: Promotion of motorcycle with mitigation.....	224
9.3.4.	Motorcycle promotion effects on impacts delay.....	226
9.3.5.	Summary of results	228
9.4.	Scenario set C: Sustainable transport Chiang Mai	231
9.4.1.	Scenario C1: Full scale public transport system.....	231
9.4.2.	Scenario C2: Decrease in road capacity.....	232
9.4.3.	Scenario C3: Enhancements to walking and cycling facilities	232
9.4.4.	Scenario C4: Parking management.....	233
9.4.5.	Scenario C5: Shared-taxi service improvement	234
9.4.6.	Scenario C6: Land development control.....	235
9.4.7.	Scenario C7: Combined policies.....	236
9.4.8.	Summary of results	237
9.5.	Scenario set D: Other scenarios.....	241
9.5.1.	Scenario D1: Post Peak-oil.....	241

9.5.2. Scenario D2: Cheap oil.....	242
9.5.3. Scenario D3: Visionary	243
9.5.4. Summary of results	246
9.6. Chapter findings and conclusion	249
10. Conclusions	251
10.1. Summary of Main findings	252
10.1.1. Literature review (Chapter 2)	252
10.1.2. Development of the city's land use and transport system (Chapter 3)	253
10.1.3. Trends observation (Chapter 4) and Analysis of mobility behaviour (Chapter 5)	255
10.1.4. Understanding transport system and evaluate the perceptions of the decision makers (Chapter 6)	258
10.1.5. Establish the goal: A sustainable transport vision (Chapter 7).....	259
10.1.6. MARS and assessment of transport policy (Chapter 8 and 9)	260
10.2. Significance and limitation of the study	262
10.3. Recommendations	267
10.4. Discussion.....	268
10.4.1. Can promotion of the Motorcycle be part of the solution for a more sustainable transport system?	268
10.4.2. Shared-taxi, a marginal public transport service with potential?	270
10.4.3. A suitable form of public transport for the city?	273
10.4.4. From a System's perspective... ..	280
10.4.5. Urban sprawl, likely but inconclusive.....	287
10.4.6. The need for training on Systems thinking and open discussions.....	287
10.4.7. Use of transport models as tools for decision makers.....	288
10.5. Conclusion.....	289
Appendices.....	291
Appendix A: Past studies on Chiang Mai city's transport problems.....	292
Transport system planning related.....	292
Public transport system provision	299
Environment and air qualities	305
Non-motorised transport	309
Other relevant studies.....	310
Appendix B: A suitable transport model for sustainable transport planning	311
Chiang Mai city's state of the Practise: the Four-stage model (FSM).....	311
Land use and transport interaction (LUTI) model	314
Sustainable transport system planning models	316
Appendix C: Chiang Mai mobility and transport survey (CM-MTS).....	327
Introduction and Background	327
Comparison with other cities' mobility surveys.....	328
Appendix D: Summary of decision maker's interviews	331
Respondent No. 1	331
Respondent No. 2	332
Respondent No. 3	333
Respondent No. 4	334
Respondent No. 5	334
Respondent No. 6	335

Respondent No. 7	336
Respondent No. 8	337
Respondent No. 9	338
Respondent No. 10	339
Respondent No. 11	339
Respondent No. 12	340
Respondent No. 13	341
Respondent No. 14	342
Appendix E: Definitions of Sustainability and Sufficiency Economy	343
Sustainability or Sustainable development	343
Sufficiency Economy	346
Appendix: F MARS model concise descriptions.....	349
Transport sub-model.....	350
Land use sub-model.....	350
Friction factor and subjective valuation principles	351
Accessibility.....	353
Connection between subsystems in each iteration	353
Use of MARS model in strategic Land use and transport planning	354
Appendix G: Fuel consumption and emission Equations	356
Appendix H: About the author	357
Bibliography	358

Figures

Figure 1-1 Area covered by this study and the CM-MTS.....	9
Figure 1-2 Possible effects of unsustainable transport system	11
Figure 2-1 Chiang Mai province, Aumpor Muang district, and Municipality of Chiang Mai	15
Figure 2-2 Sylvester H. Roper's and today's motorcycle	17
Figure 3-1 Land use guidance in Chiang Mai city according to Loa tradition and King Mangrai's status	31
Figure 3-2 Chiang Mai city in the early period (1296 - 1334), the middle period (1357 - 1457), the declining period (1558) and the modern period (2003).....	32
Figure 3-3 Illustration of Ville de Xieng Mai, inner city area (1885).....	33
Figure 3-4 Inner Chiang Mai city wall and Moat in present day	34
Figure 3-5 Pratu Chang Moi gate and La ville de Xieng Mai	34
Figure 3-6 Locations of the city gates and probable road network during early period	35
Figure 3-7 Walking distance within inner and outer wall of Chiang Mai city.....	36
Figure 3-8 Porter service and Lanna women carrying goods to market.....	37
Figure 3-9 Elephant used by the elite class in 1902 and ox cart.....	38
Figure 3-10 Advantage of ox on uneven and muddy road, the last ox cart in Chiang Mai city 1967	39
Figure 3-11 Scorpion-tailed boat approaching Chiang Mai bridge	39
Figure 3-12 Bicycle in Chiang Mai	40
Figure 3-13 Tricycle service in the past and today (1975).....	41
Figure 3-14 A private car in Chiang Mai – pre Second World War period	42
Figure 3-15 Traffic jam on Thapae Road in 1954 and an old petrol station	43
Figure 3-16 The motorcycle in Chiang Mai in 1987, today, cargo carrier, and shop set up	44
Figure 3-17 Earlier forms of shared-taxi – Rot Koob (รถคู่ปล) and Rot Kok Moo (รถคอกหมู)	44
Figure 3-18 Fixed route service (or Rot Queue).....	45
Figure 3-19 Shared-taxi or Song Teaw (non-fixed route)	46
Figure 3-20 Abandoned Charempol Transport's white bus and Chiang Mai Thai Transport's yellow bus in operation.....	50
Figure 3-21 Four bus routes run by the municipality as of 2012	51
Figure 3-22 Tuk-Tuk or motorised tricycle.....	52
Figure 3-23 Chiang Mai Bangkok railway line and Chiang Mai train station in 1952	53
Figure 3-24 Road reconstructions in 1961 and 1965	56
Figure 3-25 Radial and ring roads of Chiang Mai city	57
Figure 3-26 Development of Chiang Mai city through times (1893-2012)	60
Figure 3-27 Locations of residential development within the Principle city area	62
Figure 3-28 Changes in dominant mode of intercity transport of Chiang Mai city	62
Figure 3-29 Changes of factors that influence the city's land use and transport planning	67
Figure 4-1 A pocket of undeveloped land within the municipality area.....	92
Figure 4-2 Single house	93
Figure 4-3 Shop house and townhouse.....	93
Figure 4-4 Apartments and flats	94
Figure 4-5 Narrow and winding roads within the municipality area	95
Figure 4-6 Use of non-motorised transport modes in Aumpor Muang and outer districts areas	96

Figure 5-1 Household location and Income percentile of respondents.....	134
Figure 6-1 Transport – a means to overcome distance	146
Figure 6-2 Transport problem CLD (First version)	147
Figure 6-3 Transport problem CLD by Morichi & Acharya, (2012, p. 61).....	148
Figure 6-4 Revised transport problem CLD	148
Figure 6-5 Four entities considered in the analysis (in bold border)	151
Figure 6-6 Correlations between the calibrated entities	155
Figure 6-7 Members of Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS).....	158
Figure 6-8 Impact assessment of the road capacity expansion measure	173
Figure 7-1 Sustainable Transport system and its seven objectives	181
Figure 8-1 Location of marketplaces and shopping centres in the municipality area.....	199
Figure 8-2 CNX-MARS zone system (28 Zone)	203
Figure 10-1 the push-and-pull approach towards less car traffic in urban areas measures..	279
Figure A-1 ENTASIM model structure.....	298
Figure A-2 Chiang Mai road condition forecast (2005, 2010, and 2014).....	301
Figure B-3 Four-stage model (FSM)	311
Figure B-4 Manheim/Florian Transport Systems Analysis framework.....	313
Figure B-5 State of the practice of the Chiang Mai city model	314
Figure B-6 Land use and transport feedback cycle	315
Figure B-7 Extract from MARS model	316
Figure B-8 MARS graphical and animated output for easy comparison between different scenarios	317
Figure B-9 ASTRA model basic structure.....	319
Figure B-10 TREMOVE model basic structure.....	320
Figure B-11 TRESIS model basic structure	322
Figure B-12 UrbanSim model basic structure	324
Figure B-13 PROPOLIS analytical framework.....	326
Figure E-14 Philosophy of Sufficiency Economy.....	347
Figure E-15 Sustainable Development and Sufficiency Economy	348
Figure F-16 MARS sub-models at the highest aggregate level.....	349
Figure F-17 MARS transport sub-model and two land use sub-models.....	349
Figure F-18 Components of a public transport trip from origin i to destination j in MARS.	352
Figure F-19 Components of a public transport trip from origin i to destination j in MARS.	352
Figure F-20 Connection of MARS sub-models in different time steps.....	354
Figure F-21 Application of MARS in land use and transport policy appraisal framework ..	355

Graph

Graph 2-1 Primary energy in consumption, production, and operation of each mode.....	21
Graph 3-1 Total road and rail network lengths in Thailand	54
Graph 3-2 Area of Chiang Mai city through 1296-2012	59
Graph 4-1 Registered population and households, classified by area between 2002-2011	73
Graph 4-2 Motorised vehicle and bicycle ownership (in % of total respondent households) in 2011	78
Graph 4-3 Number of vehicles registered in Chiang Mai province per 1000 capita	79
Graph 4-4 Number of vehicles registered in Chiang Mai province and Vienna city per 1000 capita.....	80
Graph 4-5 Chiang Mai Province's car per motorcycle ratio.....	82
Graph 4-6 Trip purpose (in % based on total daily trip)	83
Graph 4-7 Comparison of daily trip origin (in % of surveyed trips)	85
Graph 4-8 AADT of selected highways within Chiang Mai city 1994-2010	86
Graph 4-9 Comparison of daily trip rate (trips per person per day)	87
Graph 4-10 Household monthly expenditures in different categories (in % of total sampled households).....	90
Graph 4-11 Percentage of household monthly spending in accommodation and transport ..	91
Graph 4-12 Observed relationship between accommodation and transport costs / distance.	97
Graph 5-1 Trip distance distribution, classified by trip purpose	107
Graph 5-2 Trip time distribution, classified by trip purpose.....	107
Graph 5-3 Trip distance and time distributions, by trip purpose (Motorcycle and shared-taxi trips only)	108
Graph 5-4 Trip distance distribution, classified by trip modes.....	111
Graph 5-5 Trip time distribution, classified by trip modes.....	112
Graph 5-6 Trip distance and time distributions, classified by trip modes and household location	113
Graph 5-7 Trip distance and time distributions, classified by trip modes and sex	116
Graph 5-8 Trip distance and time distributions, classified by registration status	118
Graph 5-9 Trip distance and time distributions, classified by registration status for motorcycle and shared-taxi trips	119
Graph 5-10 Trip distance distribution, classified by household location	122
Graph 5-11 Trip time distribution, classified by household location	122
Graph 5-12 Trip distance distribution, classified by trip makers' household income and income percentiles	126
Graph 5-13 Trip time distribution, classified by trip makers' household income and income percentiles	127
Graph 5-14 Trip distance and time distributions, classified by trip modes and monthly household income	129
Graph 5-15 Trip distance and time distributions, classified by trip modes and monthly household income percentiles.....	130
Graph 5-16 Walking time to/from embarking point of different modes.....	131
Graph 5-17 Official urban area, vehicle-kilometre travel (VKT) on the national highways, and vehicle ownership (per 10,000 capita) of Chiang Mai province	138
Graph 6-1 Annual VKT per capita on the national highways within Chiang Mai province and the highway's length.....	152

Graph 6-2 National highways length within Chiang Mai province and the city area	153
Graph 6-3 Vehicle ownership and annual VKT of Chiang Mai province	154
Graph 6-4: The respondents' view on Chiang Mai city's sustainability	160
Graph 6-5: The opinion of the respondents on the differences between Sufficiency Economy and sustainability	163
Graph 6-6 the respondents' opinion on the city's transportation problems.....	163
Graph 8-1 Average daily travel time of the CM-MTS respondents, by different sex, household location, and income groups.....	187
Graph 8-2 Comparison between the freeway speed-flow curves from HCM 1994, uses in MARS (left) and the revised HCM 2010 (right)	190
Graph 8-3 Bicycle ownership in household and accessibility to bicycle by person	193
Graph 8-4 Thailand's national population forecast 2011-2041	204
Graph 9-1 Role of motorcycle in delaying adverse effects of transportation	218
Graph 9-2 Cumulative fuel consumption and CO2 emission for Scenario A1, B2, and B3...	227
Graph 9-3 Brent oil sport price vs. Thai petrol retail price.....	242

Tables

Table 1-1 Differences between conventional and sustainable transport approach	12
Table 2-1 Area, population, and density of Chiang Mai	15
Table 2-2 Results of the models' comparison.....	24
Table 3-1 Chiang Mai bus operators' timeline	49
Table 3-2 Radial and ring roads of Chiang Mai city	57
Table 3-3 Land use change within the CMCP between 1989 and 2009	61
Table 3-4 National Economic and Social Development Plan (NESDP) that affected the city ..	66
Table 4-1 Proportion of shadow population within the CM-MTS respondents	74
Table 4-2 Estimation of shadow population from electricity usage Sep – Dec 2011	75
Table 4-3 Adjusted population for Chiang Mai city 2011	75
Table 4-4 Comparison of vehicle ownership per 1000 capita	76
Table 4-5 Vehicle/Household size ratio (in % of total sampled households)	77
Table 4-6 Comparison of vehicle ownership between Chiang Mai and other cities	77
Table 4-7 Comparison of vehicle ownership per household in 2011	78
Table 4-8 Annual growth rate for different vehicle types in Chiang Mai province	81
Table 4-9 Comparison of mode share with adjusted values (in % of surveyed trips).....	84
Table 4-10 Comparison of average daily travel time and distance (minutes and kilometre) ..	87
Table 4-11 Walking trip time proportion in 2002 and 2012.....	88
Table 4-12 Road infrastructure within municipality and Aumpor Muang in 2009.....	88
Table 4-13 Average household monthly expenditure (in Baht)	89
Table 5-1 Trip speed validation.....	104
Table 5-2 Mode share before and after validation.....	104
Table 5-3 Mode share by trip purpose	105
Table 5-4 Average trip time and trip distance by trip purpose	106
Table 5-5 Statistical analysis of CM-MTS trip data by trip modes.....	109
Table 5-6 Average trip distant, time, and speed for motorcycle users in different cities	111
Table 5-7 Proportion of respondents and trips by sex.....	114
Table 5-8 Mode share by respondents' sex.....	115
Table 5-9 Mobility indicators by sex.....	115

Table 5-10 Mobility indicators of the motorcycle and shared-taxi by sex.....	115
Table 5-11 Number and proportion of respondents and trip made by registration status ...	117
Table 5-12 Mobility indicators by registration status.....	117
Table 5-13 Mode share by registration status	118
Table 5-14 Proportion of households, persons, and trips surveyed classified by household location	120
Table 5-15 Mode share by household location (in % of total daily trip of each area)	120
Table 5-16 Mobility indicators by household location.....	121
Table 5-17 Sample distributions by income group and income/family size methods	123
Table 5-18 Mode share by trip makers' household income (Baht).....	124
Table 5-19 Mobility characteristic of each income groups	125
Table 5-20 Average walking time between origin/destination and embarkation points.....	132
Table 5-21 Average land price for different area of Chiang Mai city	133
Table 5-22 Average trip time and distance of different income percentiles (by trip purpose)	135
Table 5-23 Speed required to contain travel time from the edge of the city area to its centre at 40 minutes as urban area expands.....	137
Table 5-24 Mobility indicators comparison between car and the motorcycle	139
Table 6-1: Conventional urban transport problems	146
Table 6-2 Timeline of Chiang Mai city urbanised area.....	153
Table 6-3: The respondents' definition of a sustainable city	159
Table 6-4: Factors the respondents believe to reduce the sustainability of the city	161
Table 6-5: Measures the respondents believe will maintain the sustainability level of the city	161
Table 6-6: The effects the respondents believe will occur as the sustainability level of the city reduces.....	162
Table 6-7: The group of people the respondents believe will be affected by the reduction in the city's level of sustainability	162
Table 6-8 Factors the respondents believe to be the causes of the city's transportation problems.....	164
Table 6-9: Mitigation measures the respondents believe will solve the city's transportation problems.....	165
Table 6-10: Matching respondents' answers on questions related to sustainability	167
Table 6-11: Matching respondents' answers on questions related to the city's transport problems.....	169
Table 6-12: Ranking of category related to sustainability	170
Table 6-13: Ranking of category related to Chiang Mai transport problems	171
Table 6-14: Proposed mitigation to solve the city's transport problems	172
Table 6-15: Summary of results from the mitigations causal analysis.....	177
Table 7-1 Current visions of three administrative organisations in Chiang Mai city	179
Table 7-2 Objective and sub-objective of the city's sustainable transport planning.....	180
Table 7-3 Indicators of Chiang Mai city sustainable transport planning.....	183
Table 7-4 Background variables for Chiang Mai city sustainable transport planning.....	183
Table 8-1 Comparison of two different position on constant travel time budget (TTB).....	185
Table 8-2 Comparison of average daily travel time and distance (minutes and kilometre) .	186
Table 8-3 Ownership of appropriate driving licence for different vehicle availabilities (in % of each group).....	193

Table 8-4 Comparison of Vienna and Chiang Mai province professional status.....	194
Table 8-5 Comparison between of travel behaviour of different professional status	195
Table 8-6 % of trip purpose made by the CM-MTS respondents classified into Non-home based and home based trips (in % of total trips)	196
Table 8-7 % of trip purpose across each trip sequence (in % of total trips in each sequence)	197
Table 8-8 Ranking table of the proposed improvements to MARS	201
Table 8-9 Comparison of different average household sizes and adjusted values.....	205
Table 8-10 Projected population, household units, and density for each area.....	205
Table 8-11 CM-MTS 2012 respondents with driving licence and vehicle availability (%)	207
Table 8-12 Combined distance multipliers for different modes of transport (baseline)	208
Table 8-13 Average speed between different zones for car and motorcycle	208
Table 8-14 Assumed public bus service characteristics	209
Table 8-15 Assumed shared-taxi service characteristics.....	209
Table 8-16 Surveyed and modelled mode share comparison.....	211
Table 9-1 Scenarios considered	214
Table 9-2 Policy instruments for Chiang Mai MARS.....	215
Table 9-3 Assumed vehicle ownership characteristic for scenario A1-3.....	215
Table 9-4 Results of Scenario A1 Baseline, A2, and A3.....	221
Table 9-5 Background indicators for Scenario A1, A2, and A3	222
Table 9-6 Results of Scenario A1 Baseline and B	229
Table 9-7 Background indicators for Scenario A1 and B.....	230
Table 9-8 Assumed parking management characteristics for scenario C3	233
Table 9-9 Assumed land use policy for scenario D2	235
Table 9-10 Results of Scenario A1 Baseline and C	239
Table 9-11 Background indicators of baseline and C scenarios.....	240
Table 9-12 Effects of scenario on NMT trips and CO ₂ emission.....	244
Table 9-13 Attributes that yield required criteria	245
Table 9-14 Results of Scenario A1 Baseline, D1, and D2.....	247
Table 9-15 Background indicators for Scenario A1, and D	248
Table 10-1 Factors that influence the city's motorisation	280
Table C-1 Comparison between mobility surveys other cities and CM-MTS (1)	329
Table E-1 Type of capital in sustainability.....	345
Table F-1 Factors affecting cost and time components of the friction factors	353

Tables of equations

Equation 8-1: Weber-Fechner's law	189
Equation 8-2: Transformed Weber-Fechner's law	189

Tables of boxes

Box 1-1 Definition of urban sustainable transportation system	11
Box 6-1 Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS)	156
Box 7-1 Vision for Chiang Mai city's transport system	179

1. Introduction

1.1. *Sustainability in urban transport system*

Transport plays an important role in ensuring the vitality of a city; it contributes toward economic growth and the vibrancy of society (NIOS, 2011). Over the last fifty years, the developments of urban transportation around the world have made significant changes to our travel behaviours. Increases in average travel distance, travel time, dependency on private vehicles, and sprawling conurbation can be observed in many cities around the world (Schafer & Victor, 2000). These phenomena also result in a number of negative effects, such as worsening air quality and increased energy dependence (Black, 2010; Greene & Wegener, 1997; Steg & Gifford, 2005). All of these results contribute toward the degradation in the quality of life and environment in urban areas.

The modern day necessity for motorised transportation presents us with a dilemma which, if ignored, has the potential to create problems of enormous magnitude. How can we take advantage of all the positive attributes of transport developments and mitigate the harmful consequences to our social and physical environment? The challenge is to plan and create an urban transportation system that considers social aspects, environmental quality, and economic development as part and parcel of one objective. In other words, our challenge is to create a *sustainable* transport system, defined as achieving the following goal:

“To ensure that our transport systems meet society’s economic, social and environmental needs whilst minimising their undesirable impacts on the economy, society and the environment.” (EC, 2010)

This simple but broad objective is a neat cover over a complex challenge. Sustainable transport requires an acknowledgement of interdependences between social, environmental and economic forces. Moreover, implementation needs to be tailored to fit the local context and requires broad consideration of a wide range of elements. For example, it is important to understand the extent to which the existing political and organisational structure of different national and local government departments helps or hinders the development of a sustainable transport system. For instance if the planning department approves construction of buildings without reference to the road and transport department, the likely result is at best the creation of unnecessary problems which can be fixed and at worst

complete chaos. Clear communication between different stakeholders and decision makers involved in the planning process is vital to the success of implementing a sustainable transport system.

In the western world, this holistic approach to sustainable transport has gained wide recognition, but, as we shall see, in Thailand and, indeed, other parts of the developing world, understanding of the concept and its implementation is in its infancy. All too often, traffic congestion caused by a rapid increase in private vehicle ownership, as a result of increased personal wealth and prosperity, is met with the response of building more roads, which attract more traffic and, over time, the resulting new congestion is tackled by building even more roads. This traditional approach towards transport development needs to be challenged.

1.2. *The unsustainable nature of Thailand's transport system*

Sustainability is a relatively new concept in Thailand's transport sector. It was introduced officially for the first time by the National Economic and Social Development Board (NESDB) back in 1992. The NESDB included sustainability as an objective in its National Economic and Social Development plan (NESDP), which considered a blue print of national development strategy (NESDB, 2010). The Ministry of Transport responded by producing the *Transport for Thailand's sustainable development report* or the *Sustainable transport white paper* (Ministry of Transport, 2007). The paper provides guidelines for future development of the country's multimodal transport system. However, the white paper contains strong emphasis on motorised transport modes but a thin coverage on the non-motorised modes. The paper is a weak attempt to embrace sustainability into the transport sector by the government.

Nevertheless, the Office of Transport and Traffic Policy and planning (OTP), an organ of the ministry of transport, which is responsible for the formation of national transport strategy, embraced the white paper and embedded sustainable transport into its policy. The OTP is currently running various pilot programs to promote sustainable transport, such as providing a Walkability Index survey for regional cities, including Chiang Mai. However, its efforts in the sustainable transport field are minute in comparison to the national road infrastructure development programme. The focus of Thailand's transport development over the past five decades has focussed intensely on its road-based

infrastructure. Since the government issued the National Highway construction legislation in 1952, it has built over 51,642 kilometres of national highway, while it completely neglected the infrastructure of rail transport. Additionally, around 75% of Thailand's annual national transport budget is allocated to the three highways and road building authorities, namely Department of Highway (DOH), Department of Rural Roads (DRR), and Department of Express Way (EXAT). The rest of the budget (25%) is shared between State Railway of Thailand (SRT), Mass Rapid Transit Authority (MRTA), and 6 other transport related authorities. Consequently, the nation's passenger and cargo movements are dominated by road transport (Kakizaki, 2013).

This biased focus has caused a rapid rise in the number of road vehicles, such as the car and the motorcycle. The first car was imported into Thailand in 1904 and the number of registered sedan cars reached 6.6 million in 2013. A study by IEA predicted that the number of cars in Thailand will reach 10 million in 2035 (IEA, 2013). The number becomes even more overwhelming if motorcycles are included (19.7 million in 2013).

The rapid increase in motorised vehicles has several implications, three of which are listed here. Firstly, it deepens the country's dependency on imported energy. Thailand has to import around 60-75% of its annual fuel consumption. This dependency makes the country's energy security low. Secondly, importation of fuel comes at a high cost; the country spends around 15% of its national GDP on imported fuel (Amrannand, 2014). This makes the country highly vulnerable to any change in the global fuel price (IEA, 2013). Finally, increased motorisation has led to an increase in the severity of negative effects associated with it, such as congestion, worsening of air quality, road accidents¹, and lower quality of life, especially in the urban areas, such as Chiang Mai (Charoenmuang, 2007; GIZ, 2009).

The foregoing highlights the importance of improving the sustainability of Thailand's transportation sector. The government of Thailand is aware of the situation and has recently approved-in-principle an infrastructure upgrading program worth approximately 3 billion in June 2014². The prospective benefit of the infrastructure

¹ Thailand has the second highest road death at 44 deaths per 100,000 population (Sivak, 2014).

² A high proportion of the investment is allocated to regional train and urban rail projects; 35% is earmarked for interregional train projects and 38% is budgeted for urban rail investment. These developments are expected to

upgrading program is imminent, but more must be done to decrease the country's high dependency on motorisation.

This study aims to make a worthwhile contribution to this debate. It focuses on how to improve the sustainability of the country's transport system at the urban level. The focus is at this level because transport problems are complex (May, Karlstrom, Marler, & Matthews, 2003). And the complexity of problems in the urban areas is deemed higher because of the vast range and type of factors within the system. The higher population density of urban areas also means that the number of people and the range of stakeholders involved are vast. Moreover, the urbanisation trends observed in the 20th and 21st century also point to the significant importance of further research in this sector (Allen, 2009).

In order to ground this study in a practical sphere, I selected Chiang Mai city as a case study. The rationale of the case study selection is twofold. Firstly, Chiang Mai city is an emerging medium-size city, which is facing problems in transportation typical of many developing Asian cities. The city is one of Thailand's most developed regional cities and has been the centre of development in the northern region for several decades. Fast growth of motorisation, poor level of public transport, and a lack of transport and land use planning, are among many transport-related problems observed in these cities (Hayashi, Doi, Yagishita, & Kuwata, 2004). The case study of Chiang Mai should therefore reveal valuable knowledge that is relevant to other cities.

Secondly, my personal familiarity with the city gives me a valuable insight into the transport issues faced, and a deep understanding of the political and social issues that need to be addressed hand in hand with the introduction of a sustainable transport system. I was born and raised in Chiang Mai city for the first half of my life, but have, so far, spent the other half living abroad. I have seen how political determination, combined with public demand for improvements to service, has led to efficient public transport systems in Europe. As will be shown in later chapters, in Chiang Mai the political will to introduce changes to the transport system has faltered in the face of opposition by vested interests wanting to preserve the *status quo* and, thus far, the majority of public demand has been for more roads

reduce the nation's transport cost, its energy usage, CO₂ emission, and the number of traffic accidents. Additionally, these investments should provide a viable step to reducing the nation's oil imports.

to be built to serve an ever-growing number of car and motorcycle owners, rather than for an efficient transport system.

A major emphasis of this study is on the important part played by the use of motorcycles and shared-taxis within Chiang Mai, as these two transport modes continue to shape the development of the city's transport system. Detailed descriptions on this justification are in the subsequent chapters.

1.3. *Chiang Mai urban transport system*

Motorised transport was invented in Europe at the end of 19th century and was introduced into Asia in the early years of the 20th century. Initially, the use of motorised vehicles were limited but became widely available after the Second World War. Chiang Mai, like many other Asian cities, has adopted these new modes of transport and adapted them into their transport systems. The adaptation meant that transportation evolved to take several forms and characters that suit the Asian context. Many of these features are unimaginable in the west, such as an informal public transport service or extensive use of the motorcycle.

Chiang Mai city is known to have a high number of motorcycles. A survey by OCMLT (2002) shows that 60% of all registered vehicles are motorcycles. This characteristic is also quite common among countries in Asia, such as Malaysia, Vietnam, and Taiwan (Hsu, Sadullah, & Dao, 2003). The magnitude of motorcycle presence in these countries is unimaginable in the western context; for instance, the motorcycle ownership for Taiwan in 2002 is 532 per 1000 capita, while the average EU value is about 20 per 1000 capita (Hsu et al., 2003; Kepaptsoglou & Milioti, 2011).

In addition, the city has an informal transport service called Song Teaw³ (hereafter, shared-taxi), a form of on-demand paratransit service. It is the only form of transport service that has operated in the city continuously for over 30 years. Similar informal transport services have been observed in operation in various cities, mostly in developing countries, such as Indonesia (CDIA, 2011), and the Philippines (the Jeepney)

³ meaning two-rows in Thai, which characterises the seating position of its passengers seated in two rows facing each other. It is also called Rot Deang (red car) by the locals.

The dominance of the motorcycle and the existence of an informal transport service are commonly observed in other cities in Thailand and several developing countries. These unique characteristics make a strong case to enhance our understanding on the topic within the Asian context. Far too often 'best practice' and international guidelines formed in a western context are applied without deep consideration of the distinctiveness of Asian cities, and their proponents are left bemused and bewildered when they fail.

Moreover, Chiang Mai city has long suffered from its transport problems. Nernhard's (2009) reviews of the city's newspapers show that traffic congestion has been a concern since 1969. A study by Nimnual, Srisakda, & Satayopas (1980) systematically recorded the increased delay in traffic travel time. Several decades later, transport problems are still an issue for the city and perhaps have increased in their severity. Rise in congestion, private motorised transport dependency, traffic accidents, worsening of air quality, and increased street noise are among the list of transport problems (D. Charoenmuang, 2007). The city currently suffers from a high dependency on private motorised vehicles. There are no alternatives to the car and the motorcycle. The city has no systematic public transport service. Several indirect adversities, such as stress, social exclusion, and mentally sickness have also been reported (HSRI, 2003). Any improvement made to the city's transport system would be beneficial for the city and its citizens.

1.4. Objectives and research questions

The foregoing sections outlined the significance of improving the sustainability of urban transport system, for Thailand, in general, and for Chiang Mai in particular. As previously stated, the overall objective of this thesis is to contribute towards achieving sustainability in the field of transportation by focusing at the urban level. To this end, there are two main questions this study seeks to answer:

(1) What are the unique mobility features of trips made by motorcycle and shared-taxi in Chiang Mai city?

(2) What are the implications of these features in planning a sustainable transport system for the city?

Behind these questions, however, lies the need for a deeper understanding of the answers to the following:

Research Question 1:

What are the development paths that have determined Chiang Mai city's transport system and its land use? How do they affect the existing transport and land use conditions?

Research Question 2:

What are the unique features of Chiang Mai city's transport system and the mobility behaviour of its citizens? What are the implications of these features? What are the connotations of the city's motorcycle dominance and the presence of the shared-taxi service?

Research Question 3:

What are the main causal relationships between different aspects of the city's transport system and land use? How might these differ from the perceptions of the city's decision makers? What are the consequences of such differences?

Research Question 4:

What are the transferability issues of the MARS model and its principles to Chiang Mai city? How can MARS be adapted to accurately model the city, especially its motorcycle dominance, and the presence of the shared-taxi service? What is the significance of these issues and how can these be overcome?

Research Question 5:

What are the effects of transport measures, which focus on the motorcycle and the shared-taxi service, on the city's transport system? How can these measures be used to improve the sustainability of the city's transport system?

1.5. Scope and methodology of the study

The research scope of this study is limited to the urban transportation system within the city of Chiang Mai. It will seek to provide a new line of understanding on the city's transport problems. This study utilises the system approach, which looks at facing issues from the system perspective. It will employ a System Dynamics toolkit, called the Causal Loop Diagram (CLD) to reveal the perceptions of the decision makers on the city's transport system and their effects. I will also utilise a System Dynamic Transport and land-use model called MARS⁴ in this study to assess the impact of various transport policies. MARS has

⁴ Metropolitan Activity Relocation Simulator

been developed at the Research Centre of Transport Planning and Traffic Engineering, Vienna University of Technical (IVV-TU Wien).

The term “motorcycle” used in this thesis encompasses all types of on-road powered two wheelers. The broadness of the term replicates the definition commonly used in Thailand; there is rarely further classification of this mode. Thus, it includes mopeds, scooters and motorbikes with a wide range in horse power. The shared-taxi service focused on in this study is a form of informal on-demand transport service that can be hailed by the roadside. There is a form of fare framework but the fee is often set by negotiation between driver and user. The route is formulated by driver, who is entitled to pick up additional passengers *en route* and change his route accordingly. This results in a passenger who is picked up at point A and asks for destination point B being driven to points C, D, E and F before arriving at point B at a much later time than first envisaged.

In this study, the focus is on the roles of motorcycle and shared-taxi within the transport system. Nonetheless, a detailed analysis of the system itself will also be made to ensure the comprehensiveness of this study. However, the tuk-tuk, a form of informal taxi service in Thailand, is not considered in detail because of the limited number of such vehicles and the negligible proportion of trips made using this mode of transport (See Table 4-9).

The following research tasks were planned to realise the above objectives:

- Review past studies to establish the existing practice and knowledge that have been applied to solve the city’s transport problem. Establish new line of enquiries (Chapter 2)
- Describe the development of Chiang Mai city’s transport system and its land use to ascertain its development path (Chapter 3)
- Review existing data on the city’s transport system. Plan and carry out survey to collect any missing data considered to be relevant and necessary (CM-MTS report⁵)
- Compile data and use it to illustrate the trends of the city’s transport system and land use (Chapter 4).

⁵ Chiang Mai mobility and travel survey is report of the household survey undertaken by the author in 2011-2012. The exercise is part of the author’s thesis but published separately as the author was encouraged to make the survey results available as soon as possible for use by the city’s transport planners

- Undertake analysis on the mobility behaviour of the city's citizens. Identify the unique features of motorcycle and shared-taxi trips and their implications (Chapter 5)
- Catalogue transport problems and their possible causal relationships with land use and other aspects, using Causal Loop Diagram (CLD) method. Use various data to validate the CLD. Use to review the causal relationship against the perceptions of city's decision makers (Chapter 6)
- Formulate goals and vision for the city's transport system (Chapter 7)
- Review the transferability of the MARS model and its principles to Chiang Mai city, make necessary modification, construct the model (CNX-MARS) and make appropriate calibration. (Chapter 8)
- Formulate sets of proposed policies aimed at improving the sustainability of the city's transport system. Evaluate proposed policies and their impacts using CNX-MARS (Chapter 9)
- Conclude the thesis by drawing together all the findings and highlight their implications. Includes recommendations for subsequent studies (Chapter 10)

The area considered by this study is the same as the CM-MTS survey, which covers seven districts of Chiang Mai province. These districts are classified into three areas: the Municipality area, the Aumpor Muang area, and the Outer districts area. Figure 1-1 depicts the boundaries of these three areas.

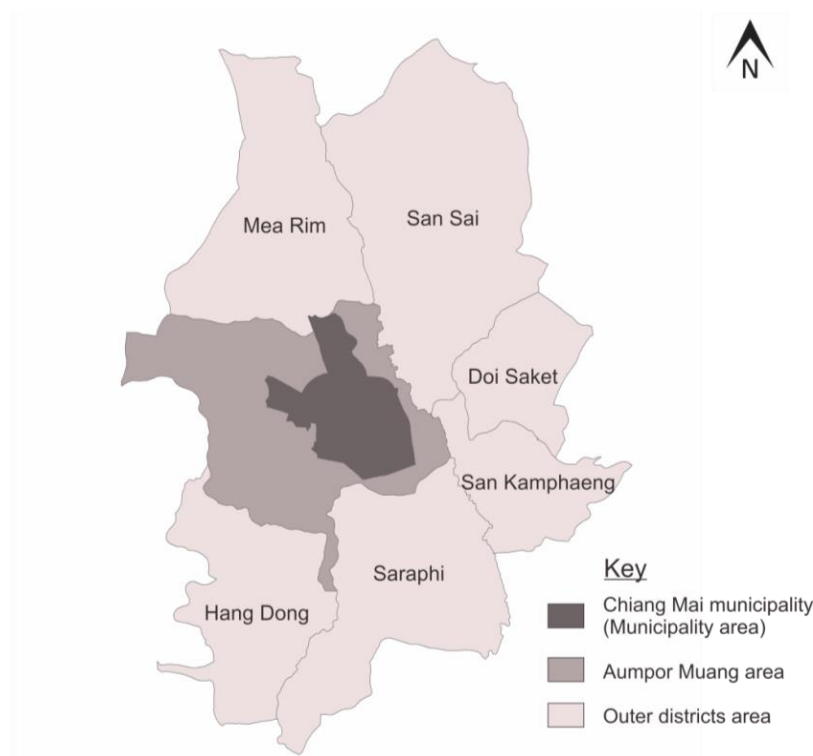


Figure 1-1 Area covered by this study and the CM-MTS

Source: CM-MTS 2012

1.6. *Introducing Sustainable transport (ST), System Approach, and System Dynamics (SD)*

Short descriptions are provided here to provide readers with a basic understanding of these topics. Materials referenced here should be consulted for more in-depth accounts.

1.6.1. Sustainable Transport (ST)

Schiller, Bruun, & Litman, (2012) purport that ST originates from the following: (1) concerns about negative effects of transportation, (2) recognition of the benefits from transport improvements, and (3) an increasing awareness of the importance of sustainability. The definition of ST can be seen as an extension or subset of Sustainable Development⁶ definitions, which specifically relate to transportation. Black (1996) defines ST as a transport system “satisfying current transport and mobility needs without compromising the ability of future generations to meet their needs”. The Gothenburg European Council (2001) built on Black (1996)’s definition to include safety, equity within and between generations, and affordability. It also emphasised the important link between sustainable transport on the development of a vibrant economy and its effects on the environment. The definition proposed by May & Minken (2003), made an improvement to the above. It is more concise and better defined, but its omission of the safety aspect is a drawback.

Thus, in order to overcome the inherent weaknesses of both these reports, the definition of ST in this study combines the two descriptions suggested by the Gothenburg European Council (2001) and May & Minken (2003). It also includes elements of the Sufficiency Economy⁷ and appreciation of the cultural aspect, as shown in Box 1-1.

⁶ See Appendix E

⁷ See Appendix E

Box 1-1 Definition of urban sustainable transportation system

A sustainable urban transportation system is one that:

- provides access to goods and services in a safe and sufficient way for all inhabitants of the urban area,
- protects the environment, cultural heritage and ecosystems for the present generation, and
- does not endanger the opportunities of future generations to reach a reasonable level of welfare, including the welfare they derive from their natural environment and cultural heritage

This definition focuses on delivering an efficient level of safe accessibility, safeguarding the biosphere and cultural traditions, and maintaining intergenerational equity. The definition contains several subjective entities (i.e. ‘a safe and sufficient way’ and ‘to reach a reasonable level of welfare’) that make allowance for local-specific interpretation. Thus, in addition to the definitions above, it may be useful to envisage the detrimental effects of an unsustainable transport system and to distinguish the conventional from the ST transport planning approaches. The effects and the approaches are depicted on Figure 1-2 and Table 1-1, respectively

Possible effects of unsustainable transport system

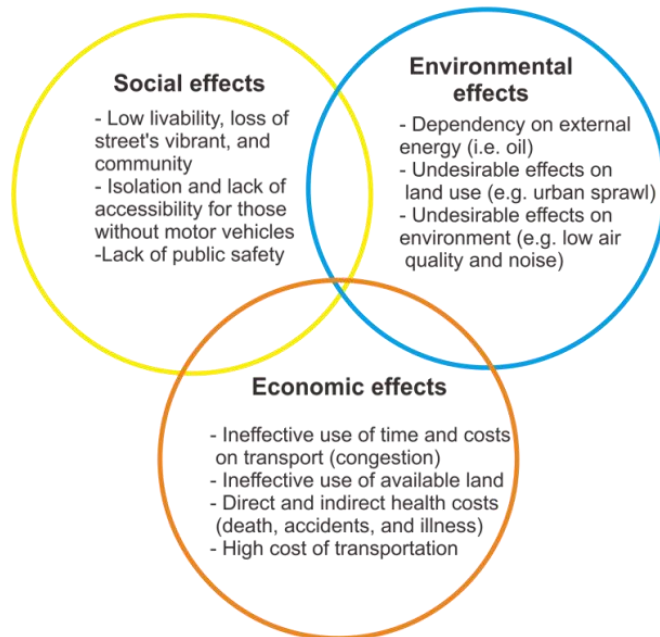


Figure 1-2 Possible effects of unsustainable transport system

Table 1-1 Differences between conventional and sustainable transport approach

Conventional approach (i.e. Business as usual)	Sustainable transportation (ST) approach
Focusing on solving transport and traffic problems with engineering specialists	Consider integrated approach, taking into account other relevant disciplines
Automobile-oriented	People oriented
Concerns for vehicular movements, ignores intra-zonal movements	Concerns for all modes, with higher priority given to pedestrian and cyclists
Considers uni-modality (i.e. automobile)	Considers multimodality with interconnection
Accommodate and accept trends (i.e. predict and provide)	Seeks to interrupt and reverse harmful trends that do not fit with set visions
Evaluation directed at road users' costs and benefits, ignores social and environmental costs	Evaluation acknowledges non-users' cost and benefit, including social and environmental costs
Emphasis on providing the highest possible level of traffic efficiency to facilitate flow of traffic (i.e. quantity)	Emphasis on providing highest quality of accessibility (i.e. quality)

Source: adapted and modified from (S. Batty, Davoudi, & Layard, 2001) and (Schiller et al., 2012)

1.6.2. Systems Approach and System Dynamics (SD)

Systems Approach (or Systems thinking) and System Dynamics are terms that are interrelated, yet they are different. Systems Approach can be defined as a problem solving method that looks to understand a complex problem and the context (i.e. the system) that it is in. It seeks to comprehend the interactions between different elements within that system as part of the process to find a solution (Aronson, 1996). System Dynamics (SD), on the other hand, can be best described by the four points put forward by its founder; Jay W. Forrester in Industrial Dynamics (Forrester, 1961; Richardson, 2011):

- SD is the theory of information feedback systems;
- SD is a knowledge of decision-making processes;
- SD is the experimental model approach to complex systems;
- SD uses digital computer as a mean to simulate realistic mathematical models

System Dynamics (SD) is a quantitative computational problem-solving method that aims to provide an understanding of complex systems over time. It is based on the principle of servomechanisms⁸ engineering and employs several of its toolkits, such as Causal Loop Diagram (CLD) and Stock and Flow diagram (Sterman, 2000; systemdynamics.org, 2013). The initial development of SD stems from the work of Jay W. Forrester, which originated

⁸ An automatic device that helps to adjust performance of a mechanical process based on information picked up from the process itself. The information is called feedback or error correction signals.

from the operational research field. The association between Systems Approach and System Dynamics is put forward by Lukaszewicz (n.d.):

“System Approach creates a foundation for the ideas of System Dynamics”

(Lukaszewicz, n.d., p. 27)

System Approach and SD can also be seen as ways to better understand problems faced, hence improving the likelihood of solving them. Since its conception in 1956, SD's fields of application have expanded from corporate and industrial problems to management, public policy, transportation, and more. SD's main strength remains in its ability to analyse and aid the design of complex policy. SD has the capability to model the causal relationship between different entities using Partial Differential Equations, which enable it to simulate the nonlinearity behaviour, time-lag, and complex feedback effect.

In the transport field, the application of SD is still at an initial stage. Abbas & Bell (1994) reported several applications of SD in the field of transportation. They also speculated an increasing trend in such application. In addition, they positively remarked that SD has high potential in addressing transportation problems. Their optimistic conclusions have given an endorsement on the application of SD in the field. Many other authors have expressed similar commendation: (R. Hansen & Kahne, 1975), (Hazel, 1989), and (OECD, 1974). Shepherd (2014) provides a recent update of SD use in the field of transport. He reviewed over 50 research studies published since 1994 in the field and concluded that SD is a tool suitable for “exploring the nature of problems” and to experiment to discover the impact of different policies and measures. It is a tool that can help to improve and define the limit of our understanding of the transport system. He concluded that SD should be used to make real impacts on the real world and reported increasing acceptance of SD by organisations, such as the EU commission and local authorities in the UK.

2. Literature reviews

2.1. *Introduction*

The purpose of this chapter is as follows: (1) to provide background into the topics that will be dealt with in this thesis and (2) to establish a new line of enquiry which offers added-value solutions to the city's current transport problems.

The chapter begins by providing a general background about the city in Chapter 2.2. In Chapter 2.3, a literature review on the motorcycle transport mode is detailed. Several aspects of the motorcycle, such as safety, ownership and usage, and its role in sustainable transport are covered. A brief literature review of studies on shared-taxi is included in Chapter 2.4. Chapter 2.5 makes a comparison between six different models that have been used to aid sustainable transport planning in Europe, Australia, and the US. The aims of the comparison are to reveal the position of MARS (Metropolitan Activity Relocation Simulator), an SD model that will be used in this study, and to highlight the model's potential improvements. Chapter 2.6 summarises the findings from literature reviews on past studies that addressed Chiang Mai city's transport problems.

2.2. *Background of Chiang Mai city*

Chiang Mai is the principal city of Chiang Mai province. Out of a total 76 Thai provinces, Chiang Mai is the second largest in terms of area and fifth highest in terms of population. Chiang Mai city is situated in the northern region of Thailand, about 700 kilometres from Bangkok. It was founded in 1296 as the capital of the Lanna Kingdom and became a province of Thailand in 1933. The province has been designated as the centre of the northern region.

Land use within the province's geographical area consists of forestry (70%), agriculture (13%), and urban and other use (17%). The province is located in a mountainous district within a large plain along the River Ping. The province is divided into 25 districts (Aumpor) and 204 sub-districts (Tambon). The central district is Muang Chiang Mai district (Aumpor Muang). The municipality of Chiang Mai city (Tedsaban Nakorn Chiang Mai or within this thesis: **the municipality**) sits within the Aumpor Muang district. The municipality area is considered to be the core of the city. The area includes the historic centre of the city, which is enclosed, and was historically protected from invading armies by

high walls and a rectangular outer moat. Today, most of the city's protective walls have disappeared, but the moat continues to define the boundary of the city centre.

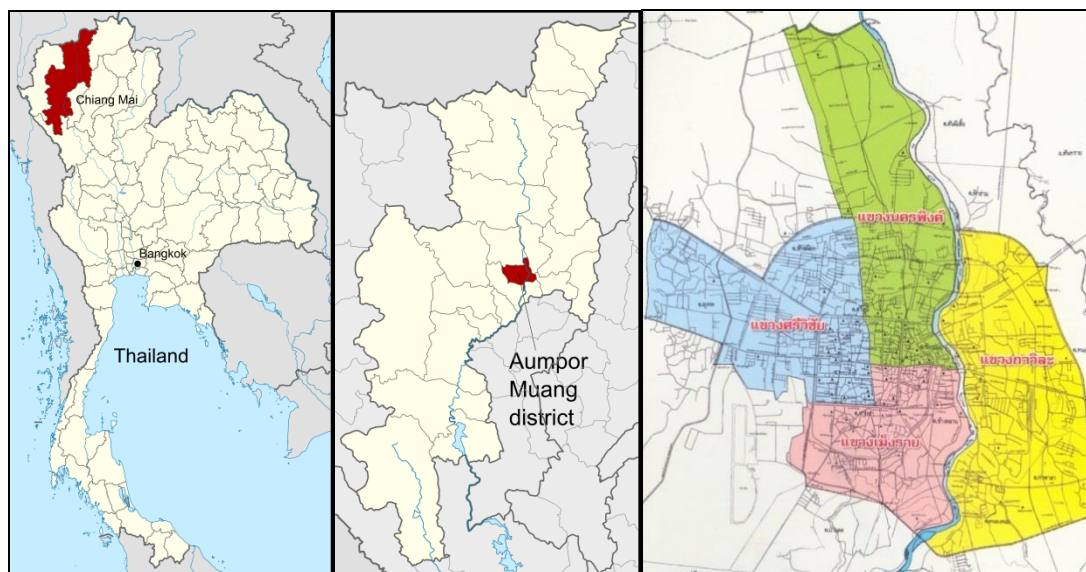


Figure 2-1 Chiang Mai province, Aumpor Muang district, and Municipality of Chiang Mai

Source: modified from Wikipedia and Cmcity.com

In 1989, the Department of Public work and Town and country Planning (DPT) designated the Chiang Mai Principle City Area (CMPC) or the principle plan area. The area is considered the urbanized area of the city. The CMPC spans 7 districts and covers over 429 square kilometres. However, it is likely that the actual urbanised area has already extended beyond the CMPC area designated in 1989. Table 2-1 presents the area and population of the areas mentioned.

Table 2-1 Area, population, and density of Chiang Mai

	Chiang Mai Municipality	Aumpor Muang (central district)	Chiang Mai Principle City Area (CMPC)	Chiang Mai province
Area (km ²)	40	152	429	20,107
Population (person)	137,797 (2012)	235,600 (2012)	630,591(2004)	1,646,144 (2011)
Density (person/ km ²)	3,426	1,546	1,469	82

Chiang Mai's Gross Provincial Product (GPP) in 2011 was 147,561 Million Baht (3,689 million Euros), within which 23.7% came from its agriculture activities. The average annual income of its population was 92,110 Baht (2302.75 Euros) per person. Apart from agriculture, the main economic activity of the province is tourism. In 2012, over 5.6 million tourists visited the city.

2.3. *Literature related to the motorcycle*

The motorcycle was invented in 1884 by Edward Butler in England. The design and form of the motorcycle has developed over time. Hsu, Sadullah, & Dao (2003) highlighted common characteristics of the motorcycle which they derived from their case studies as follows: (1) relatively smaller than other vehicles, making it more flexible, (2) more agility, enabling better manoeuvrability through congested areas, (3) lighter in weight, (4) cheaper and more affordable than a car, and (5) more vulnerable.

The motorcycle has become popular in many parts of the world, especially in Asia. It is estimated there were 313 million motorcycles in the world by 2008, of which 77% were in Asia (Roger, 2008). The motorcycle is the dominant mode of transport in many Asian cities (Hsu et al., 2003; Pfaffenbichler & Circella, 2009). In Europe, it is estimated the number of mopeds is between 13-14 million and the motorcycle is almost 10 million. It reported a rising trend for the motorcycle, while the number of mopeds seems to remain constant (Noordzij, Forke, Brendicke, & Chinn, 2001). There is also a discrepancy in ownership among different regions; the ownership rate is higher in the southern countries (50 for moped and 30-40 for the motorcycle per 1000 capita) in comparison to the northern countries (20 for moped and 10 for the motorcycle). The regulations concerning the motorcycle have become more uniform over the years, due to European regulations. However, differences can still be observed at the detailed level. Interestingly, the study purported that authorities should be aware of the special need motorcycle traffic has, for the current road network is designed primarily for car. Hsu, Sadullah, & Dao (2003) made a similar point that road infrastructure in general is highly influenced by the car-orientated mind-set of the west. Thus, decision and policy makers should pay more consideration to the need of the motorcycle in order to ensure a safer road for all. Similar opinion was also offered by Solere (2010).

The motorcycle is the main mode of transport in many other Asian cities, such as Bangkok, Ho Chi Minh City, and Kuala Lumpur. A higher proportion of motorcycles also has been found in many cities with warmer climates such as Greece (Yannis & Golias, 2007). The motorcycle is popular in these cities because of its flexibility and lower running and ownership cost in comparison to the features of a car. The rate of motorcycle use is increasing in many countries. A study by Broughton & Stradling (2005) reports an increase

in motorcycle ownership in the UK by 30% between 1998 and 2003. Authorities in Austria and China have also sought to promote a similar form of mobility, which is powered by electricity (Pfaffenbichler & Circella, 2009; Weinert, Ma, & Cherry, 2007).

Implementations of road infrastructures that support the motorcycle have been made in several countries; such as Taiwan and Malaysia. Hsu, Sadullah, & Dao (2003) described briefly the motorcycle infrastructures in these countries and their differences. Hussain, Umar, Sohadi, Farhan, & Dadang (2005) made the recommendation that motorcycle lanes should be more than 1.7 m wide to enable two motorcycles to pass one another.

2.3.1. *Motorcycle safety*

The rise of motorcycle ownership and usage has galvanised a number of research studies. Most of these studies have focused on its vulnerability in comparison to car and the safety aspects of its usage. For example, Liu, Ivers, & Norton (2008) looked at the effectiveness of wearing a helmet in preventing head and neck injury. The study found a positive correlation between helmet use and a reduced risk of head injury in an accident. Examples of other literature that looked into the safety aspects are Bayly, Regan, & Hosking, (2006); ERSO (2011); Liu et al. (2008); SafetyNet (2009), Wulf, Hancock, & Rahimi (1990) and Simpson & Mayhew (1990).

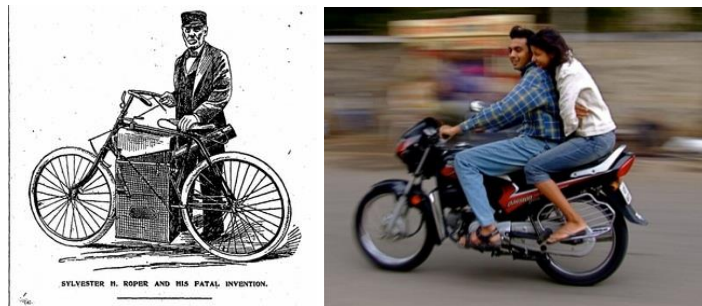


Figure 2-2 Sylvester H. Roper's and today's motorcycle

Source: Wikipedia

2.3.2. *The motorcycle in traffic engineering*

The high proportion of motorcycles in urban traffic also stirred an interest from the traffic engineering field. A number of studies seek to understand the behaviour of the motorcyclist at traffic junctions, in order to improve the effectiveness of traffic network; such as Lee, Polak, & Bell, (2009) and Vien et al. (2008). At the other end of the scale, Hung (2006)

made a detailed study on different measures that may improve the effectiveness of motorcycle dominance within the transport network.

2.3.3. Motorcycle ownership and usage

Several academic papers also looked into the ownership, usage, and mobility pattern of the motorcycle user; for example, (Broughton & Stradling, 2005; Cherry, 2007; Hsu et al., 2003; Kepaptsoglou & Milioti, 2011; Minh, Sano, & Matsumoto, 2006; Pinch & Reimer, 2012; Prabnasak & Taylor, n.d.; Rose, Thompson, Amani, & McClure, 2012; Solere, 2010; Vien et al., 2008; Yannis & Golias, 2007). The reviews of this literature reveal interesting information listed below.

There is wide variation in the scale of these research documents. For instance, (Cherry, 2007; Rose et al., 2012), and to a certain extend (Solere, 2010) that focused at city scale. Other research, such as (Hsu et al., 2003; Kepaptsoglou & Milioti, 2011; Yannis & Golias, 2007) is focused on the country scale.

The sources of data use in these studies are also varied. Some are based on primary data (Cherry, 2007; Kepaptsoglou & Milioti, 2011), while other on secondary data (Hsu et al., 2003; Solere, 2010). Studies that utilised primary data are noticeably more comprehensive and more consistent in their comparisons. Some studies also focused solely on motorcycle trips (Cherry, 2007; Hsu et al., 2003), while others provide mobility data of other modes for comparative purposes (Kepaptsoglou & Milioti, 2011; Solere, 2010; Yannis & Golias, 2007). The inclusion of other modes of transport seems to provide a more complete picture. For instance, (Cherry, 2007) omission of respondents that use other mode of transport made it impossible to understand its analysis in the context of the cities. Its average numbers of trip per day are also low, which leads to a suspicion that walking trips were also omitted. Moreover, several studies such as Cherry (2007) and Hsu et al. (2003) can improve the consistency of their data by enabling a like-for-like comparison between the cities considered.

Another apparent difference in these studies is their classification of powered two-wheeler (PTW) based on engine size. Solere (2010) classified powered two wheeler (PTW) trips by their engine size; PTW with less than 50cc is called a moped, and PTW with more than 50cc is classed as a motorcycle. Cherry (2007) separated PTW by their fuel type (i.e.

LPG and electric). Other studies, such as Hsu et al. (2003), Yannis & Golias (2007), and Kepaptsoglou & Milioti (2011) studied PTW as a whole.

Several factors that affected the usage and ownership of a motorcycle have been reported by these studies. Solere (2010) found the percentage of motorcycle trips is three times higher in cities located in south-eastern France than elsewhere, suggesting a correlation between milder weather and PTW trips. The same study also found that the younger population made more PTW trips. Kepaptsoglou & Milioti (2011) found income, gender, age and spatial trip characteristic affected motorcycle ownership and usage. Yannis & Golias (2007) reported that driver gender, age, and experience seemed to have a stronger influence on mobility patterns than vehicle type.

The mobility patterns of motorcyclists were also reported by a number of studies. Yannis & Golias (2007) reported mileage driven against age, gender and the preference to use mopeds and motorcycles for certain types of trips (e.g., travelling in residential areas and weekdays during the daytime). Solere (2010) found PTW users made more trips per day and that they were generally younger. Cherry also observed correlations between respondents' demographics, their gender and their transport mode choices. In Shanghai, for example, pedal bicycles and electric powered bikes share the same percentage of female users (41%), which is much higher than female use of the motor scooter (29%). Other indicators, such as education, household income, wage, and household size were also recorded. Kepaptsoglou & Milioti (2011) found income, gender, age and spatial trip characteristic affected motorcycle ownership and usage. It also reported average travel time and distance of the motorcycle in comparison with other modes.

2.3.4. The motorcycle, sustainability, and its effects on land use

Motorcycle use and ownership will continue to rise in both developed and developing countries. Haworth (2012) made a strong case to deepen our understanding of the motorcycle's usage pattern to enhance its mobility potential. It provides an affordable form of personal transport that utilises less resource (fuel and space) for many people in developing countries. Olubomehin, (2012) provided an account on the tangible benefits the motorcycle offered to commercial sectors in Nigeria. However, there are also negative aspects that need to be dealt with; such as a lack of conformity to the Highway Code and increased CO₂ emission from motorcycle usage.

Rose et al. (2012) suggested that PTW may have a role in contributing toward sustainable urban transport system. However, she stated that a deeper understanding of the topic is necessary. A literature search on the motorcycle and sustainability yielded very limited returns. Pfaffenbichler & Circella (2009)'s case studies of Hanoi (Vietnam), Bari (Italy), and Ho Chi Minh City (Vietnam) examined the role the motorcycle has in maintaining the efficiency of the transport system. The motorcycle utilises only 15-20% of the space per person required by a car. It also consumes less energy in production and operation, as well as emitting less CO₂ (See Graph 2-1). Hsu et al. (2003) and Rose, Thompson, Amani, & McClure (2012) also reported similar benefits. The reduced space required for parking, and slowing the need for additional roads, can reduce urban sprawling and parking search time⁹. Moreover, the motorcycle has lower purchase cost; a car costs around 10 times more than a motorcycle. Another study by SafetyNet (2009), suggests that a motorcycle is found to take 16% to 46% less time for the same trip as a car in an urban environment. The same study also found that the accident rates for motorcycles are similar to those of cars. The common disadvantages of this mode of transport are the motorcyclist's exposure to extremes of weather, the machines stability, limited number of passengers, limited capacity for transporting goods, limited range, lack of security from thieves, and its vulnerability during accidents (Rose et al., 2012).

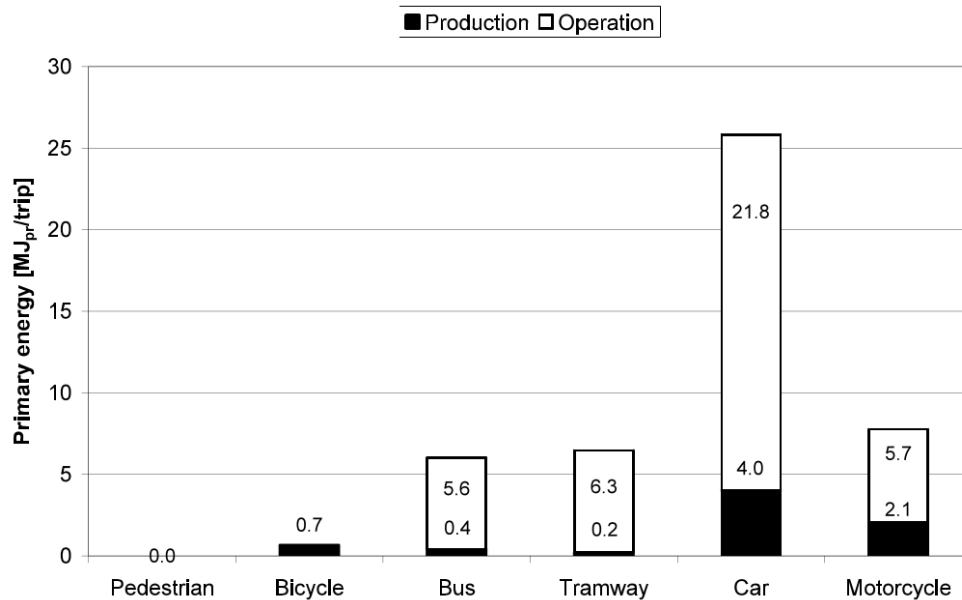
It is commonly accepted that there is an interconnection between land use and transport (P Newman & Kenworthy, 1996; Stead & Marshall, 2001). However, some researchers have argued against the connection between land use and transport, such as Boarnet & Sarmiento (1998) and Crane & Crepeau (1998). Overall, though, land use, building regulations, and environmental policy have gained recognition as measures to achieve a sustainable transport system (Lin & Yang, 2009; Stead & Marshall, 2001). Conversely, use of unsustainable transport, such as the car has become associated with urban sprawl (Salingaros, 2006).

The causes of sprawling are manifold (Brody, 2013), yet increased car usage is regularly linked with urban sprawl. Kenworthy & Laube (1999) demonstrated with their

⁹ In 1985, 1.5 million km were driven in Vienna only to search for parking space and in 1992 180,000 litres of fuel were used in this way (SafetyNet, 2009)

comprehensive database that the number of kilometres travelled by car *per capita* has an inverse relationship to urban density. Other fast modes of transport, such as the train, have also been identified to contribute towards sprawling (Wegener, 2012). However, the effect of the motorcycle on land use has not been mentioned.

Graph 2-1 Primary energy in consumption, production, and operation of each mode



Source: (Pfaffenbichler & Circella, 2009)

2.4. Literature related to Shared-taxi as a form of paratransit

Paratransit is a form of demand-responsive transport service that is flexible in its operation (Nguyen-Hoang & Yeung, 2010). This form of transport service became popular in North America during the late 1960s. The rapid motorisation and suburbanisation during the time resulted in a sharp drop of public transport efficiency. Paratransit was seen as a solution to provide accessibility to segments of the population who have no access to private transport (such as youth, elders, and handicapped), at a more cost-effective option than public transport. It was to provide the convenience and flexibility of the car, while maintaining the efficiency of public transport (Orski, 1975). Paratransit plays a significant role in many developed and developing countries around the world (Rimmer, 1984; Shimazaki & Rahman, 1996). For example, Hong Kong's taxi and public light buses (PLB) account for 30% of the 9.7 million public transport trips in 1988 (E. Lee, 1989).

Although the term was invented in the US, paratransit can take a number of forms as proposed by Kirby, Bhatt, Kemp, McGillivray, & Wohl (1974): (1) hire and reward service,

(2) hail and phone services, and (3) pre-arranged ride-sharing services¹⁰. There are several research documents that cover different aspects of paratransit transport. For example, Kwasniewski & Bojanowski (2009) looked into the safety assessment of paratransit vehicles. Nguyen-Hoang & Yeung (2010), Saltzman (1973), and Talley & Anderson (1986) looked into the cost-benefit aspect of paratransit transport. An interesting account on the transition of paratransit transport in Hong Kong from an informal operation into a legalised and a fully regulated one is provided by E. Lee (1989).

In addition to the example in Hong Kong, there are also several examples of paratransit systems that can be taken from Asia, such as the use of “Jeepney” in Indonesia and the Philippines (CDIA, 2011). These systems may seem primitive from a western perspective, yet are optimised for local conditions and needs (Silcock, 1981).

2.5. *Position of MARS in sustainable transport planning*

In this section, a comparative analysis is carried out to understand the effectiveness of using the Metropolitan Activity Relocation Simulator (MARS) model as a tool for sustainable transport planning. MARS will be used in this thesis to assess the impact of various policies on the city’s transport system.

Today’s transport systems are complex, comprising a vast range of relevant entities, which are interconnected. The planning of such a complex system is a highly challenging task. Transport modelling is one of many tools that have been employed to support planning decisions. It can help in understanding the interactions of various elements and can be used to forecast how the system responds to different scenarios. Thus, decision makers are helped in putting together a set of policies to influence the system towards a desired goal.

Six sustainable transport planning models are reviewed here and compared against each other, namely,

1. Assessment of Transport Strategies (ASTRA),
2. Metropolitan Activity Relocation Simulator (MARS),

¹⁰ The shared-taxi of Chiang Mai city takes the form of a ‘hail service’.

3. Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability model (PROPOLIS),
4. TREMOVE,
5. Transport and Environment Strategy Simulator (TRESIS), and
6. UrbanSim¹¹.

It is clear from the outset that the six models compared here are different in their structure (i.e. System Dynamic and micro-simulation), spatial resolution (city, regional, national and cross-national), and time horizon. Nevertheless, their common ground is their purpose: to evaluate sustainable transport strategy. The aims of this comparison are to reveal the position of MARS in relation to other models used in sustainable transport policy assessment, and its suitability as a tool to support sustainable transport planning. In addition, the comparison can highlight possible improvements to MARS.

The framework used to compare these models is based on that proposed by Geurs & Wee (2004).

It must be highlighted that information about the models has been obtained from the respective organisations' websites and relevant literature. In other words, the features listed here are based on secondary sources with the exceptions of MARS and PROPOLIS. The review of PROPOLIS is adopted from Geurs & Wee (2004) and has been checked against Lautso & Spiekermann (2004) for accuracy. However, there remains potential for inaccuracies within the evaluation resulting from the interpretation of data. Nevertheless, the approach taken still provides a useful comparison between these models. Table 2-2 summarises the results of this comparison.

¹¹ Brief descriptions on these models can be found in Appendix B

Table 2-2 Results of the models' comparison

			MARS	ASTRA	TREMOVE	TRESIS	UrbanSim	PROPOLIS	
	Category	Sub-category							
Model	Land use interaction		+	-	-	+	+	+	
	Transport	Car	+	+	+	+	+	+	
		Public transport	+	+	+	+	+	+	
		Non-motorised	+	-	-	-	+	+	
		Freight	-	+	+	-	-	+	
Sustainability indicators	Economic	Active user benefits	+	+	+	+	+	+	
		Passive user benefits	-	-	-	-	-	-	
		Wider economic impacts	+	+	+	+	+	+	
		Net Economic benefits	+	+	+	+	+	+	
	Ecological	Emissions	+	+	+	+	+	+	
		Noise (road traffic)	-	+	-	-	-	+	
		Natural and landscape	-	-	-	-	-	+	
		Natural resources (oil consumption, land coverage)	+	+	+	+	+	+	
	Social	Biological needs	Traffic safety	+	+	-	-	-	+
			Other health impacts	-	-	-	-	-	+
		Social needs	Access to transport	+	+	-	+	+	+
			Community cohesion	-	-	-	-	-	+
		Intellectual needs	Access to opportunities	+	+	-	+	+	+
			Transport option values	-	-	-	-	-	+
		Metaphysical needs	Noise, quiet areas	-	+	-	-	-	-
			Equity	Distribution of costs	+	+	+	+	+
			Distribution of benefits (accessibility)	+	+	+	+	+	+
		Social justice	Exposure to air pollution	+	+	+	+	+	+
			Exposure to noise pollution	-	+	-	-	-	+

Findings from comparison of Models

It should be re-emphasised here that the purpose of this comparison is to reveal the position of each model in relation to others and indicate possible improvements. Each model is made for a specific purpose (Stermann, 2000), and grading them against each other is an unfruitful exercise.

Model category

Four out of six models consider land use interaction in their analyses; the two models that omit land use, namely, ASTRA and TREMOVE, are both national-level models. The exclusion is perhaps based on their high level of aggregation, which limited the usefulness of such analysis. The same reason may be applicable for their omission of trips made on non-motorised transport modes, which is believed to be a small proportion of the overall transport modes at the national-level. Interestingly, only three out of six models consider freight transport (two at national level, and one at urban level).

Sustainability indicators category

All of the models considered, support economical assessments. All of them can analyse active user benefits, wider economic impacts, and net economic benefits, but none can assess passive-user benefits.

In the ecological sphere, all models considered can assess the amount of emissions and the consumption of natural resources. However, few models have ability to appraise the effects on nature and landscape and noise distribution.

The abilities to evaluate indicators within the social sphere are the most diverse, while most models can assess change in accessibility, distribution of benefits, distribution of costs, and exposure to air pollution. Features such as assessment of impacts on public health and transport option values are rare.

The result also indicates that PROPOLIS benefited from its comprehensive model structure in that it is able to provide the most expansive indicators. However, the magnitude of the effort required and the resulting cost to construct such a model for a city with no existing LUTI model, such as Chiang Mai, is considered prohibitive. Moreover, the lack of available data may pose a risk for such a data intensive model.

In the context of this thesis, MARS seems the most appropriate model. It operates at urban-level, incorporates non-motorised transport modes, and has relatively low data requirements. In addition, another advantage of MARS is its transferability; only two of the six models considered (i.e. MARS and UrbanSim) have been applied to case studies in different continents, while other models are location specific (European and Australian case studies).

The comparison of different models in this chapter also highlights several possible improvements for MARS, such as inclusion of freight transport and making provision for the examination of indicators that require disaggregate level analysis, such as noise pollution. The possible improvements to MARS are discussed further in Chapter 8.

2.6. *Literature review findings on Chiang Mai transport problems*

The literature review of past studies on Chiang Mai city's transport system prompted several thought-provoking aspects, gaps within the existing studies, and features that should be included in a new study. These findings also point toward possible new lines of

enquiry and methodology. The literature review indicates Chiang Mai city has experienced transport problems from its early days. Historic records show that the founder of the city, King Mangrai, established codes and regulations soon after the city was founded to address traffic accidents and conflicts (na Chiangmai, 1995).

A total of 38 studies relating to transport management and planning of the city have been reviewed here (See Appendix A for detailed analysis). The review divides the literature into four groups according to their primary focus. For most of the research projects, I made reviews from the primary sources but in some cases, secondary accounts have been included as the originals were not accessible. Their sources are cited explicitly. The findings can be summarised as follows:

Firstly, **the city's transport problems are complex, yet attempts to find solutions have been confined to the reductionist approach.** The city's transport problems interact with a wide range of stakeholders coming from different perspectives; such as social, technical, economic, environmental and political (D. Charoenmuang, 2007, 2009a; HSRI, 2003; Kongboontiam, 2010; Watthanakul, 2008). However, most past studies, especially the official ones, focused exclusively on transport problems. These studies employed the reductionist approach, which severed the connections between transport and other entities. Recommendations to 'improve' the transport problems focus mainly on the construction of additional roads suggested in OCMLT (2002). It is thought that the implementation of such recommendations will at best, provide a temporary improvement, and, at worst, accelerate the deterioration of other areas in the overall mix of the system (for example social separation and intensified use of fuel).

Secondly, there is a **lack of quantitative goals to measure the success of solving the city's transport problems.** All of the past studies revealed different facets of the problem and proposed mitigation measures, but none of them set any tangible targets that need to be achieved or provide any expected outcome. Several studies, such as (D. Charoenmuang, 2007; HSRI, 2003) proposed comprehensive sustainable transport goals and measures. However, these goals and measures are qualitative, making it difficult to evaluate progress

Goal and target setting help to provide development direction, track progress, and evaluate actions. They also help to translate complicated plans and policies into specific and

tangible tasks. Thus, clear goals and targets are essential elements to guide the city toward solving its transport problems.

Thirdly, there is **a need for a planning tool that can evaluate quantitative sustainable transport policy and includes non-motorised modes in its analysis**. The literature review finds that the Four-stage modelling technique or FSM is used by the city for its transport modelling practices. It is well documented that while the FSM is an adequate tool for capacity analysis, it has limited capacity to include non-motorised modes and to evaluate progressive transport policies. Moreover, it was found that none of the past official studies include non-motorised transport modes¹². It is believed that the omission of these modes from the analysis excluded them from improvement budgets. Consequently, the gradual worsening of related facilities makes these modes unattractive. These forgoing reasons demonstrate the need for a new transport modelling tool for the city of Chiang Mai.

Fourthly, **the focuses of transport studies of the city in the past are primarily on motorised four-wheelers**, such as saloon and pickup cars. The literature review finds past studies rarely addressed other modes, such as the motorcycle, cycling, and walking. The motorcycle, in particular, is often addressed only for its vulnerability in accidents.

The motorcycle has numerous unique characters that make it stand out (Khuat, 2007). It is even seen by some as an effective mean to increase efficiency of energy use in transportation (Pfaffenbichler & Circella, 2009). Chiang Mai is well-known for its high proportion of motorcycles in relation to other transport modes. It is believed that a study that focuses on the unique characteristics of motorcycle transport can provide a new line of enquiry to the city transport problems and contribute toward solving them.

Fifthly, the shared-taxi has been identified as part of the transport problems. Many studies emphasised the fleet's inefficiency and unreliability, but did not give any suggestion on how the service could be improved.

Sixthly, there is very limited literature addressing the mobility behaviour of motorcycle users and shared-taxi passengers. A search for literature related to the two modes found most papers in the field focus on the safety aspects of motorcycles, and there

¹² only one past academic study includes walking as a transport mode in its model

are only a handful of research documents relating to the shared-taxi. These findings point toward the gaps in current understanding, which this thesis helps to address.

Lastly, a comparison between MARS and five other different transport models reveal several possible improvements that can be made to the model and give an endorsement to its use as a macro-level sustainable transport planning tool.

The seven findings summarised above give rise to the new lines of study pursued in this thesis and underline the significance of the research, which attempts to provide productive responses to these needs, and fill the gaps within the existing studies.

3. The Development of Chiang Mai City, its Transport System and Land Use

3.1. *Introduction*

This chapter traces the development of the city with a focus on its transport system and land use. The aim is to provide information that will help give a better understanding of the current transport problems of the city and understand its path-dependent development.

“Path-dependent” describes how a certain course of actions is limited by a decision, or set of decisions, taken in the past. It has been used in economic, historic, and social science to provide an alternative analytical perspective and to deepen understanding in research studies

The structure of this chapter is as follows: Chapter 3.2 provides a starting point for the development timeline. It describes the founding of the city, its initial planning principles, and the structure of the city in the earlier period. Chapter 3.3 describes the development of Chiang Mai city’s transportation system through time, including the development of the road infrastructure in and around the city. Chapter 3.4 details the development of the city land use in parallel to its transport system. Chapter 3.5 highlights factors that influence the direction of the developments, before Chapter 3.6 concludes this chapter.

3.2. *The founding of Chiang Mai city*

Chiang Mai city is a large ancient city, founded by King Mangrai, a powerful ruler of the Lanna Kingdom. After his accession to the throne in 1259, King Mangrai unified and conquered cities and states in the region and founded Chiang Mai city in 1296.

King Mangrai found a potential site for Chiang Mai during his excursion to a plain near Doi Suthep Mountain. It is uncertain whether there already were some settlements in the area prior to King Mangrai’s visit. The king called upon his avowed friends Phraya Rong, King of Sukhothai, and Phraya Ngam Muang, King of Prayao for their advice on the site selection, the planning, and the construction of the new city. The three kings agreed on the suitability of the location as they observed seven auspicious virtues of the site (T. Charoenmuang, 1986; Yuparaj, 2005).

These seven auspicious virtues are relevant to today's city planning philosophy and can be summarised as follows:

- The location was on a plain next to the Ping River. The flat land made it highly accessible from other surrounding cities while the river provided a means for the transportation of goods. The location was ideal for an administrative and trade centre.
- The Ping River plain was the largest fertile flat land of the Lanna Kingdom. It was an ideal location for agricultural activity and had plenty of space for future expansion.
- The Ping River provided a natural fortification from any invasion from the east.
- The site is located on the west-east declension between Doi Suthep and the Mae Ping River. The inclination of the plain provided the city with flooding protection. The Mea Ka River and the large swamp on the northeast ensured that the city had a plentiful water supply

King Mangrai gave the new city a name: Nophaburi Sri Nakhon Ping Chiang Mai and the construction of the new city began. A carved stone tablet at Wat Chiang Man, the oldest temple of the city recorded that building Chiang Mai city commenced on Thursday 12th April 1296 (Wichaikatika, 1986).

The historical planning principle of Chiang Mai city

Chiang Mai City is planned in accordance with an ancient custom. The attempts to accurately determine the exact custom have provoked an on-going lively discussion among experts in the field (D. Charoenmuang, 2007). Wichiankhieo (1996) proposed that the planning principle was based on the Loa custom that the city functions in the same way as a human body. A city can be divided into three sections: the upper section or the city's head, the middle section or the city's umbilical, and the lower section or the city's feet (D. Charoenmuang, 2007; Jankao, 2008). The use of the area within the city should be allocated according to Loa beliefs which are summarised in Figure 3-1.

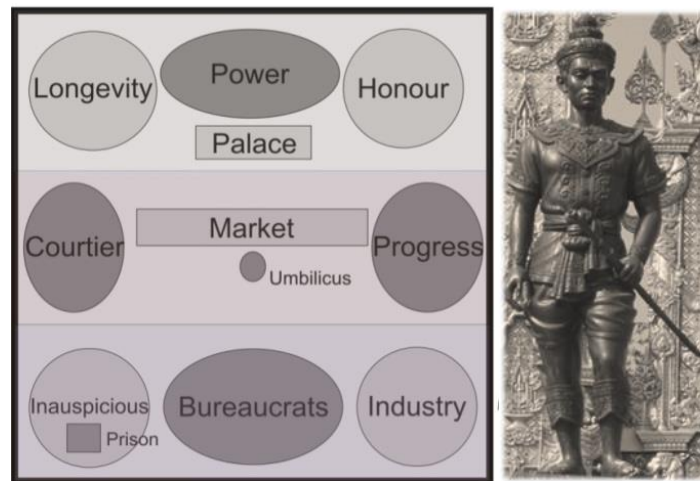


Figure 3-1 Land use guidance in Chiang Mai city according to Loa tradition and King Mangrai's status

Source: Modified and translated from (Jankao, 2008)

The upper chapter of the city, or the city's head, was associated with Longevity (th. อายุเมือง), Power (th. เดชเมือง), and Honour (th. ศรีเมือง). Royal and official buildings should be placed in this section. The facilities within Chiang Mai city that were built in this section included: the royal residence, the official seats, the treasury, the royal horse and elephant stables, and the military assembly area.

The middle section of the city, or the city's umbilicus, was associated with trade, economic activities, the governor and his courtiers. The facilities within Chiang Mai city that were built in this section included: the city's umbilicus (a statue that mark the city's centre) during King Mangrai period (1296-1311), the city's markets and its umbilicus during Phraya Kawila's period (1782-1815).

The lower section of the city, or the city's feet, was associated with a residential area for the supporters of the city's physical functions, such as the bureaucrats and the skilled workers. It is also connected with industrial and other inauspicious activities (e.g. prison and grave yard). The facilities within Chiang Mai city that were placed in this section included: centres for castings, centres for handicraft, and the exit gate toward Hai-ya, the city's cemetery.

It is widely accepted that, historically, Chiang Mai city comprised two areas; the inner city and the outer city areas. But the exact original structure and form of King Mangrai's city is still the subject of heated academic debate. Figure 3-2 shows the forms of the city during the three periods identified by Damrikul (2012).

(1986) and Yuparaj (2005) believed the inner city dimensions were between 1,800 metres by 2,000 metres. In contrast, Bacon (1873) and Prachakitkornrajak (1961) recorded the city's dimensions as 1,600 metres by 1,600 metres. Nevertheless, the aerial estimation using Google Earth shows that the dimensions of the wall today are approximately 1,550 metres by 1,550 metres which yielded an area for the inner city of 2.40 km².

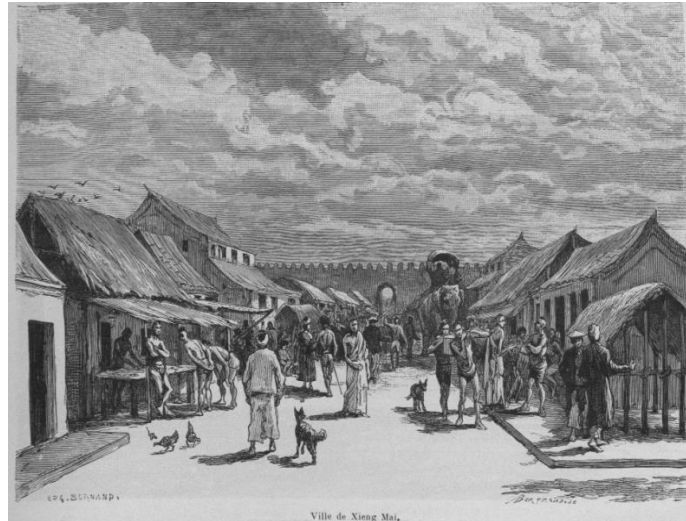


Figure 3-3 Illustration of Ville de Xieng Mai, inner city area (1885)

Source: Voyage dans le haut Laos (Neis, P.)

The official royal residence, official buildings, markets, and important temples, occupied a large proportion of the inner city area. It is believed that the Thai Youn or the local ethnic group was the only group allowed to reside within the inner city area (Bacon, 1873; Bowring, 1857; Valipodom, 2002).

The inner city wall was surrounded by a manmade moat. The main purpose of the moat was to obstruct intruders from attacking the city wall but it was also used to store water for the residents during drought. The water supply of the moat came from a stream which originated from Doi Suthep Mountain and entered the moat on the northwest corner of the city (Jaing Hua Lin). The 18 metres wide moat was constructed during the same period as the wall. It is believed that the earth, dug out to construct the moat, was used as the construction material for the inner city wall.



Figure 3-4 Inner Chiang Mai city wall and Moat in present day

Source: <http://www.flickr.com/photos/zozo2k3/> and <http://www.flickr.com/photos/g-na/>

The outer city area

The boundary of the outer city area was defined by the crescent-shaped earth wall which spanned across the north east corner of the city (Jaing Sri Pom) and the southwest corner (Jaing Kuu Heung) (Yuparaj, 2005). Although it is evident that there is little left of the outer wall, its shape can still be traced by following the moat that was constructed around its outer perimeter (Wichaikatika, 1986).

Skilled workers, merchants, and common citizens resided in this outer city area. The people who lived here comprised diverse ethnic backgrounds from Burma, Khmer, Shàn zú, Khün, Yunnan and Kon Muang and included local Chiang Mai residents.

City Gates (Pratu) and access roads

Access to the city area was controlled by gates. Chiang Mai city had a total of six inner and five outer city gates. Figure 3-5 shows an historical picture and sketch of some of these gates.

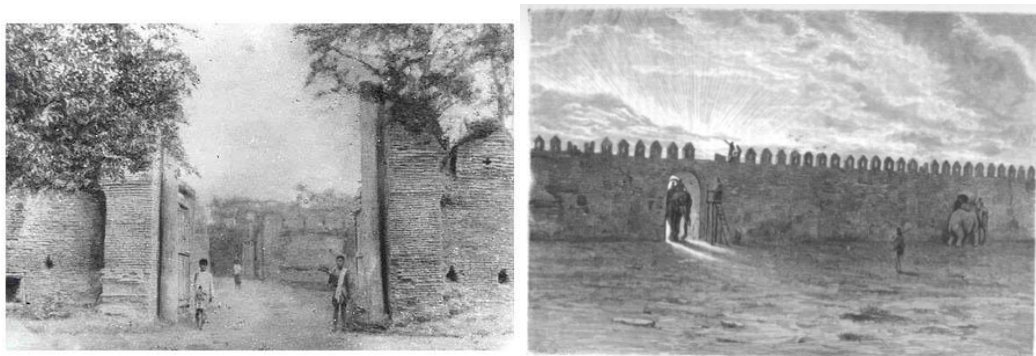


Figure 3-5 Pratu Chang Moi gate and La ville de Xieng Mai

Source: (Sattrapai, 2011) and (Neis & Burnand, 1880),

It is believed that each gate was used for a different individual purpose. The four gates (Gate a, b, c, and d) that provided access into the inner city area were 8 meters in

width. Figure 3-6 shows the location of city gates and probable road layout of the city during King Mangrai period.

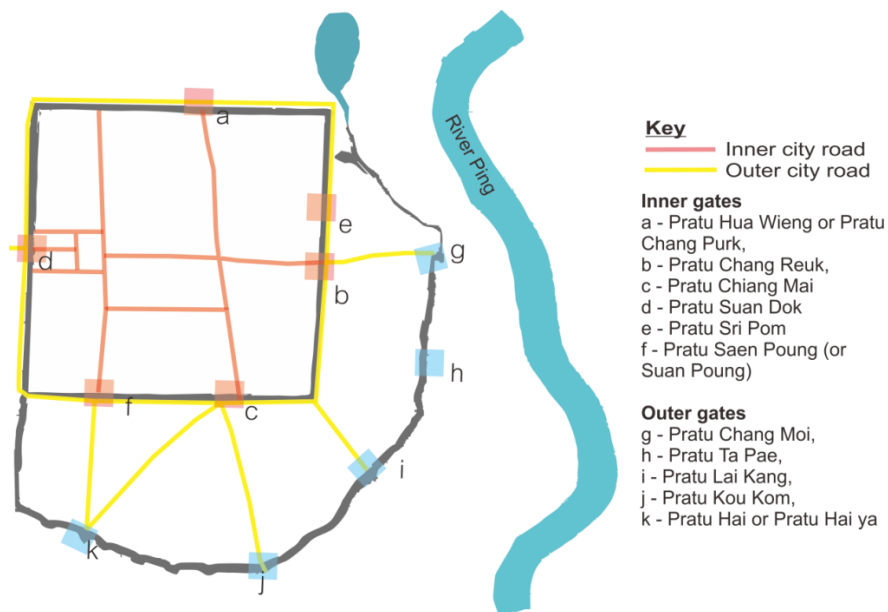


Figure 3-6 Locations of the city gates and probable road network during early period

Source: Translated and modified from (Sukkan, 2008; Wichaikatika, 1986; Yuparaj, 2005)

The roads within the inner city took a regular geometric shape while the outer city roads were narrow and did not have any particular shape or pattern (Vichaikatka, 1986). It is believed that there were transportation routes between Chiang Mai city and its neighbouring cities. These routes mostly lay alongside rivers or streams, perhaps to avoid any extreme change in altitude (Siri, 2007). However, the condition of these routes was appalling by European standards at that time, as recorded by an English explorer G.J. Younghusband in 1888:

“Throughout Siam (Thailand), as far as we have seen 1000 miles or so, there are no made roads at all.

The most important towns are connected only by mere footpaths, worn by pack animals and passengers. These paths are never straight for fifty yards together, and in forest land wind very much. This of course makes the distances between places much greater than need be”

(Younghusband, 1888, pp. 85–86)

The first recorded road construction and expansion project to upgrade footpath and cart way networks was in 1893 with a second one in 1899 (Charoenmuang, 2007). The

objective of these projects was to provide levelled routes for ox carts between the city and its surrounding area.

3.3. Development of the city's transport system

A transport system can be defined as “a facility consisting of the means and equipment necessary for the movement of passengers or goods”¹³. Developing over a period of time the system's purpose is to serve people's need to travel to undertake desired activity.

This chapter describes the development of facilities available to aid the movements of passengers and goods in Chiang Mai city. It classifies the development of the system into two periods: the non-motorisation period (1296 – 1901) and the motorisation period (1901-present). Each sub-chapter, where possible, provides a detailed account on each mode of transport and its infrastructure.

3.3.1. The Non-motorisation period (1296 – 1900)

This period spanned between the year Chiang Mai City was founded by King Mangrai in 1296 and the year Thailand imported its first Automobile in 1901. During this period, the form of the city remained relatively stable and the modes of transportation were walking, animals, boat, bicycles and tricycles.

Although Chiang Mai city was the capital of Lanna Kingdom, it was compact. Figure 3-7 shows the maximum geodesic distances within the inner and outer city areas on an aerial map of the city.



Figure 3-7 Walking distance within inner and outer wall of Chiang Mai city

¹³ <http://www.thefreedictionary.com/transportation+system>

The dimension shown is based on the current shape and form of the city. The maximum geodesic distance within the inner city area is 2.2 kilometres. This distance increases to 2.8 kilometres, if the outer city area is included. These distances equate¹⁴ to 33 minutes walking time for the first case and 42 minutes for the latter case.

Walking or ambulation



Figure 3-8 Porter service and Lanna women carrying goods to market

Source: (MOD, 2011) and (Sattrapai, 2011)

Before any motorised vehicle was imported into Thailand, the transportation in Chiang Mai city was dominated by walking (Bacon, 1873). Trading goods and cargos were also transported by walking. Various types of baskets and tools were used to carry goods. Porter service and slaves were available to assist in carrying heavy loads (MOD, 2011).

¹⁴ Assume average walking speed of 4 km/h

Animal Transportation

Various types of animal were used as modes of transportation in Chiang Mai city. Historical records show that ox, horses, mules and elephants were used to haul goods and passengers by riding, packing, and harnessing (Siri, 2007).

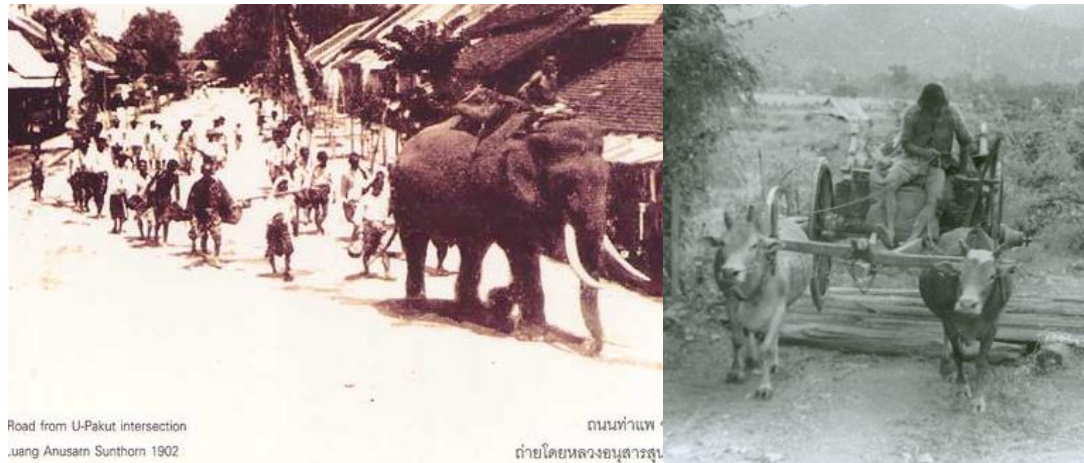


Figure 3-9 Elephant used by the elite class in 1902 and ox cart

Source: (Anusarnsoonton, 1902; Sattrapai, 2011)

Ox were the most popular as they were widely available in the area and could be used for agriculture activities. Harnessed to a cart, an ox could transport an extra 40-50 kilograms, or more, than if the goods were strapped to its body. It is believed that ox carts were introduced to the city in 1873-1896 (HSRI, 2003). It was an important and popular method to transport goods from the rural areas into the city; it was suitable for muddy routes and poor condition roads. Ox cart porter service was widely available at the markets to transport agricultural goods and food to the surrounding areas of the city, and *vice versa*.

The footpath and cart way improvement projects between 1893 and 1899 increased the accessibility, when using carts, to the natural and agricultural resources which were located in the borders of the city and the surrounding areas.

Using horses was a less popular mode of animal transport. Horses were mostly used for personal transit as they were faster but could carry less weight (approximately 25-30 kilograms). Elephants were also used to transport goods and people but only among the upper classes such as royalty, the elite, and the government and/or army officers (MOD, 2011; Salahlanna, 2011).



Figure 3-10 Advantage of ox on uneven and muddy road, the last ox cart in Chiang Mai city 1967

Source: (Sattrapai, 2011)

Ox carts became an obsolete mode of transport because of the increased popularity of motorised vehicles such as cars and motorcycles. They were faster and had a higher carrying capacity. Chiang Mai city officially banned ox carts from the city and the municipal areas in 1967. They were seen as obstructions to other traffic. In addition, the strong odours from ox's excrement was another reason that the ban was imposed (Sattrapai, 2011).

River transportation

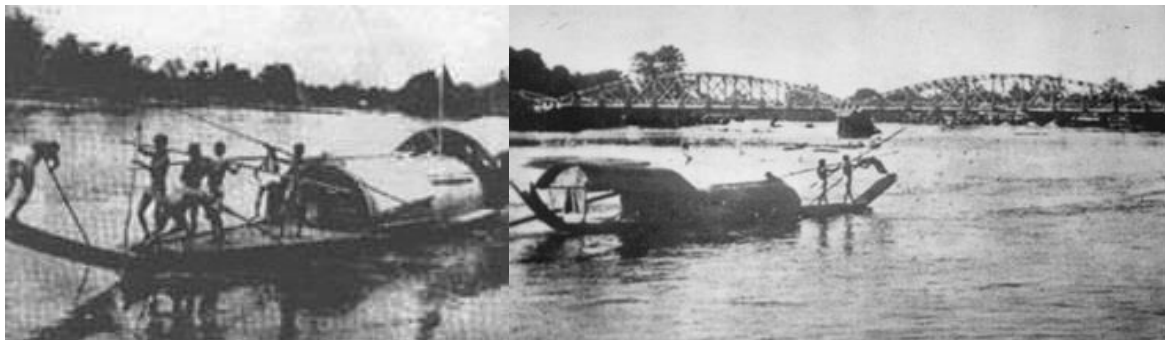


Figure 3-11 Scorpion-tailed boat approaching Chiang Mai bridge

Source: : (Salahlanna, 2011) and thairath.co.th

River transportation such as ferry, raft, and scorpion-tailed boat were used to transport goods and people across the Ping River and between the city and its surrounding areas. River ferry boats were used mostly for short distance trips across the Ping River, while rafting and Scorpion-tailed boats were used for medium and long distance trips. Scorpion-tailed boats, in particular, were used to transport goods between Chiang Mai and Bangkok as it was faster than land transport. However, it was less favourable than land

transport, because of its dependence on weather conditions, fluctuating water levels, and the dangers from natural disaster, wild life, and piracy (Salahlanna, 2011).

Bicycle Transportation

The first bicycle was imported from Europe to Thailand in 1868 although the first commercial bicycle was not available until 1877 (YABC, 2011). Bicycles were first available to a small circle of royal family and the elite classes in Bangkok. The first bicycles used in Chiang Mai arrived between 1901-1909 (HSRI, 2003). The British consulate reported that, in the year 1926, a total of 2,000 bicycles were registered in Chiang Mai city (Narksuk, 2000).



Figure 3-12 Bicycle in Chiang Mai

Source: left and right –Authors, middle - www.chiangmainews.co.th

Using bicycles has become a marginal mode of transport in the city nowadays. It is believed that the fear of accidents and increased air pollution are the main factors that deter people from using bicycles as a commuting mode of transport. However, a large proportion of residents still use bicycles for short journeys within their local area and for exercising purposes. There are over 15 bicycle clubs within the city, the biggest of which is the Chiang Mai Sunday Bicycle Club. In addition, bicycles have also become a popular means of transport for tourists and young people.

Tricycle or Samlor Transportation

The tricycle or Samlor in Thailand was first manufactured in 1933 by a Thai inventor. The tricycle was a popular form of personal taxi service in Thailand before the import of motorised vehicles. It was widely used in Chiang Mai city to transport goods and people of all ages and was so well-integrated into the culture and tradition of the city, that it became associated with the city itself (Sirius, 2009).



Figure 3-13 Tricycle service in the past and today (1975)

Source: Internet and (Sattrapai, 2011)

In 1973, there was a total of 3,700 registered tricycles in Chiang Mai (Namwong, 2002). However, the tricycle became less popular as motorised modes of transport such as the car, the motorcycle, and shared-taxi, offered a faster means of travel. In addition, as previously mentioned in reference to the use of bicycles, it has been suggested that the worsening of the city's air quality deterred citizens from using this mode of transport (Sirius, 2009). Today, it has become a means of transport associated with elderly people who have been regularly using the tricycles for many years, and they are also used by a small number of tourists. In 2003 it was estimated that around 600-1,000 tricycle services still operated and could be found at market places around the city (HSRI, 2003). The fare per trip starts at 10 Baht (0.25 Euro) and increases depending on the distance. However the fare is negotiable (Patiphantarkarn, 2007).

3.3.2. The Motorised period (1901-present)

This period began when the first car was imported into Thailand in 1901. Initially, cars were only available among the elite of the population, such as the royal family, high ranked officials, and influential westerners, as they were expensive and ineffective. Their wheels were not suitable for the muddy and uneven roads that existed at that time in most of Thailand. The intercity train transport is included here, because its arrival had significantly affected the land use of the city. A short account on air transport is also included here for completeness.

Private car

The first car owner in Chiang Mai was Phrya Jaror-racha Mai-tri, the chief judge of the northern region at that time. It is uncertain when he brought his car to Chiang Mai city.

Nevertheless, it could be estimated from the Royal Automobile records that his car arrived in Chiang Mai city between 1906-1908¹⁵, as the record shows Phrya Jaror-racha Mai-tri requested the King to name his cars during this period (RTY9, 2001).



Figure 3-14 A private car in Chiang Mai – pre Second World War period

Source: (Sattrapai, 2011)

As mentioned above, car wheels at that time were not suited for the muddy and uneven roads in the surrounding area and so car usage in Chiang Mai was initially limited to the city centre. Cars became a more convenient method of transport after many road improvements and construction projects had begun between 1906 and 1916. These roads provided connections between the city and its surrounding rural area (Charoenmuang, 2007). Additionally, several roads within the city area were widened to a minimum of 6 metres to ensure that two cars could pass side-by-side (HSRI, 2003). However, the number of cars remained limited during this period, only 50 registered vehicles were found from official records kept in 1922 (Tuptong, 2012).

The construction of roads and highways stimulated the expansion of the city along these infrastructures. In addition, it increased the amount of road traffic between Chiang Mai and Bangkok (Charoenmuang, 1998). Travel time by road was greatly reduced; a journey between Chiang Mai and Bangkok by car took approximately 8 - 10 hours, in comparison to a 12-15 hours journey by train. Moreover, the improvement of the national road network increased the flexibility of road transport; there came a point in time when the number of destinations accessible by road transport was greater than those accessible by the

¹⁵ The first car was imported into Thailand in 1901.

train. The number of passenger and goods transported by road increased further as rail infrastructure deteriorated and became more unreliable.



Figure 3-15 Traffic jam on Thapae Road in 1954 and an old petrol station

Source: (Sattrapai, 2011) and this thesis

As the number of cars in the city increased, residents began to experience congestion problems. The first reported severe regular congestions were at the Chiang Mai Stadium junction and area adjacent to Chang Phuek market in 1990 during peak hours. The regular congestions were temporarily resolved by the traffic police's one way scheme project (Nernhard, 2010).

The motorcycle

The first motorcycle in the world was created in 1868 by Sylvester H. Roper, an American inventor. It is unclear; however, when the first the motorcycle was imported into Thailand. It probably arrived around the same period as the private car and became commercialised between 1940 and 1950. Motorcycles became a popular private mode of transportation in the city due to their affordability to own and to use, in comparison with car. Although, it has the disadvantage of a lack in carriage capacity, various adaptations have been made to overcome this limitation. The motorcycle with side cargo carrier or shop front can often be sighted in Thailand.

The typical price of a motorcycle in Thailand today (2013) is *circa* 40,000 Baht (1,000 Euro), while the typical price of a car is *circa* 1,000,000 Baht (25,000 Euro). In addition, the purchase can be paid by instalments (e.g. 18 months) as retailers normally offer hire

purchase agreements, resulting in an average monthly cost of 2,000 Baht (50 Euro) for motorcycle ownership

Today, motorcycles account for approximately 70% of the total vehicles registered in the city. The number of registered motorcycles in Chiang Mai in 2011 was 636,168. It is the second highest in the country (MOT, 2011).



Figure 3-16 The motorcycle in Chiang Mai in 1987, today, cargo carrier, and shop set up

Source: (Sattrapai, 2011), http://lantongmotor.blogspot.com/2010/03/blog-post_3054.html, and http://www.codsana.com/img/ec6/767/ec6767dbba3581ee41752ffb397e63c4_3.jpg

Rot Koob and Rot Kok Moo

The improvement in road conditions between the city and rural areas in the period 1906-1919 enabled goods to be transported efficiently by truck and an increasing number of merchants and tradesmen purchased trucks to transport their goods. This increase in demand eventually gave rise to an earlier form of the shared-taxi and bus transport. Rot Koob or Rot Kok Moo, a modified truck with seating was used to provide transportation of passengers and goods between rural areas and the city. The service was privately run by the truck owners or wealthy merchants. It was eventually replaced by official bus services and shared-taxis.

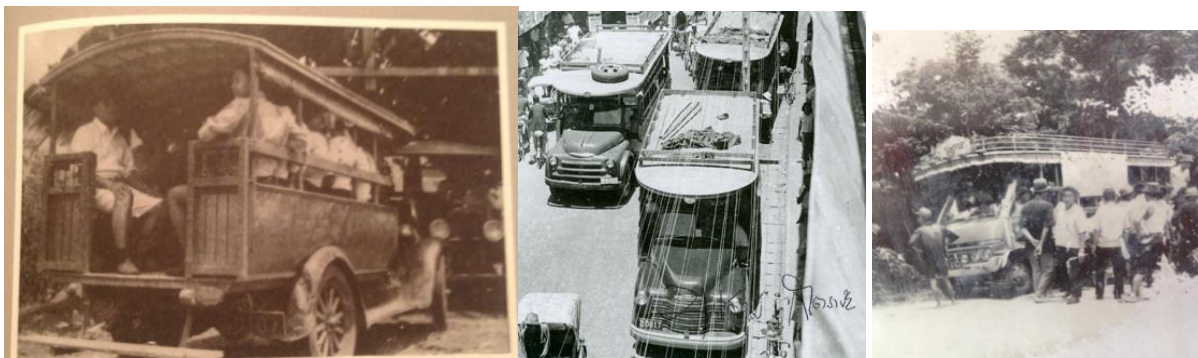


Figure 3-17 Earlier forms of shared-taxi – Rot Koob (รถกูบ) and Rot Kok Moo (รถคอกหมู)

Source: (Sattrapai, 2011) and author's

Shared-taxi or Song Teaw or Rot Deang (Red Car)

The shared-taxi or Song Teaw is a modified pickup car with a semi-capsulated canopy, which protects its passengers from the elements, such as rain and sun. It is a form of informal transport service and can officially carry up to 11 passengers¹⁶. There are two forms of shared-taxi service within Chiang Mai province: the fixed route service and the on-demand service. The fixed routes provide service to the surrounding area of the city, while the non-fixed routes are normally operated within the urban area. The distinction between the two is the colour of the fleets; the non-fixed route is generally red, while the fixed route destination is generally indicated by its colour (white/yellow/blue/green/orange but sometimes red).



Figure 3-18 Fixed route service (or Rot Queue)

Source: <http://www.reviewchiangmai.com/1887>

The official record shows that the shared-taxi began its operation in Chiang Mai city around 1965, although similar forms of transportation might have operated earlier. It is the only form of non-private transport that has been operating continuously in the city. Its demand responsiveness, speed, and high capacity, soon established it as the preferred mode of transport in the latter half of the 1960's. Its popularity contributed towards the decline of ox cart, tricycle services and the use of public buses.

Initially, it was an informal operating service as anyone with a pickup truck could become a vehicle operator. However, the lack of safety standards and widespread violation of the land transport law¹⁷ compelled Chiang Mai's Department of Land and Transport (CM-DLT) to enforce safety and registration regulations on the service in 1975. Additionally, the CM-DLT imposed routing regulations on the service by establishing 51 shared-taxi routes

¹⁶ In reality, it has been seen carried up to twenty passengers.

¹⁷ The service's type of registration at that time only permitted transportation of goods not person

and requesting that the vehicle operators form a number of co-operatives to bid for the operation of each route (Watthanakul, 2008).

The CM-DLT enforcement resulted in the formation of three shared-taxi co-operative groups: the Lanna Transportation Co-operative (LTC), the Chiang Mai Transport Co-operative (CTC), and the Sankampang Transport Co-operative (STC). Total membership of the three groups was estimated at between 2,900 and 3,300 although only 70% of them (approximately 2,000) were actively operating. The LTC was the largest co-operative in the city and in the country with a membership of over 2,000. It was authorized to operate on 32 out of 51 shared-taxi routes in Chiang Mai (CMU, 2012a; HSRI, 2003; Watthanakul, 2008).

Although each co-operative group must run its service in accordance with its authorized routes, in reality vehicle operators often infringed the regulation and operated their vehicles as non-fixed route services. It is believed that low passenger levels on some routes provided this motivation as vehicle operators on these routes inevitably received less income. In some cases, they were operating at a loss and were forced to infringe the regulation in order for the business to survive. In 2003, HSRI (2003) estimated that only 786 vehicles were operating on a fixed route basis, while around 2,000 vehicles, or approximately 80 % of the active fleet, were operating on a non-fixed route basis



Figure 3-19 Shared-taxi or Song Teaw (non-fixed route)

The route of a non-fixed route service was determined by its drivers, with the drivers adapting the route according to their preference and passengers' destinations. The CM-DLT permitted a minimum charge for the service of 15 Baht (0.38 Euro) for an adult and 10 Baht (0.25 Euro) for a students and monks for a 2-5 kilometres trip. The final charge depends on the length of journey and negotiations between the passenger and the driver. However, in

reality the fare is unpredictable and often depends solely on the bargaining positions of the driver and the potential passenger. (CMU, 2012a; HSRI, 2003).

At the time of writing this thesis, various measures were being implemented by the CM-DLT to improve the effectiveness of the operation of shared-taxi. In 2012, CM-DLT reviewed the service routes and launched a pilot project operating fixed routes. The pilot project designated three routes for the shared-taxi service. Thirty vehicles participated in the pilot scheme. The service operated between 07.30 and 17.00 during weekdays and 08.30 and 18.00 during weekends. The frequency of the service was every 20 minutes during the peak period (07.30-08.30 and 1500-1700) and every 40 minutes during the off-peak period. During the weekend the service frequency was every 30 minutes. The fares were fixed at 15 Baht (0.37 Euro) for adult and 10 Baht (0.25 Euro) for students and monks. The project began on 5th November 2012 and was scheduled to operate until 5th February 2013 (CMNews, 2012).

However, the effectiveness of the pilot project is questionable. Firstly, the operating hours of the service make it unlikely to match the travel pattern of prospective passengers such as school students and office workers. Secondly, the frequency of the service is too low. The Chiang Mai mobility and travel survey in 2012 shows that the average travel time of its respondents is 16 minutes per trip. Thus, the service frequency will not be sufficient to attract prospective users.

In August 2014, a similar project to the 2012 was launched. The shared-taxi service was organised into 15 routes (three of which provide an exclusive service for students). Fifty shared-taxis are assigned to Route 1 to 11. Six municipality buses were assigned to Route 12. It was unclear how many fleets were assigned to the three students' services. The service hour for Route 1-12 is 05.00-20.00. The fare for route 1-11 is 20 Baht fixed and for route 12 is 15 Baht. The service hour for the three students' service is 06.00-09.00 and 15.00-18.00 with 10 Baht fixed fee. The frequency of the service is every 20 minutes. In addition to the organisation of the shared-taxi service, all fixed-route services began and terminated from one transit terminal (Chang Phuek bus interchange). They were also prohibited to enter the city to pick-up passengers.

The project caused much discontent amongst both the operators and passengers, who found the fixed-route services increased the transport time and cost and were very

inconvenient. Rather than having the desired result, the number of passengers travelling into the city via the fixed-route services diminished. Previously, the fixed-route services provided direct connections between the main market (Warorot Market) and the outer areas. In October 2014, the fixed-route services were eventually allowed to return to the *status quo*

Although the shared-taxi has provided the longest serving non-private transport system of the city, its co-operative structure prevents it from becoming an effective public transport mode for the city. The three shared-taxi co-operatives are autonomous associations of shared-taxi owners. They were formed in response to the CM-DLT's requirement in 1965. Members join voluntarily and while the associations have codes of conduct they cannot enforce any rules on their members. In addition, the financial benefits or losses are not shared by the members of the co-operatives. This financial risk may be another factor that forces the drivers to adjust their individual operating strategy to optimise personal gains. As a result, the service's routes, trip times, and fares have become totally unpredictable from the general public's perspective.

Public Bus

Although, the bus service between Chiang Mai and other cities began as early as 1917¹⁸, the operation of public bus services within Chiang Mai city only began in 1972. At its peak, five operators offered public transport services in the city; however, only one operator is still running its services today. Table 3-1 summarises the details of these bus operators and their services.

Table 3-1 Chiang Mai bus operators' timeline

Year of operation	Bus operators	No. Route (network length in km)	Frequency (every min.)	Fare (reduction % for students)	Hour of operation	Capacity per bus (number of vehicle)	Note
1972 - 1976	Charempol Transport Company (Private)	3 (43.0)	n/a	n/a	n/a	n/a	"The white bus"
1979 - 1995	Chiang Mai Thai Transport Company (Private)	4 (53.0)	7 - 8	2 Baht per trip (50%)	0600-2100	50 (8 veh)	"The yellow bus"
						35-40 (45 veh)	"The yellow bus"
1985 - 1995	Prempracha Transport Company (Private)	2 (40.4)	15	2-4 Baht (50%)	0600-1800	25-30 (16 veh)	"The red bus"
1994 - 1998	ACC Real Estate Company (Private)	1 (25.5)	30 - 40	10 Baht (n/a)	0500-2200	25-30 (5 veh)	"Kuawn-wiang bus"
2003 - 2005	ACC Real Estate Company (Private)	1 (25.5)	30 - 40	10 Baht (n/a)	0500-2200	25-30 (5 veh)	"Kuawn-wiang bus"
2004-present	Chiang Mai municipality (Government)	4 (?)	4 per day	15 Baht (n/a)	0600-1800	25-30 (26 veh)	"The municipality bus"

Source: compiled and translated from (D. Charoenmuang, 2007; HSRI, 2003; Watthanakul, 2008)

The first company was Charempol Transportation Company, which began its operation in 1972. It ceased operating in 1976; its ineffectiveness in fee collection caused the company to go bankrupt (D. Charoenmuang, 2007).

The Chiang Mai Thai Transportation Company began its operation in 1979 and the Prempracha Transportation Company followed in 1985. Both companies ceased their operations in 1995 as they became unprofitable. The prime reason for their insolvency was an inability to compete with the shared-taxi service (Patiphantharkarn, 2007).

The ACC Real Estate Company provided public transport for the city during two periods. The first period was between 1994 and 1998 and the second period was between 2003 and 2005. It ceased operations in both periods because of unprofitability. In addition, the shared-taxi groups strongly opposed the ACC service. Five days before the first ACC

¹⁸ The first official bus route was between Chiang Mai – Lamphun city. The first bus was called "Praya Phap" (HSRI, 2003).

service began its operation the shared-taxi groups gathered its members to park their vehicles across the carriageways within a 360 degree radius of Thapae Gate, blocking traffic from passing through the area in protest at the introduction of the new service. Eventually, agreements were made between local government officials and the shared-taxi representatives. It was agreed that the ACC routes would not enter the central city area and the service fleet would be limited to 5 buses, instead of 15 buses as planned. The route alteration and the limit on fleet size significantly setback the effectiveness of the ACC service. The service was losing approximately 2 million Baht per year before it ceased operating in 2005.

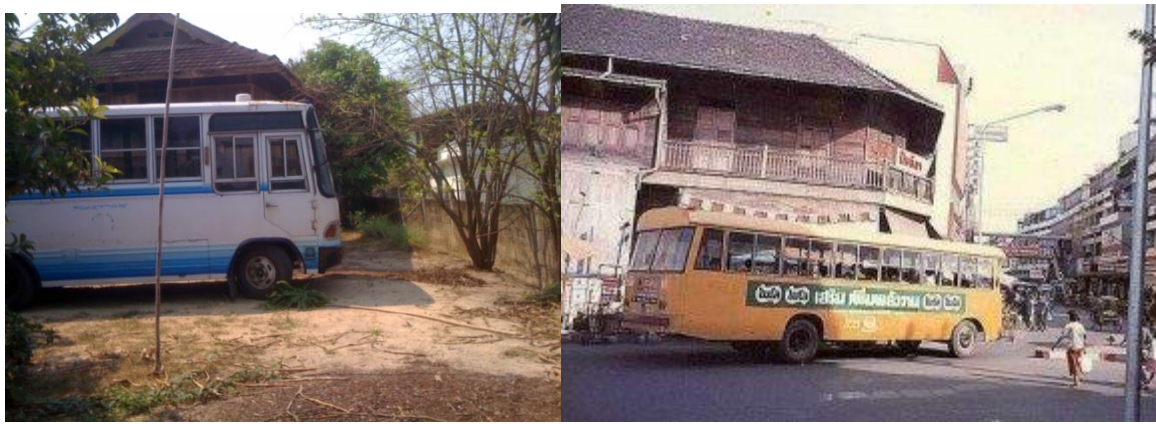


Figure 3-20 Abandoned Charempol Transport's white bus and Chiang Mai Thai Transport's yellow bus in operation

Source: This report and <http://www.oknation.net/blog/tigerjun/2009/07/14/entry-1>

The municipality of Chiang Mai began its own bus operation after it purchased 26 microbuses, worth 62 million Baht (1.6 million Euros) in 2004. The purchase was funded by the ministry of interior under a project aimed at promoting Chiang Mai as an aviation hub of the northern region and to provide service to/from the Royal Flora exhibition. The municipality invited the LTC and ACC to run their services alongside the municipality's 4 routes service. The service was still unable to enter the central city area as the shared-taxi operators were strongly opposed to its operation. The ACC ceased its operation in 2005, but no information is available on the viability of LTC's operation. At the time of writing this thesis, it is believed that the municipality still runs three of its four routes.

The bus service between the city and surrounding areas began in 1964, when the Chiang Mai Department of Land Transport (CM-DLT) was founded. The CM-DLT is responsible for all administration related to land transport, traffic regulation enforcement

and planning of road transportation (CM-DLT, 2012a). The CM-DLT founded the first bus government-owned interchange, or the Chang Phuek bus interchange, located on Chang Phuek Road, a short distance to the north of the old city area. It still provides today an embarkation point for all bus services within Chiang Mai province and Lamphun, a neighbouring city located 21 kilometres from Chiang Mai.

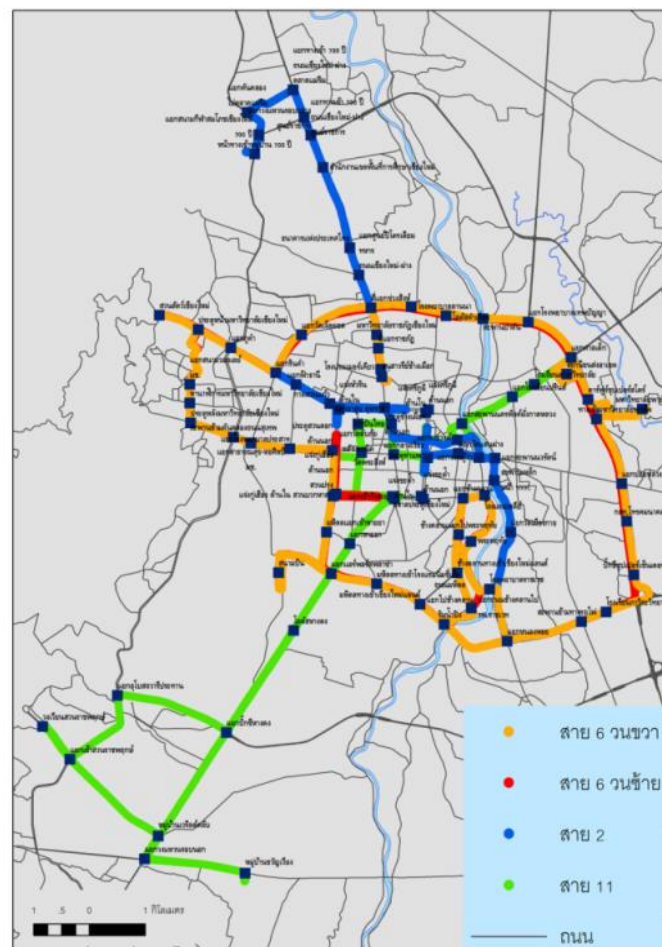


Figure 3-21 Four bus routes run by the municipality as of 2012

Source: (CMU, 2012b)

Motorised Tricycle or Tuk-Tuk

Tuk-Tuk drivers offer a similar personal taxi service as the traditional tricycle but at a faster speed. This form of transportation was imported from Japan in 1960. It acquired its name from the noise of its two-cylinder engine. It proved popular among tourists and locals who required a fast door-to-door service. The fare depended on the trip distance and the negotiating skills of the passenger as is still the case today.

Tuk-Tuk came under threat in 1965 when the Thai government of the day came close to banning it as these noisy, fast-moving vehicles were seen as a hindrance to other road traffic. Moreover the shared-taxi co-operative groups in Chiang Mai city had pressured the CM-DLT to prohibit their use. However, rather than total prohibition, the government imposed a limitation on the number of Tuk-Tuk licenses. In 2011, there was a total of 1,092 registered Tuk-Tuk in Chiang Mai (CPLTO, 2011).



Figure 3-22 Tuk-Tuk or motorised tricycle

Source: www.phatthaisf.com and this report

Rail (Intercity)

The operation of The Bangkok-Chiang Mai train route began in 1921. The route was proposed by King Rama V in 1887. It was the first planned rail network of Thailand, albeit the construction of the Bangkok - Nakorn Rachasrima route was completed first in 1900 (SRT, 2012). The train station of Chiang Mai city is situated approximately 3.5 kilometres east of the city.

The main objective of the train project was to provide better access between the capital of Bangkok and the city of Chiang Mai for the transport of goods and to ensure that the cities within the region were well-governed. It was believed that an increase in accessibility between Bangkok and Chiang Mai would improve the political control over the city which was a dominion state of Siam at that time (Charoenmuang, 2007).

Rail transport provided a cheaper and faster mode of transportation between Chiang Mai and Bangkok than the river boat. For example, it cost 500 Baht and took three (1921 price) to transport 3 tons of goods to Bangkok by boat and 150 Baht and 14 hours by train (Nernhard, 2010). Train transport was also more reliable than river boat as it was less affected by adverse weather conditions.

This reduction in cost and time in transportation increased the amount of trade between Chiang Mai and Bangkok and changed the life style of the people in the Northern city. It increased the boundaries of local agricultural sales which hitherto were confined to markets within the city and its immediate environs, to new regional, national, and international markets. It began to transform the production of agricultural goods from local household sufficiency to export-orientated agricultural products (Charoenmuang, 2007; Nernhard, 2010; Sattrapai, 2011).

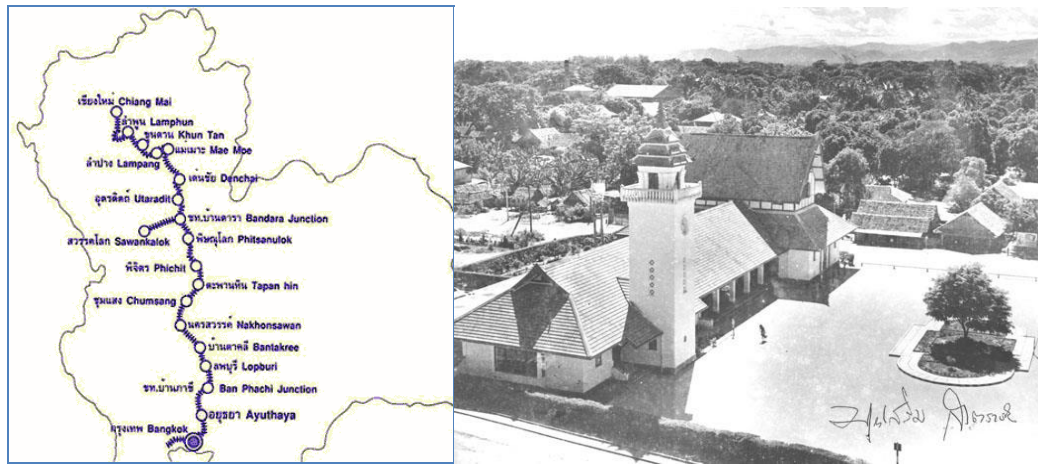


Figure 3-23 Chiang Mai Bangkok railway line and Chiang Mai train station in 1952

Source: <http://www.rtaf.mi.th/rtaf-travel/jd-bytrain.htm> and (Sattrapai, 2011)

Even though the train service was used only for intercity transportation, it must have increased the demand for goods transportation within the city as it increased the volume of the intercity trades. In other words, *the rail service stimulated ancillary transport activity within the city*, even though it did not provide an additional means of transportation within the city.

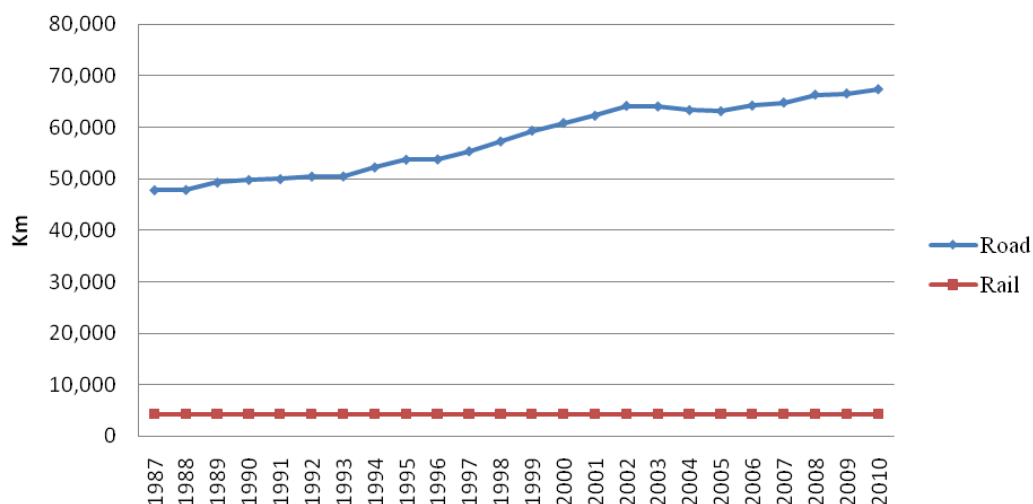
However, train transport became less significant after the end of the Second World War due to lack of investment by the government into its infrastructure. The quality of the rail service decreased, with delays and derailments becoming regular features of train journeys. In addition, the national rail network's length remained stagnant which limited its accessibility and competitiveness against other modes of transport. In contrast, the national road network had been expanding rapidly during this period. Graph 3-1 compares the total lengths of road and rail networks in Thailand.

Today, rail transport has become a marginal part of the national and Chiang Mai city's passenger and goods transportation. The proportion of goods transported by rail

nationally is 2.5% compared to 82.6% by road. Furthermore, the amount of goods transported by rail is decreasing annually (MOT, 2011).

In January 2012, the government approved a budget to construct a route for a high speed train link between Chiang Mai and Bangkok. The Chiang Mai – Bangkok route is one of the five high speed train routes proposed by the Department of Transport. It is planned to begin its operation in 2019. The high speed train is expected to reduce the travel time from 12-14 hours to 3 hours 43 minutes (Thairath, 2011). However, the future of the project has been greatly affected by the instability of the internal politics, which has been on-going since 2012.

Graph 3-1 Total road and rail network lengths in Thailand



Note: The data only includes only roads under DOT's responsibility
Source: Data from Department of Transport (DOT), Thailand

Air transport

The first commercial flights to Chiang Mai began in 1947 before the official opening of the Chiang Mai airport in 1954. The flight was operated by Siamese Airways Co. Ltd. as part of Bangkok – Phisanulok – Lampang - Chiang Mai and Chiang Mai – Mae Sariang – Mae Hong Son routes. The site of the airport was previously a sports field and was suitable only for small aircraft with a single engine. The airport is located approximately 4 kilometres west of the city.

Initially, air travel was used by a limited group of people due to its cost. However, the industry received high publicity during the 9th annual PATA (Pan Asia Travel

Association) workshop held in the city in 1969. Delegates from many nations travelled to the city by air. The event gave the city a high profile as a tourist destination (PATA, 2011).

Chiang Mai airport became an international airport in 1970. It is the third largest airport in Thailand today. In 2010, it served 11 airlines with a total of 27,422 flights of which 2,744 were international flights. The total number of passengers in 2010 was over 3.1 million, 250,000 of which were international passengers. The amount of goods passing through the airport in the same year was over 20,000 tons, most of which had an internal destination/origin. The majority of incoming goods were printed materials from Bangkok and majority of outgoing goods were agricultural products (AOT, 2010).

3.3.3. Development of road infrastructures

Although, the development of paths and roads in Chiang Mai city must have been gradual and continuous, the first recorded period of road construction in the city was between 1906 and 1916. During this period, several roads were built to connect the city and its surrounding area and many walking paths were converted to cart drawn paths (D. Charoenmuang, 2007). The condition of these mainly dirt roads was poor by today's standards but was adequate for carts and trucks.

Thailand transferred its political system from absolute monarchy to Constitutional monarchy in 1932. The transport policy of the country was also transformed at the same time. Road-based development became preferred due to the perceived lower maintenance costs than rail and its flexibility in services. The country issued its first national road construction plan in 1936. The plan aimed to build a comprehensive 15,000 kilometre road network system over an 18 year period, linking Bangkok with its surrounding regions. However, the roads built during this period were constructed to a relatively low standard (Kakizaki, 2013).

As Chiang Mai became a province of Thailand in 1933, it received funding from the central government for building and improving its public amenities. Many main roads in Chiang Mai such as Tha Phae Road, Charoen Muang Road and Loi Khro Road were reconstructed as concrete roads during this period. In addition, many walking paths between the city and the surrounding rural areas were upgraded to cart road standard (Charoenmuang, 2007).

Most of these road construction projects were within the municipality area and were the responsibility of the municipality itself. This responsibility, among 23 other municipality's duties is enshrined in law¹⁹. The municipality is obliged, "to provide and maintain the means of land and water transport" and "to provide and control marketplaces, ports, river crossings, and parking spaces, and to plan the city and to control the construction".



Figure 3-24 Road reconstructions in 1961 and 1965

Source: (Sattrapai, 2011)

After the end of the Second World War, another period of road expansion in and around Chiang Mai city began. The National Highway Construction Legislation, issued in 1952, set a target for the national highway department to construct 88 highways around the country within a four year period (1952-1955). Eighteen of these highways were situated in the northern region. One of the most significant road projects in Chiang Mai city during this period was the first ring road (National Highway No. 11) in 1969 (Charoenmuang, 2007). The highway connected Chiang Mai with Lampang, other cities in the lower northern region of Thailand, and Bangkok.

The quality of roads and highways constructed during this period was relatively much higher than previous efforts to build a national road grid. Much of this improvement is due to modern highway construction technology imported from overseas in 1951 (Pintapun, 2002). In addition, the majority of roads constructed in this period were the direct responsibility of the government of Thailand. The Department of Highway (DOH)

¹⁹ ตามพระราชบัญญัติเทศบาล พ.ศ. ๒๔๙๖ แก้ไขเพิ่มเติมถึง (ฉบับที่ ๑๒) พ.ศ. ๒๕๔๖ – Municipality Royal decree, Issue 12, last modified in 2003.

and Department of Rural Roads (DRR), which are subsidiaries of the Ministry of Transport, led the planning and construction of these projects.

The construction of numerous highway projects has continued into the twenty first century. Table 3-2 and Figure 3-25 show and summarise the development of the city's main highways.

Table 3-2 Radial and ring roads of Chiang Mai city

National Highway number	Details	Length with in Chiang Mai Province (km)	Year *
11	Chiang Mai - Bangkok (part of 1st Ring road)	22.0	1995(1969)
1141	Mahidol Road (part of 1st Ring road)	7.0	1998(1970)
3029	2nd Ring Road	23.1	(1994)
121	3rd Ring Road	53.0	1998(1994)
1004	Chiang Mai - Doi Suthep	3.6	(1934)
107	Chiang Mai - Mea Tang	36.7	(1935)
1001	Chiang Mai – Praao	100.0	Unknown
118	Chiang Mai - Chiang Rai	54.2	(1899)
1006	Chiang Mai - San Kamphaeng	34.8	Unknown
1317	Chiang Mai - San Kamphaeng (New)	42.0	Unknown
106	Chiang Mai - Lamphun	16.9	(1895)
108	Chiang Mai – Hot	156.0	1992(1986)
L	Railway Local road (Chiang Mai – Lam Phun)	13.8	Unknown

* No. in parenthesis is the year of construction; the other is the year of latest known improvements

Source: compiled and translated from (D. Charoenmuang, 2007; Sattrapai, 2011)

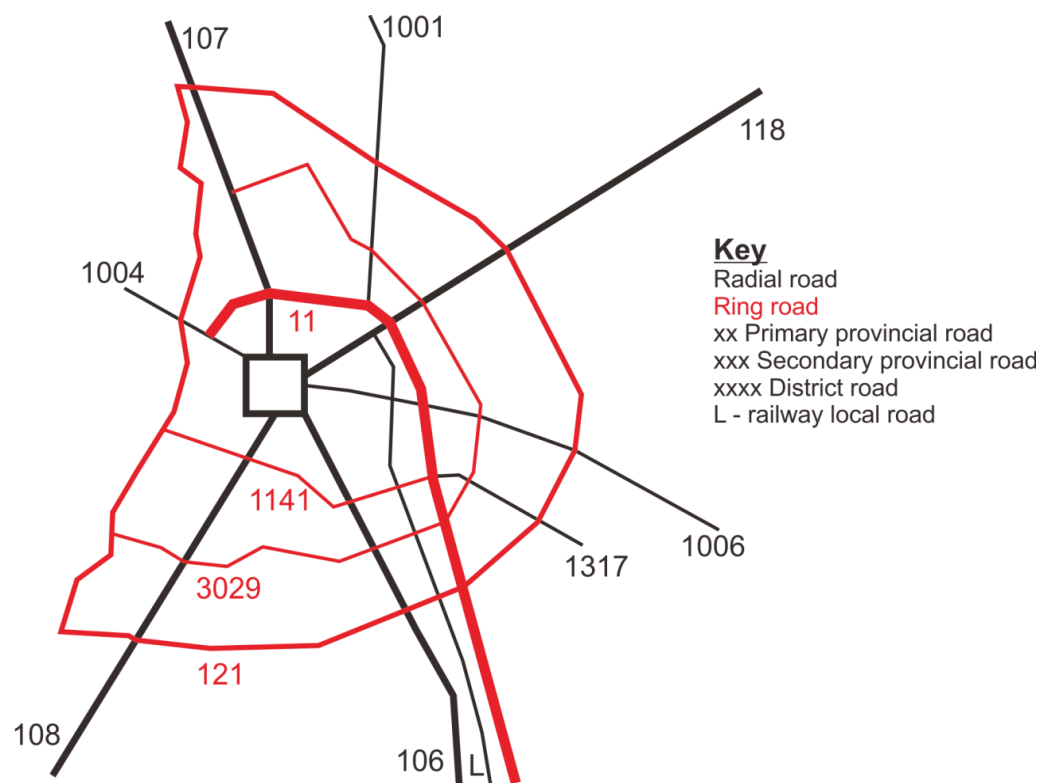


Figure 3-25 Radial and ring roads of Chiang Mai city

The road development of Chiang Mai city in the latter part of the twentieth century can be summarised as taking place in three phases as defined by Wannavichit(2004):

1. Radial roads development phase (1986-1993), such as Route 106,108, and 11
2. Ring roads development phase (1994-2000), such as Route 121 and 3029
3. Radial and ring roads connecting phase (2001-2004) such as improvement to Route 1141 and opening of Routes 121 and 3029 to connect with other radial roads. (Wannavichit, 2004, pp. 99–106)

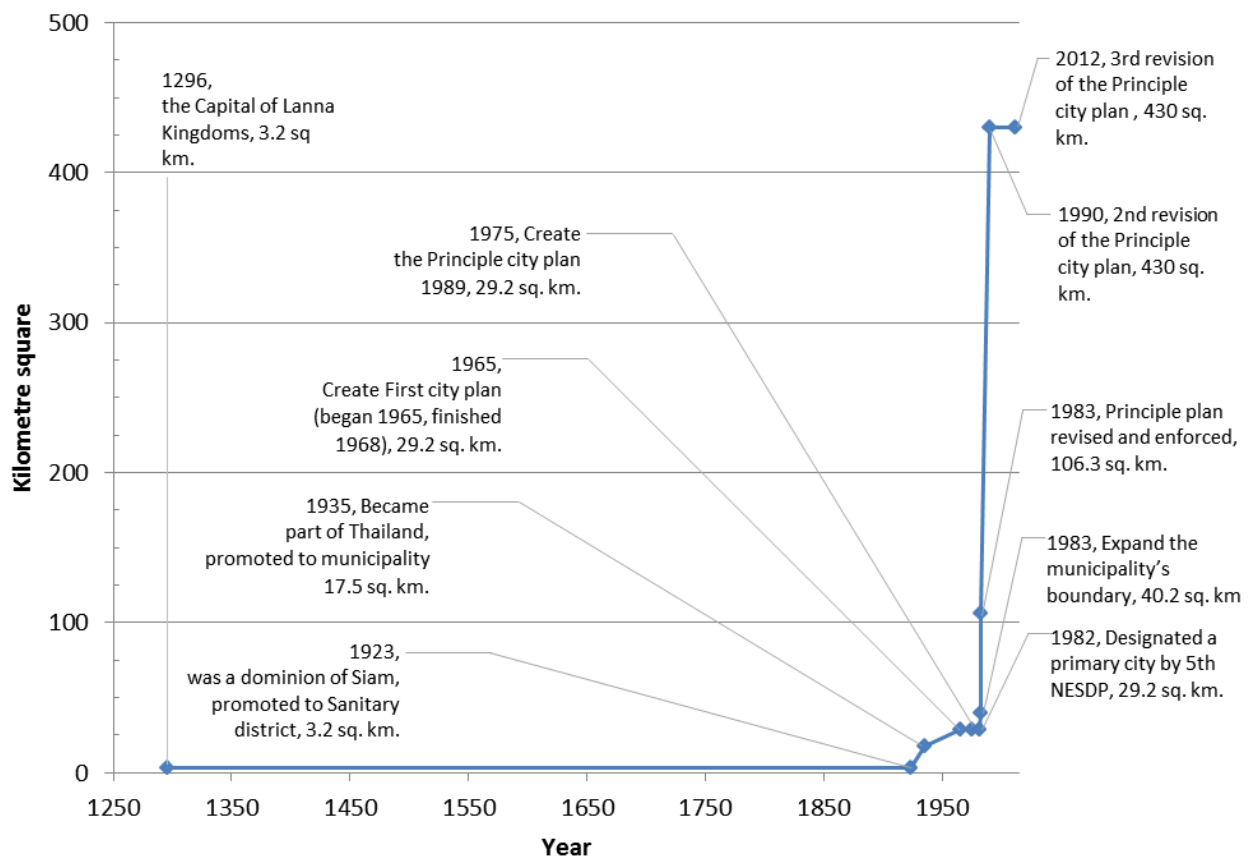
A meeting of the Ministers Cabinet in January 2012 in Chiang Mai sent a signal that a further development of the city's highways network was imminent. The cabinet approved budgets for transportation development projects of the Northern region, totalling 380,000 million Baht (9,500 million Euros). Although 80% of the budget is allocated to the Chiang Mai – Bangkok high speed rail project, ten highway projects around Chiang Mai were approved, worth in total 15,000 Million Baht (375 million Euros) (CMnews, 2012).

In conclusion, the overall development of road infrastructure of Chiang Mai city, since the early 1900's can be divided broadly into two periods; the local roads construction period (1906-1952), and the intercity highways construction period (1952-current). During the first period, the municipality was responsible for all the road constructions that connect the municipality with its surrounding area, as well as roads within the municipality. In contrast, the central government and its agencies, such as the Department of Highways, were, and continue to be, responsible for the major road and highway constructions in the second period. The municipality's role was reduced to the maintenance and upkeep of roads within the municipality due to its limited resources.

3.4. *Development of the city's land use*

The area considered as the city of Chiang Mai remained the same for 666 years. It began to expand significantly after the end of the Second World War, when it increased 134 fold from of 3.2 km² to 430 km². Graph 3-2 shows the area of Chiang Mai city between 1296 and 2012 and Figure 3-25 depicts maps of the city at different points in time.

Graph 3-2 Area of Chiang Mai city through 1296-2012



Source: translated and modified from (Borisutthiyangkun, 2006)

The area of Chiang Mai city remained at 3.2 km² until it became part of Thailand in 1935 and received municipality status. At that point the city area expanded to 17.5 km². By the time the first city plan was created in 1965, the plan focused on an expanded 29.2 km² area around the city. The plan was revised and its name changed to the Principle city plan in 1975. In 1983, the municipality was granted a Royal Decree²⁰ to expand its boundary to 40.216 km². The expansion was to keep up with the development of the city, the increase in its density, and its expansion (Chiang Mai Municipality, 2011). In the same year, the Principle plan was revised and expanded its coverage area to 106.3 km². Seven years later in 1990, the principle city plan was extended further to 430 km².

Royal Thai Government Gazette (ราชกิจจานุเบกษา) special issue no. 100 chapter 53 dated 5 April 1983

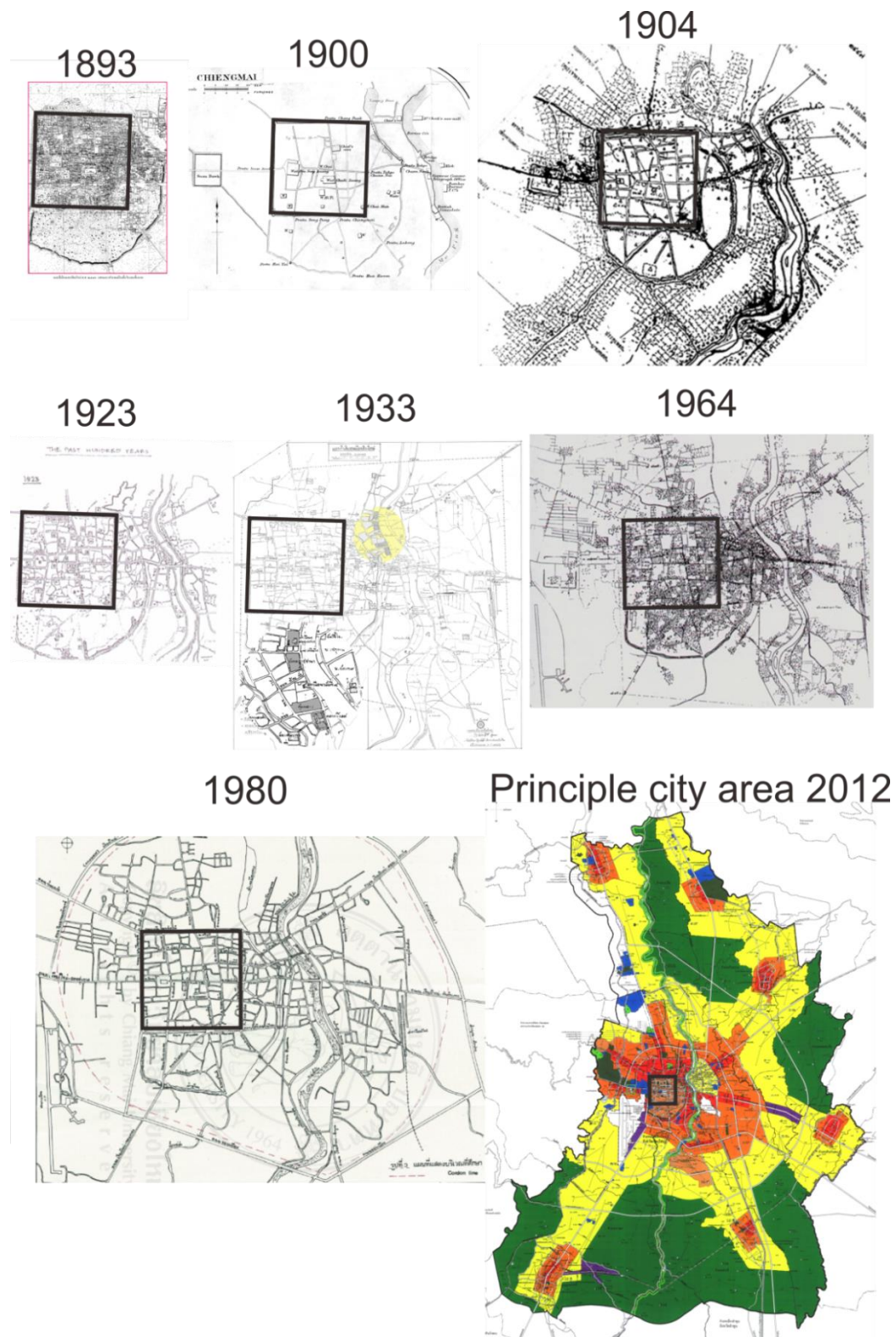


Figure 3-26 Development of Chiang Mai city through times (1893-2012)

Note: the black square borders demarcate the historical city area, Source: from various sources

In addition to this change in the city's size, there are transformations of land use within the city area. The proportions of land used for different purposes within the CMCP

area in 1989, 2000, 2006, and 2009 are shown in Table 3-3. The data was obtained by remote sensing and geographical information system (GIS).

Table 3-3 Land use change within the CMCP between 1989 and 2009

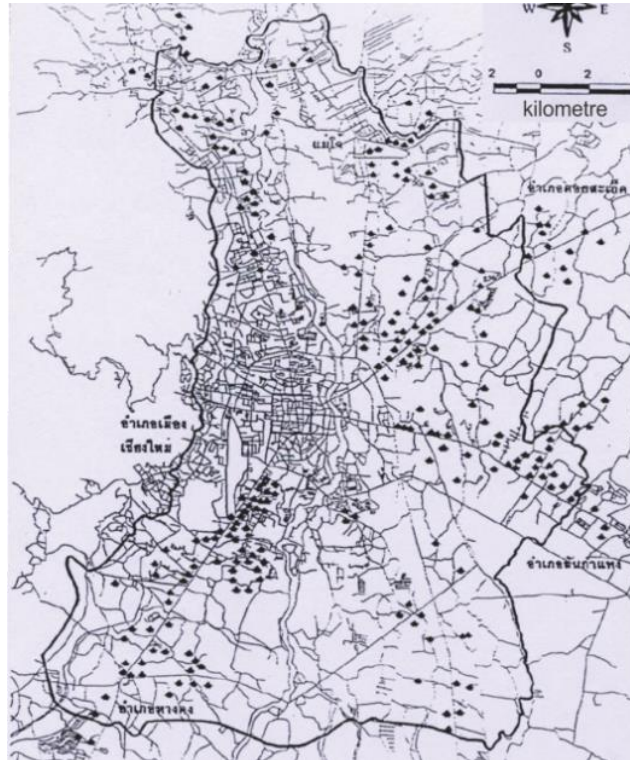
Land use	1989		2009	
	Area (km ²)	%	Area (km ²)	%
Agriculture	199.8	49%	140.3	34%
Forest	97.2	24%	95.6	23%
Urban	37.5	9%	137.4	34%
Water	6.4	2%	5.4	1%
Other	68.1	17%	30.3	7%
Total area	409.0	100%	409.0	100%

Source: modified from (Sangawongea et al., 2011)

In 1989, the outer districts area of the city was largely used for agricultural purposes but by 2009 had reduced by nearly 55 km² (-30%). In contrast, the urban area increased by 100 km² (+270%) over the same period. The construction of various roads and highways (Chapter 3.4.3) increased the accessibility by motorised vehicle into this area, making them viable locations for residential developments. This had the knock-on effect of increasing the price of the land. Wannavichit (2004) reports the asking prices of land between the middle ring road and the outer ring road were up to four times higher than the official estimated price. This high profit margin encouraged farmers to sell off their land. The land acquired by private developers was mainly used to build gated-residential areas. Thus, these residential areas are concentrated along the radial highway routes, such as Route 108, 107, 1006, and, 118 and becomes the ribbon and leap-frog developments along these routes (HSRI, 2003). Figure 3-27 shows the residential development within the city in 2003.

Moreover, the shift of the dominant mode of intercity transportation also influenced the city's land use. Figure 3-28 shows the relocation of the intercity transport hubs of the city: from water-based to rail-based transport in 1921; from rail-based to road-based after the Second World War period, and the relocation of the intercity bus terminal in 1980 and 1992.

The first shift occurred in 1921 when the train network linked Chiang Mai to Bangkok. The decline of the shipping industry on the east bank of the Ping River (Wat Ket area) and the area surrounding the port followed shortly. By contrast, settlements and businesses along Charoen Muang Road, which provided a link between the city and the railway station, prospered during the train transport 'boom'.



Key – black dot denoted new residential development

Figure 3-27 Locations of residential development within the Principle city area

Source: (HSRI, 2003)

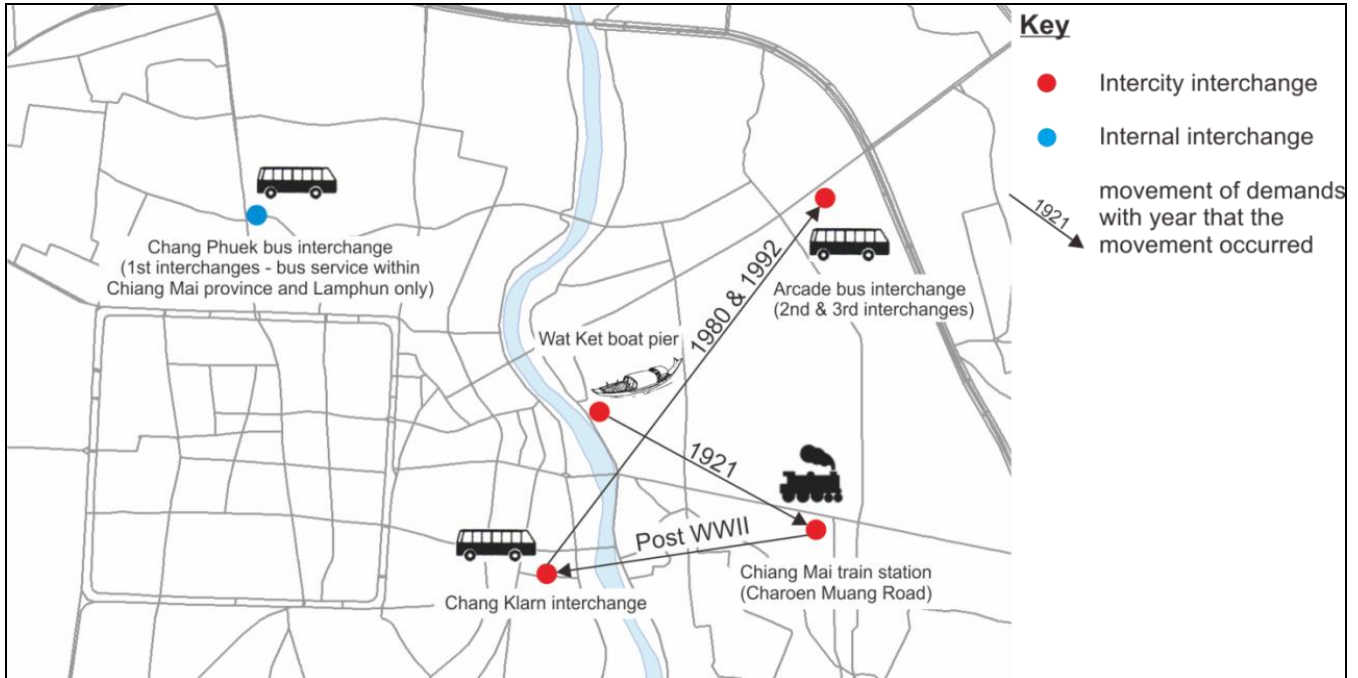


Figure 3-28 Changes in dominant mode of intercity transport of Chiang Mai city

However, after the end of the Second World War the second shift began. The decline of the train industry and the opening of the privately-owned intercity bus interchange at

Chang Klarn Road caused the settlements along Charoen Muang Road to lose their vitality. Instead, the businesses and the settlements along Chang Klarn Road began to thrive. Chiang Mai's first handicraft night market called the Night Bazaar was founded also on Chang Klan road in this period. The market became a new hub for commercial activities, which focused on tourism (Charoenmuang, 2007; Nernhard, 2010).

The third shift began in 1980; the year CM-DLT completed the second bus interchange. It is located on Kaew Naowarat Road, adjacent to the national highway route number 11. The CM-DLT transferred the intercity services from Chang Klarn Road centre to the new interchange. The CM-DLT also constructed the third interchange in 1992, adjacent to the second interchange. The two interchanges were handed over to Chiang Mai municipality in 2008 and 2011. They provide embarkation points for all the intercity coach services. Consequently, the businesses along Chang Klarn road began to decline after the transfer of the intercity services was completed. However, it is unclear whether this decline was solely because of the relocation of the interchange; the national economic crisis, in 1998, may also have contributed to the decline.

It should be noted that the Chang Phuek interchange still provides a hub for the bus services that link the city with other areas within Chiang Mai and Lamphun provinces.

These shifts, from water to rail to road transport, were initiated by the government but the effects were purely market-controlled. The government provided the infrastructures enabling the new modes of transport to thrive but the shift in the demand for the new services was driven by market forces seeking lower cost (monetary and time) transport. The shifts of demands were drastic and uncontrolled in both instances because the incoming new mode proved a direct substitution to the existing one. The shifts benefited individuals as their transport costs were lowered, but they also created negative effects.

The negative effects caused by these drastic shifts are thought to have been felt most by the people and businesses that had relied on the previous modes of transport and its related infrastructure, which had become obsolete. In addition, these replacement modes, in both cases, have proved to be more energy intensive and produced more external problems than had the previous ones (i.e. trains are more energy intensive than boats). It was unclear whether the government intended, or, indeed, understood the effects of its measures or not,

but it is apparent that it did not attempt to mitigate, prevent, or lessen, the decline of river and train transport industries.

Air transport is also an additional intercity mode that has become increasingly popular. However, its effects on city land use are less apparent than other modes. Several factors contribute toward concealing its effects, such as the restrictive land use around the terminal. Another factor is that passenger share of air transport is relatively low when compared to other modes (3,178,941 air passengers, compared with 7,605,394 intercity bus passengers in 2010) and the higher transport cost limits its suitability as an efficient method of transporting goods. However, the impact and effect on land use may become more apparent in the future, as more international carriers operate direct flights to and from Chiang Mai. It should also be noted that there has been a high increase in the number of air passengers over recent years due to the operations of several low-cost airlines.

3.5. *Factors that influence transport and land use development*

The development of transport and land use of a city is normally set by its administrative bodies. Since its founding, Chiang Mai city has had different administrative statuses²¹. This chapter focuses on the factors that influence the developments in the period after Chiang Mai became a province of Thailand in 1932.

Throughout its history, the status of Chiang Mai city changed several times, from a capital city of Lanna Kingdom, to a city within the Mangrai Dynasty, a dominion city of Burma, a dominion of Siam, and a major city within a province of Thailand. Before the city became part of Thailand, it is believed that the city was able to set the direction of its land use and transport developments locally, even though some limitations must have been in place²². Thus, the control of the city's developments remained at the local level with rulers of the city determining the shape and structure of change. However, the influence of the residents over their land use, such as household locations, was limited. They had to settle wherever the city's rulers permitted them to. Additionally, the limitation of transport mode

²¹ There are four periods, as follows: (1) Chiang Mai during Mangrai Dynasty, (2) Chiang Mai under Burmese's occupation, and (3) Chiang Mai as a dominion of Siam (which changed the name to Thailand after 1932) and (4) Chiang Mai as a province of Thailand.

²² i.e. prohibition of city war reinforcement or military related structures

was also a significant constraint on the land use. Most residents had to travel by walking. Other means of transport, such as animals, water, and motorised transport were available to the merchants and the elite class only.

After it became part of Thailand in 1932, the city began to receive financial support from the central government to develop its infrastructure, but this came at the expense of its planning autonomy. Although Chiang Mai city municipality still had responsibility²³ for its land use and transport developments, its activities were limited by the central government's budget²⁴. Clearly, in order to win funding, locally proposed infrastructure projects had to be in line with central government policy.

Furthermore, the government formed additional local administrative bodies within the province of Chiang Mai²⁵. This makes the responsibility for planning of transportation and land use within the area fragmented and difficult to co-ordinate. For example, there are 11 local administrative bodies within the Aumpor Muang district, or the central district of Chiang Mai province (152.4 km²). In other words, the power to develop the transport system and control land use was fragmented and weakened. The authority in these matters was also transferred to the central government in Bangkok and separated the control of city land use and development of transport infrastructure. The transport planning duties are assigned to the Ministry of Transport (MOT²⁶) and the land use planning duties are assigned to the Ministry of Interior (MOI²⁷). Hence, the *responsibility for land use and transport has become centralised but disconnected*.

The government has influenced the transport and land use planning of Chiang Mai city through various plans and policies. Three of them are highlighted here: the National Highway Construction Legislation (NHCL) issued in 1952; the National Economic Social Development Plans (NESDP), which began in 1961; and the Principle City Plan. Only the NESDP is covered here. See previous chapters for the NHCL and the Principle City Plan.

²³ For Municipality statutory functions and discretionary functions see Municipality Acts Rev. 2000

²⁴ Based on 2011 46% of the municipality of Chiang Mai's income are from the central government (Source: Annual report 2011 - http://www.cmcity.go.th/report/2011/AR_2011.pdf)

²⁵ under the Municipality Royal Acts Rev. 12, 2003

²⁶ through its subsidiaries, such as: the Department of Highway (DOH) and the Department of Rural Roads (DRR)

²⁷ through its subsidiary: the Department of Public Works and Town & Country Planning (DPT)

The NESDP is the blue-print of national development strategies and projects. It is renewed every five years. The construction projects of several roads around Chiang Mai city after the Second World War period were in response to the first NESDP. The plan's objectives were: 1) to enhance national living standards by improving the country's infrastructure, 2) to intensify its agriculture productivity for exporting, and 3) to induce growth in its industrial sector (Anusarnsoonton, 1902; NESDB, 2010). The road construction projects were seen as a key measure to increase accessibility to resources in the regional areas and to transport them into the capital. It was also part of the nation's political security measures; improving the wealth of Thai citizens and their quality of life were key strategies to combat the communist movement which was gaining momentum in the neighbouring counties of Thailand at that time (Nernhard, 2010; NESDB, 2010). Other NESDPs which contain policy explicitly for Chiang Mai city and their effects are summarised in Table 3-4.

Table 3-4 National Economic and Social Development Plan (NESDP) that affected the city

NESDP Plan (Year)	Effects to Chiang Mai city
1 st Plan (1961-1966)	Initiated the city's several transport infrastructure improvements
4 th Plan (1976-1981)	Designated the city as the development centre for the upper northern region
5 th Plan (1982-1986)	Designated the city as a centre for commercial and services for the upper northern region. Expands the city airport and forms the Northern Region Industrial Cluster. Improves the city's drainage and flood protection system, transport system, bridges, and slums
6 th Plan (1987-1991)	Develop satellite city around Chiang Mai and highway projects around the city
7 th Plan (1992-1996)	Designated the city as a centre for business, commercial, service, aviation hub, and tourism for the upper northern region.
9 th Plan (2002-2006)	Designated the city as part of the northern region economic cluster that would form connection with other 6 counties in the Great Mekong Sub-region economic area

In addition to the regular government policies discussed above, several special development plans, or Mega projects²⁸, have impacted the city development, especially in the period between 2001 and 2006, such as the Night Safari, the Royal Agricultural Research Centre, and affordable housing projects. These projects have affected the city's land use and transport developments both during and since this period (D. Charoenmuang, 2007).

²⁸ High value governmental projects that are put on fast-track process to shorten development time, such as the International Horticulture project, Chiang Mai or Suvarnabhumi Bangkok International Airport

The development of city land use and transport systems and their influences can be summarised by Figure 3-29.

The figure depicts the transformation of factors that have driven the city's transport and land use developments over the years. Prior to 1932, the local influences over developments strategy were higher; the developments were dictated at local level and focused on the city centre. The residents' choices on transport and land use were restricted. After the city became part of Thailand in 1933, the central government determined and controlled the direction of developments using national plans and policies. Yet while the authority to plan development at local level has become fragmented and less influential, local residents, in contrast, have increased liberty to make decisions about their land use and transport. They have more flexibility to choose their household locations and the number of available modes of transport has increased.

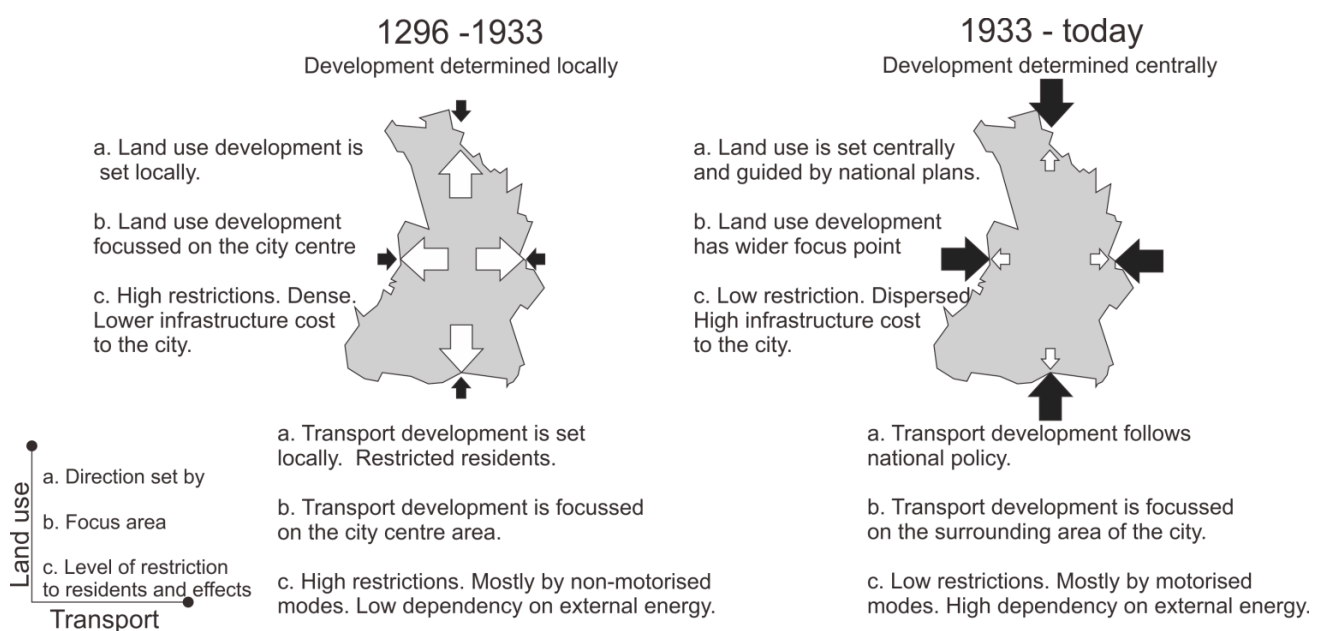


Figure 3-29 Changes of factors that influence the city's land use and transport planning

3.6. Chapter findings and discussion

The chronological development of the city's transport system shows **Chiang Mai has been a non-motorised transport city for most of its history**. As demonstrated in Chapter 3.3.1 walking was the main mode of transport of the city's residents for over 600 years. The infrastructure of the city during this period was appropriate for this mode with the size and layout of the city remaining compact. Other modes of transport, such as animal and river ship were also available but only to privileged groups, such as the merchants and the elites.

The first form of motorised transport to arrive in Chiang Mai was the private car (in 1901), whereas the first bus operation began in 1972. This is in contrast to many European cities, which had some form of public transport many years prior to the arrival of the private car. For example, the first horse tramway in Vienna began its operation in 1840, while the first car is believed to have arrived in Vienna around 1900. Thus, Chiang Mai city has had a **late exposure to public transport in comparison to the private car and can be said to have evolved directly from a non-motorised transport city to a private motorised transport city.**

In addition, Chiang Mai city has never had a consistent public transport service. The bus service operated by Chiang Mai Thai Transport Company during 1979-1995 had the longest service period of 16 years. **The shared-taxi (Song Taew) has been operated continuously in the city since 1965 until present; it is the non-private motorised mode of transport that has the longest serving period.** However, it is not a form of public transport *per se*. Its informal operation and demand-oriented nature makes its routes, fees, and service frequency, unpredictable. In comparison, a city such as Vienna has over 146 years of consistent public transport services. This illustrates that Chiang Mai city has **a relatively low public transport culture.** The low public transport culture and the evolution observed in the previous paragraph imply **a likelihood of high resistance to shift away from private vehicle.**

It is also apparent that the government has been passive in providing public transport services. This can be illustrated by the following points: Firstly, the municipality commenced its bus service only in 2004, prior to that the bus service had been entirely organised and operated by private firms. Secondly, the public sector did not provide any subsidy or any other forms of support to the public transport operators. Finally, the public sector (CM-DLT) failed to provide strong enforcement to regulate the city's public transport system. This resulted in over 80% of the shared-taxi vehicles violating routing regulations and operating their vehicles as non-fixed route shared-taxi services. Consequently, the profitability of the bus services was reduced, and eventually the bus companies went bankrupt as the shared-taxi service could be more flexible and readily respond to demands. Therefore, it can be concluded that throughout the history of Chiang Mai city there has been **a lack of active involvement in providing public transport from the government.** Moreover, it is believed that the effort needed to organise public transport system for the

city today is much greater than if the organisation was done prior to the establishment of the disorderly demand-driven shared-taxi service. This experience shows that the development of a transport system for a city has to take account of the historical nature of the collective transport experience of its citizens and their local travel traditions/expectations. As a general conclusion, therefore, **the planning and the organisation of public transport system in growing cities should be done at an early stage.**

The development path of the city transport system shows **strong, locked-in effects that promote motorised transport modes, especially the car and motorcycle.** After the Second World War, many infrastructures associated with road transport, such as concreted and paved roads, were built intensively in and around the city of Chiang Mai, linking it to the surrounding area and other regional cities. The improvements of road infrastructure in and around Chiang Mai city made motorised modes of transport more convenient to use, as muddy and uneven roads became paved and levelled. Alternative forms of motorised transport, the motorcycle, car, shared-taxi, and Tuk-Tuk became widely used. They replaced the non-motorised modes such as ox cart and tricycle. Furthermore, the National Highway Construction Legislation (1952) and the first NESDP²⁹ (1961-1966) stimulated rapid construction of, and improvements to, the national highways. International bodies such as the World Bank and the Japan International Cooperation Agency (JICA) were also influential in encouraging road construction projects through their loan and funding programmes. The improved connectivity between different cities made the car more efficient, more flexible, and more convenient for intercity transport than the train. As a consequence, the demands for train transport stagnated and declined. Additionally, there are various policies that encourage the ownership and usage of private vehicles, such as the First Car reimbursement policy (2011-2012) that subsidised car purchase, and parking policies (Jittrapirom & Emberger, 2011; Jittrapirom, 2009). In contrast, the government has either

²⁹ The formation of the first NESDP was at the request of the World Bank, whom Thailand There is something missing at the end of this sentence

been active in prohibiting non-motorised modes³⁰, or passive in promoting alternative modes³¹.

The motorisation of Chiang Mai city is also unique in that **a high percentage of registered motorised vehicles are motorcycles**. In fact 70% of the total vehicles registered in the city are motorcycles. In comparison to a typical European city, this number and proportion is hugely different. For example, it is estimated that trips made by motorcycle in Vienna are less than 1% of the total³².

Given the magnitude and importance of the motorcycle as a mode of transport in Chiang Mai, it is a surprise to see the lack of attention from the authorities regarding this mode. The motorcycle is known to have high vulnerability in mixed traffic of four-wheelers and heavy good vehicles, yet little effort has been made to improve its safety. Road infrastructure is typically designed for the car. Thus, it can be said that **the government has taken an active role in promoting private four-wheeler vehicle over the last 60 years**.

In land use development, the urbanised area of the city had remained constant for over 600 years before it began to increase in 1935. The increase intensified after the Second World War; it has expanded from the 3.2 km² to 430 km². This period of expansion coincides with the second road expansion period and the rapid motorisation of the city. The composition of land use within the Principle City Plan has also undergone a rapid change, within 20 years (1989-2009). The urbanised area increased from 9% to 34% (a net increase of 100 kilometres square) of the total principle city area. These coincidences will be explored in detail in the next chapter or in subsequent chapters. Nevertheless, the coincidences suggest that **the development of the city land use accelerated greatly after the end of the Second World War and was influenced by the city's motorisation**.

The organisations responsible for the transport and land use developments of the city have changed over time. Prior to becoming part of Thailand, the city was able to determine its own development policies. However, it eventually lost its autonomy; it is central government that determines the direction of its developments through legislations

³⁰ Such as the prohibition of cow drawn cart from the Chiang Mai municipality area to ensure high speed and therefore, high capacity on its road system

³¹ As evidenced by lack of government support in promoting a public transport system in Chiang Mai

³² <http://www.nachhaltigkeit.wienerstadtwerke.at/daseinsvorsorge/oepnv/modal-split.html>

and budget controls. In addition, responsibility for land use and transport planning became segmented and was determined by central government. Centrally focused policy tends to be more bureaucratic and inflexible in allocation of budgets and in development planning than a localised one. It is also questionable as to how far plans formed centrally in Bangkok take into account the local context³³ and public opinion. It can be concluded that the **decision making in land use and transport planning of Chiang Mai city has become centralised and disintegrated.**

The descriptions of Chiang Mai city's land use and transport system development in this chapter have provided a clear illustration of the city's past, which made the city what it is today. This information exemplifies the nature of the city and adds insights and understanding of the city's transport problems. Comprehending the nature of these problems provides a firm base to developing effective transport solutions for the city

³³ See Appendix A for the city's principle plan third revision proposed by Department of Public work and Town and country Planning (DPT) in 2008, which suggested 35 road widening projects around the city.

4. Urban socio-demographics and transport indicators

4.1. *Introduction*

This chapter presents various types of socio-demographic and transport indicators with the aim of illustrating the trends of the city and its transport system. They provide the context for the analysis in subsequent chapters and give an insight into the city's transport system behaviour.

The data is classified here by its sources: primary and secondary data. The primary data is from the Chiang Mai Mobility and Transport Survey 2012 (CM-MTS). The detail of the survey is summarised in Appendix C and in the survey report published in May 2013. The secondary data is from three sources; 1) the government registry, 2) official statistical records, and 3) past household travel surveys.

4.2. *Socio-demographic trends*

4.2.1. *Population and household*

Population data is the basic building block of any analysis related to demographic data. The data presents here is the actual registered population, which is maintained by the National Statistic Office (NSO) and the Department of Provincial Administration (DOPA).

The data is grouped according to the CM-MTS area classification: municipality, Aumpor Muang, and Outer city area. Graph 4-1 shows both sets of data between 2002 and 2011.

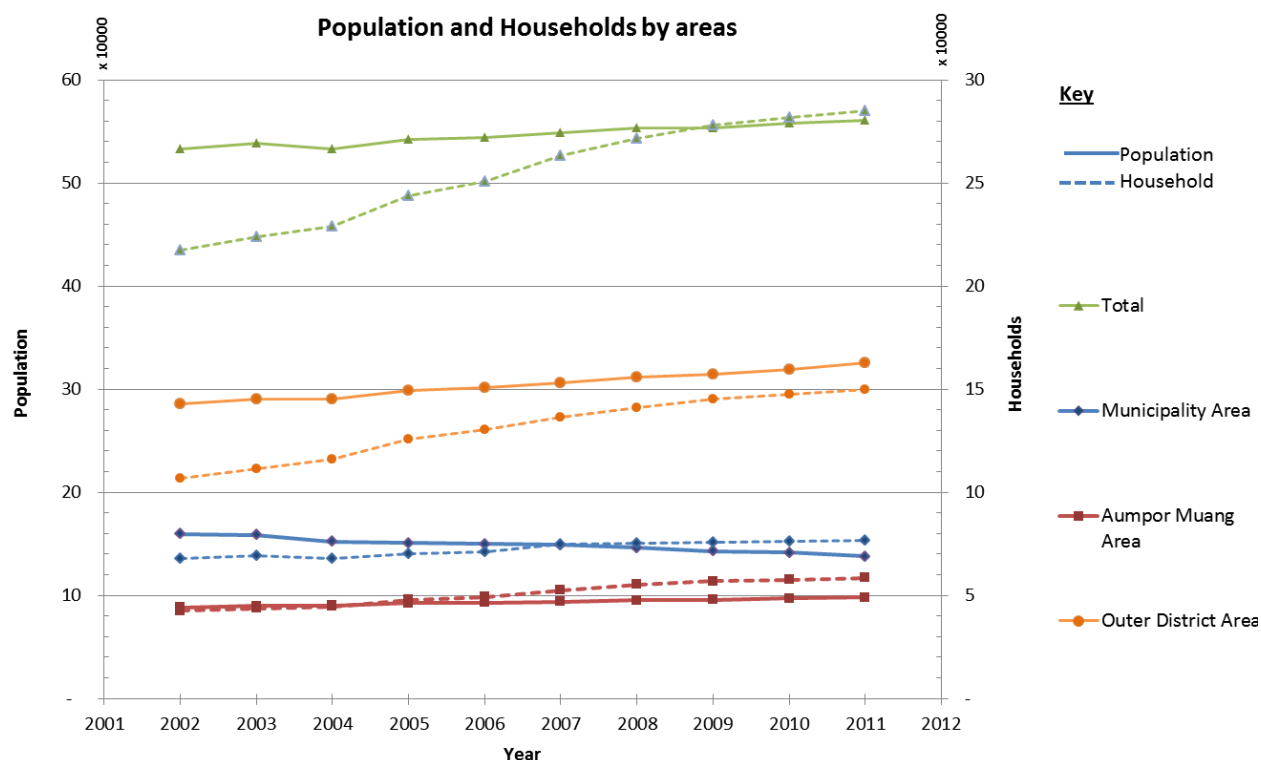
The registered population of the study area increased by 0.6% annually, which was higher than the average national rate of 0.2% during the same period. Yet the population in the municipality area decreased by 1.6%, while the outer district area increased by 1.1% and the Aumpor Muang area by 1.5%. This trend suggests a degeneration of the municipality area.

The number of households in all areas increased during the period by an average annual rate of 3% within the study area, 4% in the outer district and Aumpor Muang areas and 1%, in the municipality area.

It is apparent from the study that the rate of increase in population was much lower than the rate of increase in the number of households, which suggests a decrease in the

average household size. However, the population data considered here is registered population, thus the actual population (registered plus unregistered) maybe higher.

Graph 4-1 Registered population and households, classified by area between 2002-2011



Source: Compiles from Municipality data and DOPA records

Shadow population

All Thai citizens are required by law to register with the administrative area they reside in within 15 days after any relocation; however, a high proportion of the residents do not abide by this law (NESDB, 2009). This group of unregistered residents is called the shadow population³⁴.

It is believed that the city has a high proportion of shadow population, most of whom are students, employees, and foreign employees. Chiang Mai city is a centre of education and employment for the northern region. The province also borders with Myanmar. However, the city has no records or even an estimate of the numbers of its shadow population.

³⁴ those who come to live or work in an administrative area without updating their resident status, also extended to include illegal immigrants

An effort to estimate shadow population is made here, because analysis based only on the registered population can result in solutions that are inappropriate³⁵.

Estimate the shadow population of Chiang Mai city

The CM-MTS recorded the registration status of its respondents. The data reveals that the proportion of shadow population varied between 10-19%. The proportion is higher in the municipality area (19%) and lower in the outside district (10%), see Table 4-1.

Table 4-1 Proportion of shadow population within the CM-MTS respondents

Area/Status	Registered	Not registered
Municipality (n=1284)	81%	19%
Aumpor Muang (n=1618)	82%	18%
Outside districts (n=2086)	90%	10%
Total Average (n=4988)	85%	15%

Source: calculated from CM-MTS 2012 data

A further estimate of the city's shadow population was made by calculating the difference between the registered population and the estimated population based on electricity consumption.

Firstly, an average electricity usage per day is calculated for each district from their monthly³⁶ electricity consumption. The data was obtained from the Provincial Electricity Authority (PEA)³⁷. It is based on the supply of electricity to residential buildings only. Secondly, the estimated population for each district is calculated from the daily average values. It is assumed here that each person uses an average of 1.4 kWh per day³⁸. Finally, the calculated number of population is compared with the registered data to gain the ratio between the two values. The results are shown in Table 4-2

The calculation shows that the percentage of population not registered can be as high as 124% of the registered population. It is apparent that this calculation yields a much higher estimate than the CM-MTS survey, especially in Aumpor Muang and San Sai districts. These anomalies can result from the higher usage of electricity per person in these areas or the use of residential electricity for other purpose. Interestingly, in some areas such

³⁵ The population which, register in the city but do not live there should also be deducted to provide actual population

³⁶ the monthly values are also an average of a 3-months period

³⁷ between September and December 2011

³⁸ This value is the highest estimated personal electricity daily usage value from the NESDB (2009)

as Saraphi, the calculation shows the estimated population to be lower than the registered population.

Table 4-2 Estimation of shadow population from electricity usage Sep – Dec 2011

District	Average daily electricity usage (kWh/day)*	2011 Registered population (person)	Calculated population** (person)	% of population not registered
Aumpor Muang	712,457.31	235,600	508,898	116%
Saraphi	101,074.47	77,126	72,196	- 6%
Sankampang	131,564.81	78,061	93,975	20%
Doi Saket	106,346.69	67,249	75,962	13%
San pa tong	118,243.31	75,427	84,460	12%
Hang Dong	163,127.25	102,819	116,519	13%
San Sai	294,364.13	93,900	210,260	124%
Mae Rim	122,760.43	85,581	87,686	2%
Total	1,749,938.39	815,763	1,249,956	53%

Note: * residential purpose only –average value obtain from Sep. – Dec. 2011

**Assume average electricity usage of 1.4 kWh per person per day

Source: Electricity data from Provincial Electricity Authority (PEA) and Population data from NSO

This rough and ready calculation has several obvious weaknesses, such as its assumption of a uniform rate for daily electricity usage and that the classification of electricity use is accurate. But by combining these estimated values with the CM-MTS data an approximation of actual population can be derived. The adjusted population is shown in Table 4-3.

Table 4-3 Adjusted population for Chiang Mai city 2011

Area	Registered		Adjusted		% different between registered and adjusted
	Population	HH size	Population	HH size	
Municipality	137,812	1.8	200,637	2.6	+46%
Aumpor Muang	97,803	1.7	175,272	3	+79%
Outer districts	325,415	2.2	494,970	3.3	+52%

This empirical estimation is based on the two calculations made above. It assumes that most of the shadow population will be in the Aumpor Muang area, where rent is cheaper, yet the accessibility level is still high. The factors calculated here will be used only in the MARS model. The analysis of the data in this chapter will be based on the registered population. Additionally, the adjustment factor calculated here will not be applied to other years.

4.3. Mobility trends

4.3.1. Vehicle ownership and number of motorised vehicles

The number of vehicles obtained from official government sources and the number of vehicles owned, which were obtained from the household travel surveys are considered here, in Table 4-4.

Table 4-4 Comparison of vehicle ownership per 1000 capita

Vehicle ownership	Motorised vehicle+ /1000	All car+ / 1000	Passenger car only / 1000	Motorcycle / 1000	Bicycle / 1000
Urban values:					
1994 SAT	354	n/a	86	256	n/a
1994 OCMLT*	470	126	n/a	344	n/a
2002 OCMLT	637	254	n/a	383	n/a
2002 Punravee	806	390	n/a	416	n/a
2012 CM-MTS	857	304	160	535	270
Provincial values:					
CM-DLT 1994	347	79	n/a	254	n/a
(CM-DLT, 2012b)	619	226	121	400	n/a
CM-DLT Dec 2012*	689	246	n/a	421	n/a

Note:* calculated by this report + All car is passenger and pickup cars and motorised vehicle includes are all car plus other type of motorised vehicles.
Source: CM-MTS 2012

The vehicle ownership values of the household surveys are much higher than the CM-DLT's values for the same year. The comparison between the CM-DLT and the CM-MTS values reveals that the surveys' values are up to 25% higher than the CM-DLT's values.

There are two possible reasons for these differences. First, the surveys have different areas of interest; the household surveys focused on the urbanised area of Chiang Mai (the Principal city area), while the CM-DLT's represent the whole of Chiang Mai Province. Second, the CM-DLT's values are derived from the cumulative number of vehicles registered with the CM-DLT and the number of population in the province. In other words, the CM-DLT values do not take into account of vehicles that are registered in other provinces but brought into Chiang Mai, or vehicles that are registered with the CM-DLT and taken outside the province. In contrast, the household surveys consider the actual number of vehicle within the study area.

Next, a calculation was applied to available research data to estimate the number of vehicles in each household in comparison to the household size, as shown in Table 4-5.

Table 4-5 Vehicle/Household size ratio (in % of total sampled households)

Vehicle : Household size ratio		
	Motorised vehicles (%)	Bicycle (%)
Less than 1.00	45.4	91.8
1.00	35.3	6.9
more than 1.00	19.3	1.3

Source: CM-MTS 2012

The result shows that 54% of households have at least one motorised vehicle per each household member. In contrast, only 8% of households own one or more bicycle per each household member.

In order to understand the context of these values, vehicle ownership of other cities is compared with Chiang Mai city in Table 4-6.

Table 4-6 Comparison of vehicle ownership between Chiang Mai and other cities

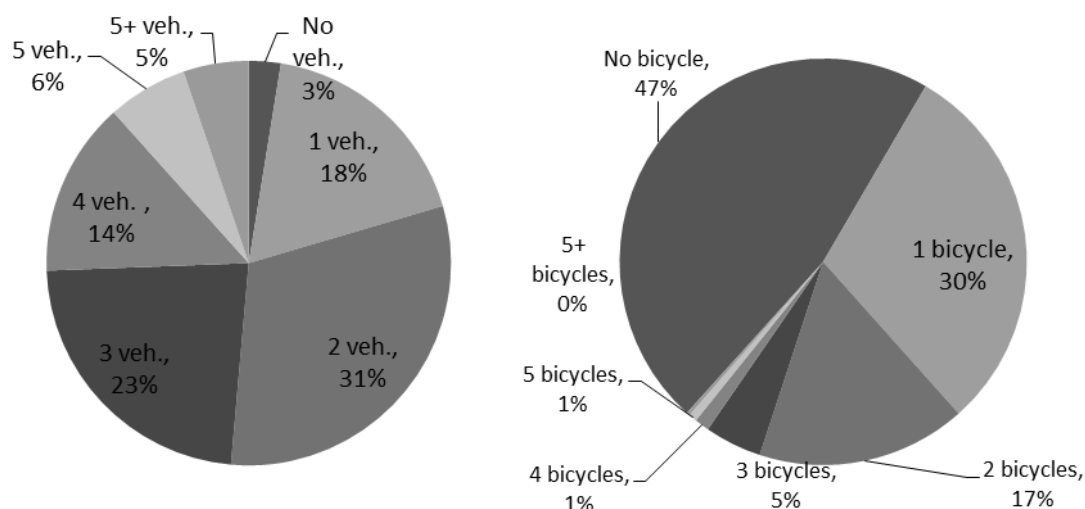
City	Population (year)	Vehicle ownership per 1000 capita		
		Car	Motorcycle	Car and motorcycle
Hanoi*	6,500,000 (2009)	12	400	412
Ho chi minh*	7,990,000 (2013)	12	371	383
Delhi*	22,000,000 (2012)	82	174	256
Jakarta*	10,200,000 (2011)	125	165	290
Bangkok*	8,300,000 (2010)	316	316	632
Taipei*	2,700,000 (2012)	257	379	636
Vienna+	1,760,000 (2013)	390	46	436
Chiang Mai city++	602,000 (2011)	304	535	839

Source:* from (Khuat, 2007), + from (City of Vienna, 2013; Stadtwerke, 2012) and ++ from CM-MTS 2012

The comparison reveals that vehicle ownership in Chiang Mai, reported by the CM-MTS, is the highest. Its car ownership is still in the same range with other cities (i.e. Vienna and Bangkok) but its motorcycle ownership rate is much higher (33% higher than Hanoi).

The results of the 2012 CM-MTS survey also show that 97% of households own at least one motorised vehicle, and 53% of households have at least one bicycle. Additionally, 55% of all households have at least one motorised vehicle for each of its members and 19% has more vehicles than its members. In contrast, only 8% of the households have at least one bicycle for each of its members. These results are presented in Graph 4-2 and Table 4-5.

Graph 4-2 Motorised vehicle and bicycle ownership (in % of total respondent households) in 2011



Source: CM-MTS 2012

These results indicate that **households within Chiang Mai city are highly motorised**. However, it shows that bicycle availability is also high.

Table 4-7 shows average vehicle ownership numbers for each type of vehicle per household.

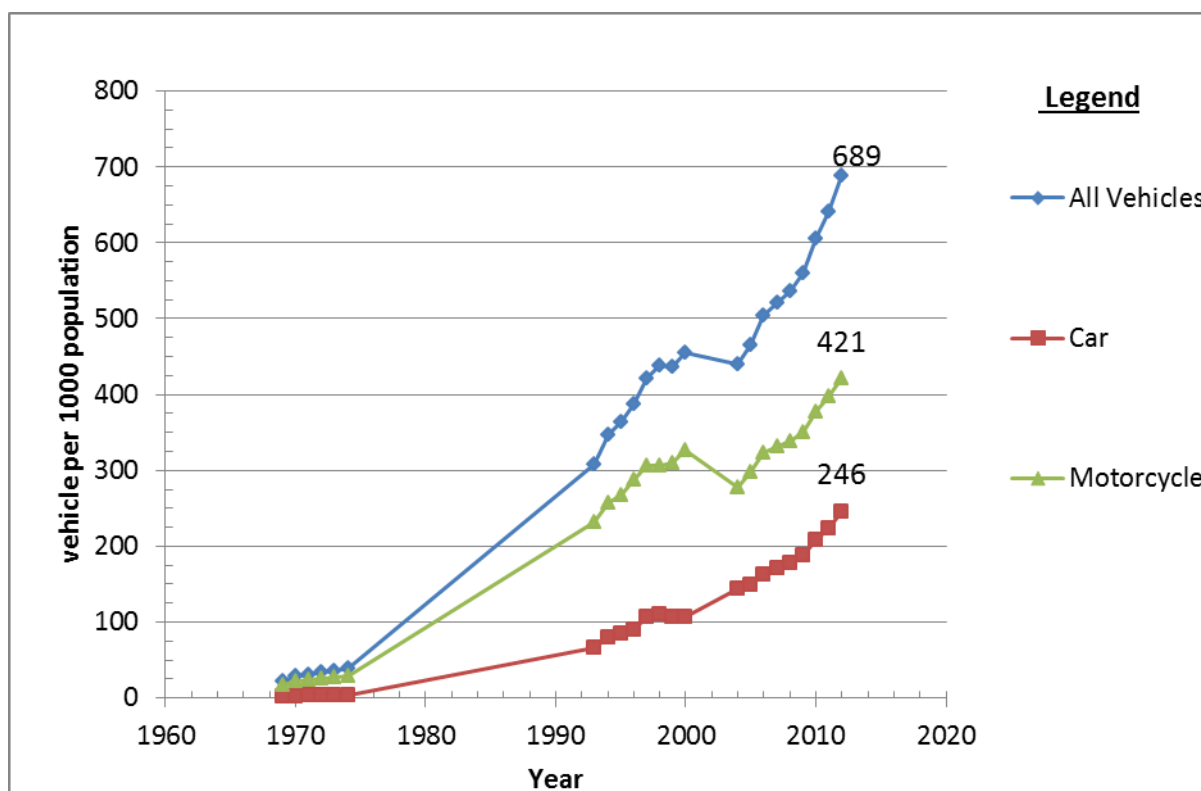
Table 4-7 Comparison of vehicle ownership per household in 2011

Vehicle per household							Motorised vehicle	Bicycle
	Saloon	Pickup car	Van/SUV	4-wheeler	Motorcycle	others		
2002 Punravee	0.65	0.34	0.03	1.02	1.09	0.01	2.12	0.24
2006 OTP	n/a	n/a	n/a	n/a	n/a	n/a	2.75	n/a
2012 CM-MTS	0.51	0.46	n/a	0.97	1.72	0.06	2.8	0.87

Source: CM-MTS 2012

It is apparent that the motorcycle had the highest level of ownership per household in 2002 and 2012. The ownership rate of four-wheeler vehicles has reduced by 0.5% annually (between 2002 and 2012), while motorcycle ownership has increased by 4.7% annually.

The number of register vehicles in Chiang Mai Province per 1000 population 1969-2012 is illustrated in Graph 4-3.

Graph 4-3 Number of vehicles registered in Chiang Mai province per 1000 capita

Note: In 2004, the DLT introduced a regulation to deregister vehicles that fail to pay tax for three years or more. In addition the DLT records between 2001 and 2003 are not included here. These records are unreliable due to changes in the administration system.

Source: data from CM-DLT

The starting point for the graph above is the year 1969. The graph shows a relatively low level of vehicle ownership; 20 vehicles (3 cars and 17 motorcycles) per 1000 capita in year 1969. The value reaches 689 vehicles (246 cars and 421 motorcycles) in the year 2012. From this data, the growth rate of vehicle ownership of the city can be classified into four periods

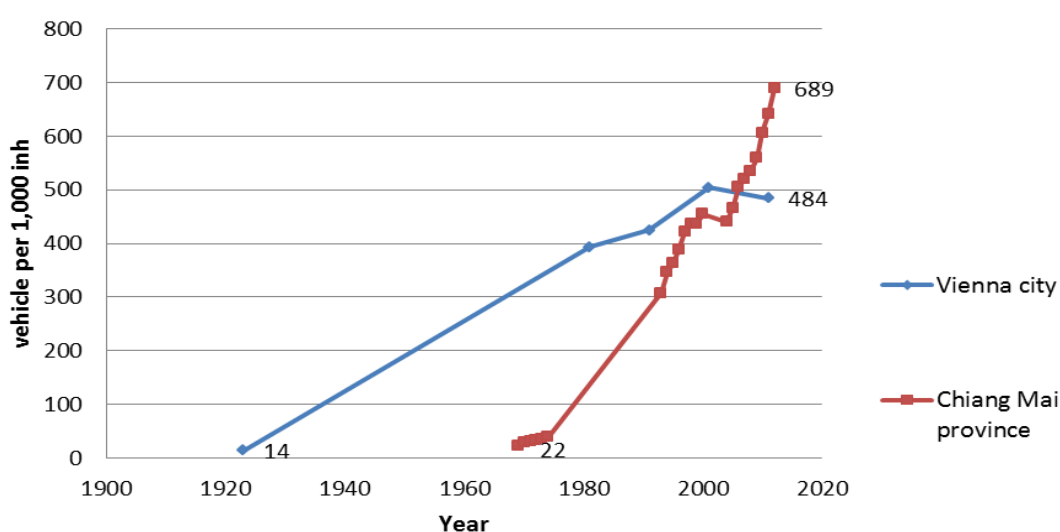
- First period (1969-1974): average 12% annually (9% car and 11% motorcycle)³⁹
- Second period (1975-1994): average 12% annually (16% car, 12% motorcycle).
- Third period (1995-2009): average 3% annually (5% car, 2% motorcycle)
- Fourth period (2010-2012): average 7% annually (9% car, 6% motorcycle)

³⁹ The average % increase is the rate of increase for total vehicle, whereas the car and motorcycle percentages relate to their respective growth rate

It is apparent Chiang Mai is experiencing a transition away from the dominance of the motorcycle and moving more towards the car as the preferred means of personal transport.

Data from Vienna city is included here to demonstrate the unique features of Chiang Mai city's motorisation. The two cities are similar in size (Chiang Mai city, 430 km², Vienna city 415 km²) and in population (Chiang Mai city⁴⁰ 1.5 million, Vienna city 1.7 million). The comparison is made in Graph 4-4.

Graph 4-4 Number of vehicles registered in Chiang Mai province and Vienna city per 1000 capita



Note: the comparison uses Chiang Mai province data because there is a lack of such data at the city level
Source: data from CM-DLT and Statistik Austria – Kfz-Bestand.

The comparison reveals several differences. Firstly, motorisation began earlier in Vienna (1920s in Vienna and 1960s in Chiang Mai), perhaps due to the delay in technology distribution. It is widely acknowledged that the car was invented by Karl Benz in Germany.

Secondly, Vienna has a slower rate of motorisation (average annual increase of 4.1% over the whole period) than Chiang Mai province (8.3%). The faster rate of motorisation for Chiang Mai is perhaps due to the lack of alternative modes (i.e. public transport); whereas, the tram was available in Vienna as early as 1865 and the underground rail network was built from 1976 onwards. Finally, the motorisation rate of Vienna appears to have levelled off over recent years to a much lower value (484 vehicles per 1000 inhabitants), whereas

⁴⁰ estimated value, which includes the city's shadow population

Chiang Mai province seems to continue increasing to a much higher value (689 vehicle per 1000 inhabitants). Factors such as availability of public transport modes, promotion of other modes, and limited parking spaces are believed to contribute toward the lower motorisation value of Vienna city. In contrast, **the lack of quality public transport, urban sprawling, abundance of parking space, and affordability of private vehicles are factors that continue to drive Chiang Mai city's motorisation.**

Kakizaki (2013) also purports that the country's rapid rise in motorisation can be ascribed to the development of high standard roads, the growth of its motorised transport industry, and the rise in disposable income. Thailand's paved roads increased from 200 km in 1935 to 40,000 km by 1990. A high proportion of these roads were built in the 1960s with loans from the World Bank and other foreign aids. Indeed, successive Thai governments have actively supported growth of the automobile industry since 1960. They have passed various bills and measures to encourage continued growth of Thailand's lucrative automobile industry, such as exempting import tax on vehicle parts when the industry needed a boost. The successful growth of the automobile industry has led to a dramatic drop in the price of motorised vehicles, relative to average earnings. The annual GDP growth of the country between 1952 and 2000 ranges from 4.4% to 9.1%, which indicate the rise of individual purchasing power (Kakizaki, 2013).

4.3.2. Ratio between Car and The motorcycle ownership

The analysis above also reveals that the city's rate of car growth exceeded motorcycle growth at some point between 1975 and 1995. This finding is explored in detail in this section. Table 4-8 illustrates the annual vehicle growth rates for all motorised vehicles, including the car and the motorcycle within the province.

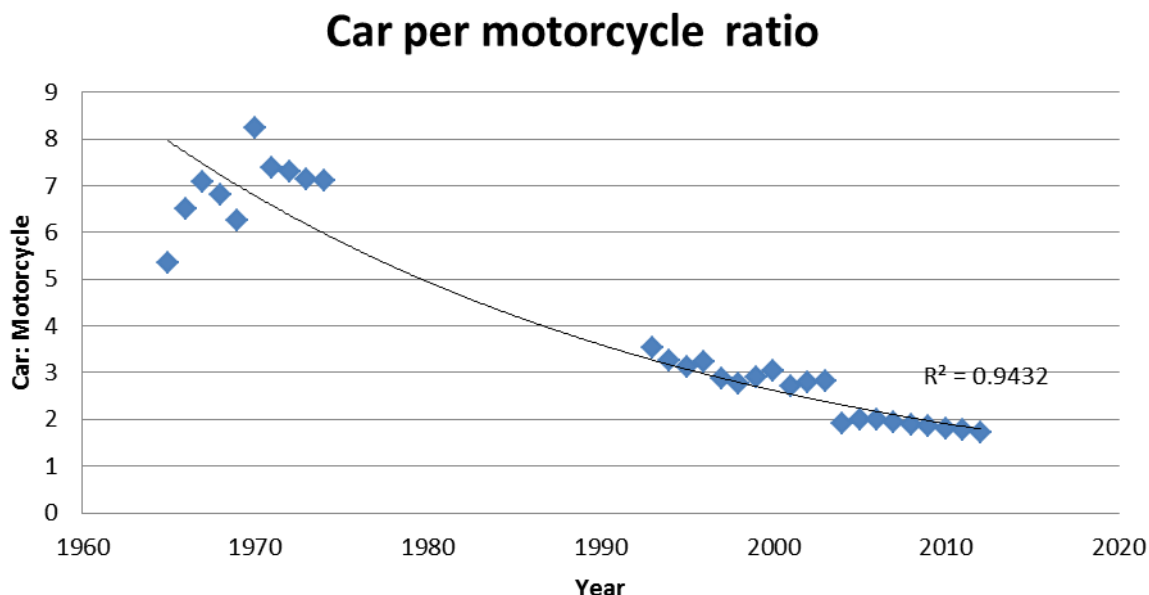
Table 4-8 Annual growth rate for different vehicle types in Chiang Mai province

Year	All vehicle		Motorcycle		Car	
	Total	Annual growth	Total	Annual growth	Total	Annual growth
1965	8,740	n/a	5,547	n/a	1,035	n/a
1970	27,851	26.1%	21,859	31.6%	2,651	20.7%
1995	563,858	12.8%	414,376	12.5%	132,178	16.9%
2000	713,314	4.8%	510,974	4.3%	168,677	5.0%
2005	759,295	1.3%	485,562	-1.0%	242,412	7.5%
2010	989,665	5.4%	614,739	4.8%	340,210	7.0%

Note: data for 1975, 1980, 1985, and 1990 were not available
Source: (Nimnual et al., 1980) and Department of land transport

The annual growth rate of cars surpasses motorcycles in 1995. Graph 4-5 depicts the car per motorcycle ratio of the province.

Graph 4-5 Chiang Mai Province's car per motorcycle ratio



Source: Department of land transport and (Nimnual et al., 1980)

The negative trend shown on the graph indicates that the number of motorcycles registered per each car reduced significantly; from between 5 to 7 motorcycles per one car in 1960s to 1.7 per one car in 2012. There are several factors that may contribute to the acceleration in car growth, such as the rise in wealth. National GDP increased by more than 100% between 1991 and 2011; national GDP in 1991 was 3,646.3 thousand millions Baht and in 2011 it was 8,208.7 thousand millions Baht (Bank of Thailand, 2013). This increase is also reflected at the local level; average income per Chiang Mai resident rose from 39,588 Baht to 55,846 Baht between 1993 and 2000 (Bank of Thailand, 2013). The rise in wealth provides the population with increased purchasing power to acquire cars, which are also seen as a status symbol (Intapun, 1994).

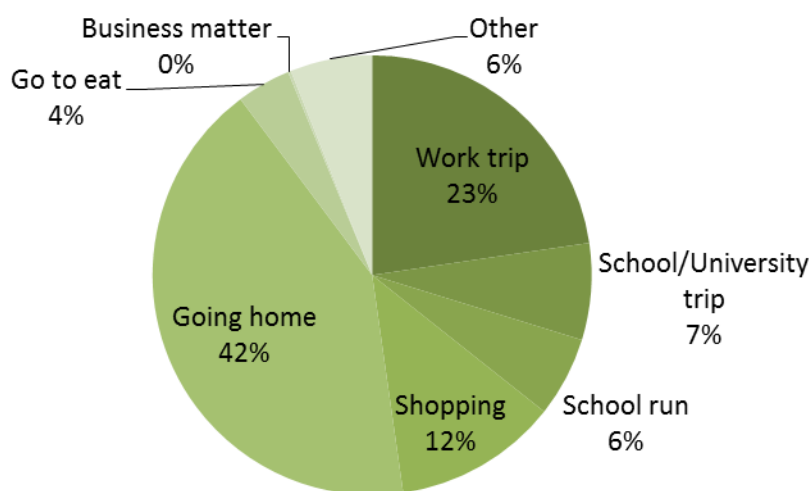
Additionally, the government's First Car policy, aimed at the first time car buyers, has contributed to an increase in the number of cars over recent years. This was an election pledge ostensibly aimed at boosting Thailand's car industry. In 2011, the government

offered a tax rebate up to 100,000 Baht (2,500 Euros) or up to 16%⁴¹ of a car's price, to car owners who purchased their first cars between 16 September 2011 and March 2013. On 31st December 2012, the Excise Department Office reported that 1.25 million cars had registered for the reimbursements. Although the final figure has not yet been reported, it is expected that this number increased to 1.3 million cars by the end of the program and will have cost the taxpayer a total of 9.05 Billion Baht (2,262 Million Euro).

4.3.3. Trip purpose

The CM-MTS classifies trip purpose into 14 categories. For simplicity, they are further aggregated here into 8 categories as shown in Graph 4-6.

Graph 4-6 Trip purpose (in % based on total daily trip)



Note: School run refers to trips to drop off children at school and School/university trips are trips to academic institutions

Source: CM-MTS 2012

Not unsurprisingly, given that work, school, college trips measure number of outbound trips, nearly half of all trips are the Going home trip. Working trip is the second highest trip (23% of the total trips). The shopping trip takes up 12% of the total trips

4.3.4. Mode share

The mode share values from six surveys on Chiang Mai city are compared here. The comparison includes the mode share for short and long distance trips from the 2001 JICA. Only two out of six surveys consider walking trips (the 2002 OCMLT, and the 2012 CM-

⁴¹ Calculated data from <http://www.thairath.co.th/page/firstCar>

MTS) and only one (the CM-MTS) considers bicycle trips. This comparison is shown in Table 4-9.

The values in parentheses are adjusted mode share values. The adjustment is based on an assumption that walking and cycling mode-shares of all the surveys should be at least equal to the CM-MTS's values. This adjustment enables a like-for-like comparison.

The 2012 CM-MTS data shows that a major proportion of trips (75%) are made by private motorised transport vehicles; 27% are car trips and 48% are motorcycle trips. Surprisingly, the non-motorised modes are combined to 21% of total trips, which is much higher than any previous report. No trips were made by public bus and only 1% by mini bus.

This comparison shows three apparent trends. First, private vehicle modes dominate the mode share, and the motorcycle has the highest share in most surveys (four out of seven). Second, the mode share of trips made by car and motorcycle is increasing. Lastly, the proportion of public transport trips is decreasing.

Table 4-9 Comparison of mode share with adjusted values (in % of surveyed trips)

Year - Survey	Walking	Bicycle	Public transport	Personal car	Motorcycle	Other
1994 SAT	n/a (15)	n/a (6)	12 (10)	34 (27)	51 (40)	3 (2)
2001 JICA - Short distance trips	n/a (15)	n/a (6)	7 (6)	43 (34)	46 (36)	4 (3)
2001 JICA - Long distance trips	n/a (15)	n/a (6)	4 (3)	53 (42)	40 (32)	3 (2)
2002 OCMLT	8 (15)	n/a (6)	10 (9)	31 (27)	45 (38)	6 (5)
2002 Punravee	n/a (15)	n/a (6)	6 (5)	46 (36)	43 (34)	5 (4)
2006 OTP	n/a (15)	n/a (6)	9 (7)	48 (38)	43 (34)	0 (0)
2012 CM-MTS	15	6	1*	27	48	3*

Note: Numbers in parentheses are adjusted mode share values using NMT trips from 2012 CM-MTS

*For CM-MTS public transport constitutes of shared-taxi (1.3%) as no trip by public bus was recorded. Other mode included school/work private van⁴² (1.9%) and other mode (1%)

The 2002 OCML values for private modes are incorrect in the report (Page 3-15), and so are adjusted accordingly, and the values quoted in (HSRI, 2003) that included calculated bicycle mode of 3.9%.

Source: CM-MTS 2012

It was not possible to draw any conclusion on the non-motorised mode shares, because only two out of six surveys consider them.

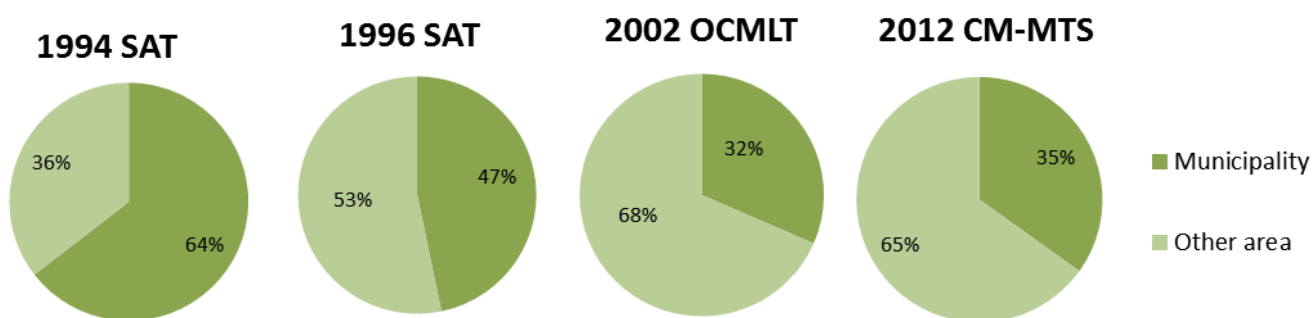
⁴² School/work private van is operated by a private individual or a company which provides commuting service for students and workers living in a certain area who travel to destinations within close proximity. The fare is paid monthly. It is a mode of collective transport for covering regular long distances

4.3.1. Trip origin

Trip origin indicates the location of the trip starting point at aggregate level. In this report, the analysis separates the city into two zones: the municipality area and the other areas. Data from four different surveys are compared in Graph 4-7.

The comparison shows a gradual shift in the trip origin proportion - from a high percentage of trips originating within the Chiang Mai municipality area (1994 and 1996) to a higher percentage of trips originating outside the municipality area (2002 and 2012). This shift indicates **the decentralisation of the city centre and significant changes in land use within the city between 1994 and 2002 and a lesser change between 2002 and 2012.**

Graph 4-7 Comparison of daily trip origin (in % of surveyed trips)

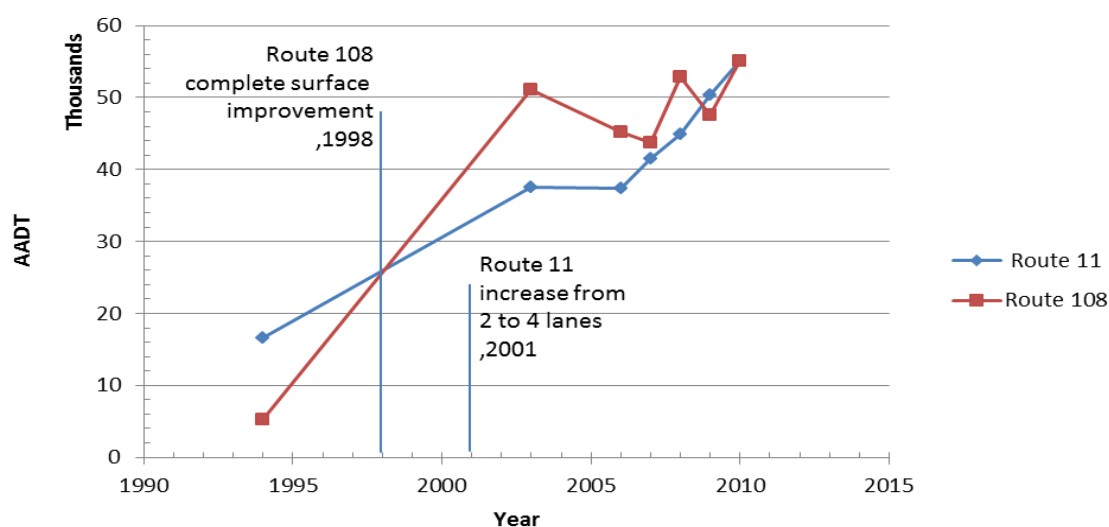


Source: 1994 SAT (Page 3-6), 1996 SAT (Page 3-11) 2002 OCMLT quoted from (HSRI, 2003, 2nd Phase p. 20) and CM-MTS 2012

4.3.2. Annual Average Daily Traffic (AADT)

Annual Average Daily Traffic (AADT) is a traffic count at a given point within a section of road or highway. AADT is a calculated value to represent the section's annual average 24-hour volume of vehicles. Graph 4-8 illustrates the AADT of two selected highways within Chiang Mai city between 1994 and 2010.

Graph 4-8 AADT of selected highways within Chiang Mai city 1994-2010



Source: Department of land transport and (Wannavichit, 2004)

The AADT values of the two highways increase significantly during the considered period; Route 11 by 3.3 fold and Route 108 by 10.5 fold. However, it appears that the values of the two highways have different growth patterns. Route 108's AADT value increases the most between 1994 and 2003 and levels off thereafter. In contrast, Route 11's AADT value levels off between 2003 and 2006, but then has continued to increase during recent years.

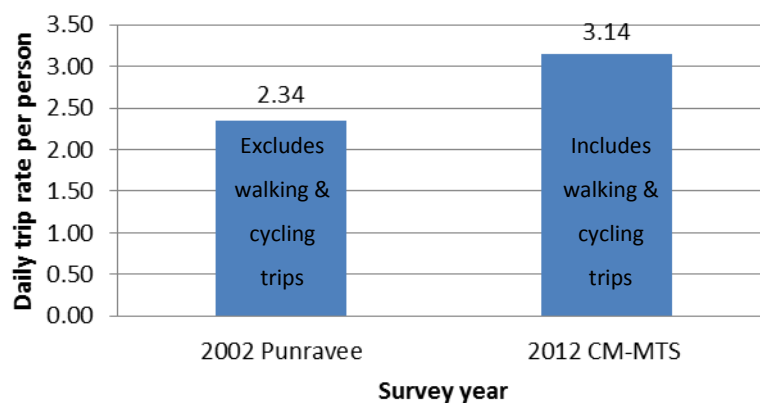
The different patterns of growth maybe because of their different natures; Route 108 is a radial road of the city but Route 11 is a ring road and part of the national highway network that connects a number of cities in the northern region with Bangkok. In addition, their physical capacities are different; Route 108 was upgraded to highway standard in 1998 but its physical capacity is still limited to two lanes in each direction. By contrast, Route 11 was upgraded from two to four lanes per direction in 2001. This increase in capacity may contribute toward the increase in AADT after 2006. It is apparent from the AADT data presented here that **the volume of city traffic is growing, especially where capacity is available.**

4.3.3. Daily trip rate

The daily trip rate is an average number of trips made by the population per day. Two sets of data are compared here; the 2002 Punravee and the 2012 CM-MTS. The 2002 OCMLT's data (1.61 trips per day) is not included in this comparison because its daily trip

rate value is derived only from trips occurring between 0600-1800hr. In other words, the 2002 OCMLT only includes trips that occurred during a 12-hour period while the other surveys include trips that occurred within a 24-hour period. Graph 4-9 provides a comparison between the two daily trip rates.

Graph 4-9 Comparison of daily trip rate (trips per person per day)



Source: CM-MTS 2012

Schafer (2000) indicates regularity in daily trip rate at aggregate level; however, Graph 2-11 shows that the 2012 daily trip rate increases by 34% from the 2002 value. This increase is thought to be attributable to the exclusion of non-motorised trips in 2002 Punravee.

4.3.4. Average travel time and distance

There are two separate sets of data available for travel time and distance comparison. Firstly, 2002 Punravee and the 2012 CM-MTS, which provide average daily travel time and distance on all modes (Table 4-10). Secondly, the 2002-OCMLT and 2012 CM-MTS, which provide walking trip time (Table 4-11).

Table 4-10 Comparison of average daily travel time and distance (minutes and kilometre)

Average daily		
	Travel time (min)	Travel distance (km)
2002 Punravee	44.9	17.9
2012 CM-MTS	49.3	17.8

Source: CM-MTS 2012

Comparison of the average daily travel times reveals that the travel time increases by 10% over the ten year period, while the average daily travel distance decreases only slightly.

The calculated travel speed shows a decrease from 23.9 kilometres per hour to 21.7 kilometres per hour over the period. In other words, the data suggests **an increase in congestion**. It also suggests that **there is not significant change in the patterns of land use and trip origin-destination during the period**, which is a similar finding to that shown in Graph 4-7.

Table 4-11 Walking trip time proportion in 2002 and 2012

Average walking trip time (min)	% of all walking trips				
	less than 5	5 to 10	10 to 15	15 to 20	30+
2002 OCMLT	57.6%	28.0%	6.6%	6.6%	1.3%
2012 CM-MTS	76.9%	10.8%	4.0%	2.8%	5.6%

Source: CM-MTS 2012

The comparison above reveals that the CM-MTS respondents made more short walking trips than the OCMLT; the proportion of short walking trips (less than 5 minutes) increases by 19%. However, the CM-MTS respondents also make slightly more long walking trips, the proportion of the longer walking trips (30 minutes +) increased by 4%. It can be deduced that there is an increase in short walking trips (less than 5 minutes) and longer walking trips (30+ min.), but further demographic information and mode choice would enable more elaborate conclusions to be drawn from these trends.

4.3.5. Transport infrastructure in the municipality

It was reported that the total length of the municipality's road network was 274 kilometres in 1994, which was equivalent to 4% of its total area (40.2 km²) (HSRI, 2003). The HSRI considered this to be relatively low in comparison with other cities. The detail on the road infrastructure within the municipality and the central district (Aumpor Muang) as of 2009, is summarised in Table 4-12

Table 4-12 Road infrastructure within municipality and Aumpor Muang in 2009

Item	Quantity
Road within the central district (Aumpor Muang)	119 Roads
Road within the municipality area	74 Roads
No. of Soi (Alley or narrow street) in the municipality area	680 Soi
Length of Alley or narrow street in the municipality area	177,504 kilometres (D. Charoenmuang, 2009a, p. 48)
No. of main junction in central district (of which a number are junctions controlled by traffic lights)	120 junctions (of which 53 junctions are controlled by traffic lights)

Source: Chiang Mai traffic police leaflet 2009

Similar data for other period was not available, thus a comparative study was not possible.

4.4. Household expenditure

Household expenditure levels presented here are from the CM-MTS survey. The respondents were asked to estimate their household monthly accommodation and transport related expenses. The average values for each category are presented in Table 4-13.

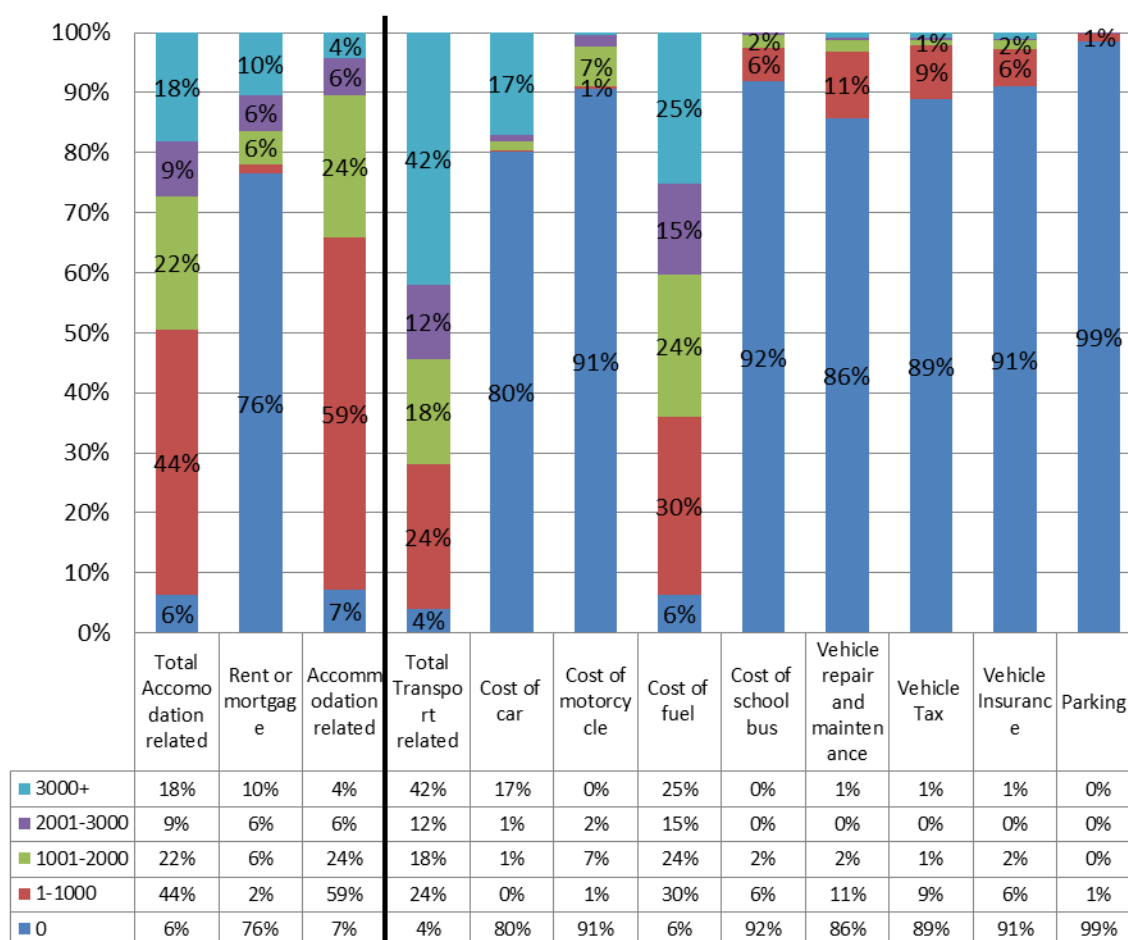
Table 4-13 Average household monthly expenditure (in Baht)

Average household income per month 19,334 Baht*	
Monthly expense	Baht
Rent or mortgage	4,770
Accommodation related expense	1,240
Average of the total Accommodation	2,272 (12% of average hh income)
Standard deviation of the total Accommodation	3,721
Cost of car	7,588
Cost of motorcycle	1,906
Cost of fuel	2,804
Cost of school bus	923
Vehicle repair and maintenance	1,352
Parking	797
Vehicle tax	996
Vehicle insurance	2,631
Average total Transport costs	4,905 (25% of average hh income)
Standard deviation of the total Transport costs	8,069
*Note: average value excludes “no response” and “zero value”	
Average monthly income per household is a mean of 18,323 (official 2011) 20,345 (CM-MTS, 2012) Average income per household per month is an average of two values 18,323 (official 2011) 20,345 (CM-MTS, 2012)	
Exchange rate: 1 baht = 0.025 Euro	
Source: © CM-MTS 2012	

The results indicate that each household spent 25% of their monthly income on transportation. However, the calculations also show a high level of standard deviations, which imply high variation from the average values. Thus, these average values should be read with caution.

Graph 4-10 shows the respondents' estimate of the percentage household income spent on fixed and variable transport and housing costs.

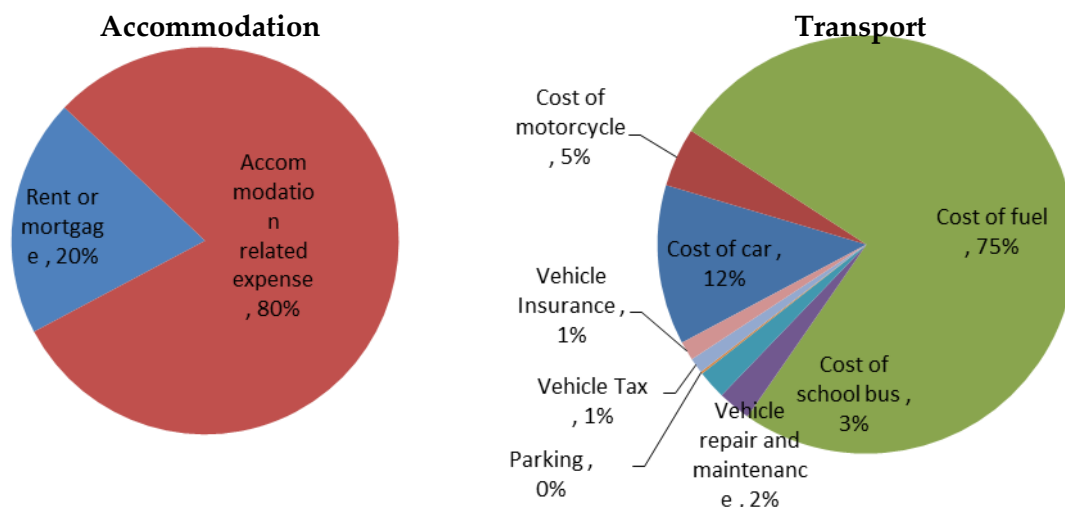
Graph 4-10 Household monthly expenditures in different categories (in % of total sampled households)



© CM-MTS 2012

These results show the respondents' estimation/perception of how much of their household income was spent on accommodation and transport. It also shows that most of the respondent households owned their accommodation, with only 24% of them paying monthly rents.

Most of the respondents indicated that the capital cost of cars and motorcycles was zero (80% and 91% respectively). It is understood that the remaining 20% (cars) and 19% (motorcycles) were paying for their vehicle by monthly instalments at the time of the survey. Another striking fact is that 86-99% of the households estimated costs relating to vehicle use (repair, tax, insurance, and parking) as 0%. In other words, **they perceive fuel cost to be the only cost for transport**. Further analysis is made on the average proportion of monthly spending for the households and the results are shown in Graph 4-11.

Graph 4-11 Percentage of household monthly spending in accommodation and transport

Source: data from CM-MTS 2012

The results show that only a small part of the expense of accommodation is rent or mortgage (20%); it appears that most of the respondents fully own their homes (CM-MTS shows 80% live in own-accommodation). In relation to transport, an average respondent estimates that 75% of their monthly transport cost is fuel cost, 17% is vehicle cost (12% for car and 5% for motorcycle), 3% is monthly school bus, and 4% are other costs related to vehicle use.

It is clear that high proportions of both costs are 'running costs'; 80% in accommodation and 79%⁴³ in transport. The respondents seem to treat purchasing costs (i.e. cost to buy house or car) as sunk costs once the costs are paid. In other words, **respondents who paid for their accommodation/vehicle costs in full no longer take these costs into account; they only perceive the running costs as the sole cost to use these facilities.**

4.5. Informal observations made during the CM-MTS

The household surveys provided opportunities to visit many areas of the city and to make observations on the residents' mobility behaviour. Although born in this city, a large part of my life has been spent away from it. These trips reintroduced the city to me. Many areas visited were unknown to me. Local leaders shared their challenges in supporting their

⁴³ Cost of fuel plus tax, parking and repair and maintenance costs

communities and gave vent to their concerns on the degradation they perceived in their quality of life. The struggles of people living in slums and the challenges faced by migrants from countries, and other cities within Thailand, were very apparent. Views were exchanged with a cross section of people of all ages and from all walks of life: high school students, seniors, housewives, high powered businessmen and humble street vendors. These visits were an invaluable experience in helping to gain first hand witness accounts of present day life in Chiang Mai. This sub-chapter contains a concise account of this experience and the observations made.

a) Variation of density within the urbanised area

Apart from the area within the ancient city, the density of Chiang Mai city's principal area varies greatly. The density of the municipality area is uniformly high in the central area but becomes highly fragmented away from the city centre. **Pockets of undeveloped land can be found in places** even within the municipality area; for example, the area to the east of the railway station. These areas could be used for residential development to densify the area or for the provision of local amenities such as public parks and fitness trails. However, who owns these spaces was not known by local people living in the vicinity.



Figure 4-1 A pocket of undeveloped land within the municipality area

b) Type of accommodation and parking space

The city in general is thought to have low density. Most accommodations are 2-3 storeys, although some high rise buildings can be found in areas close to universities, higher education institutions, and large employment centres such as Chiang Mai University,

Chiang Mai Rajabhat University, and Central Plaza Chiang Mai Airport⁴⁴. In general, housing within the municipality area mainly consists of:

- a) Single houses - standalone housing units with either one or two storeys
- b) Shop-houses and town houses - a row of housing units normally with two or three storeys, where the ground floor is often used for economic activities or parking space
- c) Apartments or flat units, in condominium blocks of between eight and ten storeys.



Figure 4-2 Single house



Figure 4-3 Shop house and townhouse

⁴⁴ A shopping centre situated close to Chiang Mai International airport, has over 500 retailers with a total retail area of 75,918 square metres



Figure 4-4 Apartments and flats

All of these different types of housing have one thing in common: **allocated parking spaces within close vicinity**. Although, roadside parking spaces within the city are mostly free of charge, it is apparent that the residents preferred to park their vehicles within the proximity of their house, perhaps for ease of accessibility and for security reasons.

There are also several slums scattered around the municipality area. Housing in these slums is of poor quality in general; units are built closely to each other and often accommodate large families. Visiting a household with two bed rooms and discovering this accommodated twelve family members was a grim reminder of the inequality of the relatively affluent middle class and their poor cousins. Most of these slums are situated on public land.

c) Variation in types of road

From personal observation, roads within the city can be classified into 3 general types:

1. Ancient roads, which may or may not have been paved. This type of road can be found mostly within the ancient city area, parts of the municipality area, and within the rural regions of the city. They are generally narrower and more winding. Most of these roads were originally ancient footpaths or cart tracks that may have been upgraded to concrete roads, yet their narrowness made them unsuitable for fast motorised vehicle. These roads provide feeder access into communities.



Figure 4-5 Narrow and winding roads within the municipality area

2. New local roads - this type of road is straighter and wider. I believe that they were built specifically for motorised vehicles; they generally have straighter alignment. These roads provide feeder access within communities and in some cases, between communities of the city. It was observed that the speed on these roads is generally low
3. Main roads and highways - this third type of road is often built to a much higher standard. They usually have road markings, lighting, and other facilities that allow vehicles to travel at high speed during both day and night. They provide regional and national connections.

During the survey period, several 'near-miss' accident cases were observed, most of which were at the points where these different types of roads cross. It is suspected that the differences in speeds and the frame of mind of drivers on these roads may be the cause of a high rate of traffic accidents at these intersections.

d) Use of the motorcycle and non-motorised modes in low income group

Motorcycles were found to be the most popular mode of transport within the municipality area, perhaps due to their manoeuvrability, compactness, affordability, and flexible range. Packs of motorcycles are to be found parked under dormitories and apartments, which confirms it is the primary mode of transport for students and lower-wage workers who live in this type of rented accommodation. This observation is in accord with the CM-MTS survey, which shows a higher amount of motorcycle trips in the municipality area, even though its density is higher.

A high proportion of walking and bicycle trips were observed in small communities within the municipality, but particularly more in the Aumpor Muang and the outer districts

areas. It was mostly children and seniors who were seen making trips with bicycles in these areas.

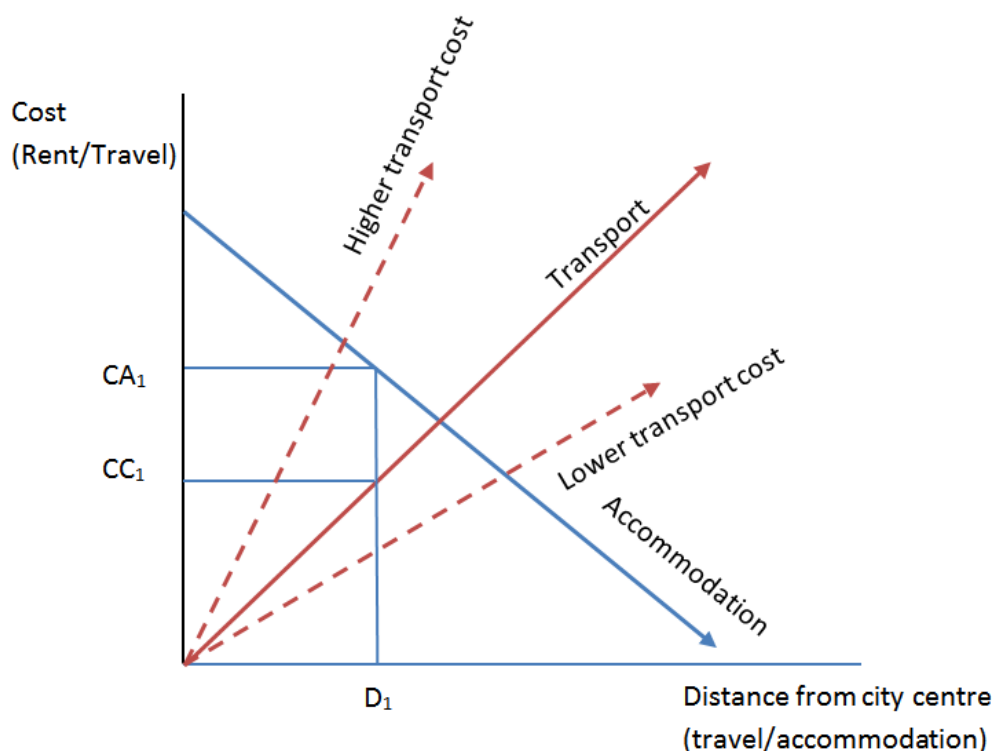


**Figure 4-6 Use of non-motorised transport modes
in Aumpor Muang and outer districts areas**

From these observations, it would be interesting to consider here the likely reasons for the different mode choices of students/lower-wage workers group in the municipality area (motorcycle) and the children/seniors in the Aumpor Muang and outer districts areas group (non-motorised transport) as both are lower income groups.

It is thought that the type of road and population density have little influence on transport mode choice, as the municipality has narrower and more winding roads with a higher density land use⁴⁵. It is suspected that the motorcycle is preferred by the students/lower-wage workers because it allows them to trade-in the increase in travel time and cost for a lower accommodation cost. In other words, it allows them more flexibility in choosing the location of their accommodation. The benefit from such a trade-in must be higher than the cost (both time and financial costs) of using the motorcycle. This relationship can be illustrated as follows, in Graph 4-12

⁴⁵ factors that are generally thought to favour non-motorised modes

Graph 4-12 Observed relationship between accommodation and transport costs / distance

The cost of accommodation located some distance from the city centre (D_1) consists of different elements; there is a rental cost (CA_1), a cost of commuting (CC_1), and a cost in time spent commuting (CT_1)⁴⁶. CA , CC , and CT are summed together to derive the total cost of living in such accommodation (service costs are excluded here). It is thought that residents who choose to live in rented accommodation compare the costs of each location and seek to minimise their total outlay⁴⁷ by substituting/varying the distance of available accommodation. The slope of the transportation cost line differs according to the cost. However, this relationship is informally observed and is a simplified one.

In addition, as these residents live in rented accommodation⁴⁸, it is likely that they will value the ability to make longer trips. This ability enables them to travel to their family

⁴⁶ CT is the time spent travelling (D divided by average speed) multiply by perceive cost of time

⁴⁷ Other factors, such as liability, access to service can also be included to improve the sophistication

⁴⁸ The Municipality (16%) and Aumpor Muang (14%) have above average proportion (11%) of residents in rented accommodation

homes during weekends, which are probably located outside the municipality area⁴⁹. By way of contrast, the children/seniors group make shorter trips located close to their permanent homes, such as to local schools or temples. Thus they do not benefit from increased travel speed, and instead minimise their travel costs by using non-motorised transport modes.

e) Strong dissatisfaction with the shared-taxi service

During the interviews, several respondents expressed strong dissatisfaction with the shared-taxi service. In general, they felt the fare was unfairly set and that journey time is usually too long and the service is unreliable. It seems that the service was only used by tourists and residents who could not drive or did not have access to a vehicle, such as disabled persons, elderly, and new migrants who cannot afford a motorcycle or car.

f) Shared-taxi service: a way of life

Conversations with shared-taxi drivers gave a fascinating insight into operating a red-taxi as a profession. It is in fact more than a profession; it is deeply integrated into the driver's life style. The nature of shared-taxi (i.e. unscheduled and flexible) enables these drivers to run their services as an additional means of income to their regular jobs. I met a shared-taxi owner who is a teacher (he earned extra income by picking up students along his route to school), a civil servant (who earned extra income by picking up his colleagues or students along his commuting route), a grandfather (who picked up his grandchildren and other children who live nearby the same school), and a farmer (who ran his service during the morning and evening peak periods, while working on his farm during the day). These aspects of the share taxi, as a supplementary income stream, has perhaps not been understood by policy makers and academics who proposed a conversion of this service into a formal regulated public transport service. Such a conversion would prevent these drivers from earning extra income and deeply impact their life styles. Thus, such a proposition will never be acceptable to them.

⁴⁹ There are shared-taxis connecting the municipality with the surrounding area; however, these connections are limited to only several destinations and less-frequent during the weekend. Further connections into smaller towns can also be expensive.

g) Land use of the city

Although the city area has expanded into the Aumpor Muang and the other districts over the recent years, a large proportion of these areas have remained agricultural or handicraft based communities. Only those areas within the municipality, parts of the Aumpor Muang district, and areas along the main roads in the outer districts were observed to be developed. Nevertheless, conversations with the locals pointed out that a large proportion of these agriculture areas have been purchased by developers, who based their investments on speculation of governmental projects, such as the national high speed train project⁵⁰. Although, this land will be developed rapidly after the commencement of these projects, it is currently abandoned and undeveloped. Conventional wisdom would see these areas providing natural growth of the city's population and immigration housing requirements, but commercial speculation means accommodation has to be provided elsewhere, encouraging the city to sprawl.

4.6. Chapter findings and discussion

Observation and analysis of the city's social demographic and mobility data detailed in this chapter demonstrate several interesting trends, four of which are specifically listed here:

- a) An increase in urban population and urban sprawling.
- b) Connections between high dependency on private motorised vehicle and the infrastructure of the city,
- c) Rapid motorisation
- d) High use and ownership of motorcycles but a high increase in car ownership over recent years.

⁵⁰ In September 2013, the cabinet approved a 2,000 billion Baht (52.2 Billion Euro) budget for the infrastructure improvement package, 80% of which will be invested in the rail transport system. This includes four high-speed rail routes consisting of 1,400 kilometres tracks, which will provide connection between Bangkok and regional cities, such as Chiang Mai. The high-speed rail network is also expected to provide connections between Thailand and counties in the Asean Economic Community (AEC). This investment project is expected to increase the important of Chiang Mai as the primary city of Thailand's northern region.

a) An increase in urban population and decentralisation of city centre (sprawling)

The total number of registered citizens in the urban area is rising; however, there is a shift in the population distributions. The proportion of the registered population in the core city area (the municipality area) is reducing, while the ratios of the population in other areas (Aumpor Muang/the Outer districts) are increasing. This shift is highly significant. The trip origin data (Chapter 4.3.1) suggests the decentralisation of the city centre and significant changes in its land use. In 1994, the majority of trips originated from within the municipality area, whereas in 2012, the majority of trips have origins in areas outside the municipality.

The causes of sprawling are manifold (Brody, 2013). Population growth, increased demand for cheap housing, and low transport cost are among the suggested reasons for urban sprawl. The chief consequences of such phenomena are a decrease in the city's resource efficiency (energy, time, space) and an increase in the amount of pollution resulting from increased consumption of resources needed for increased travelling.

It should be noted that the population trends observed here are based on registered population alone. It is suspected that the shadow population represents a high proportion of people living in the city. Estimates are made in this chapter to confirm and approximate the percentage. The actual population (registered plus shadow population) is estimated at between 46% – 79% more than the registered population, depending on the area. This analysis demonstrated the possible magnitude of a 'hidden' population within the city, which can distort the results of any analysis based solely on official population data. Thus, it makes a strong case for *the city administration to place high priority on making an accurate estimation of its total population.*

b) High motorcycle usage and ownership

Chiang Mai city has a high rate of motorcycle ownership and usage. Nearly 50% of all trips in the city are made by motorcycle and over 60% of the vehicle ownership value is made up of motorcycles (421 out of 689 per 1000 inhabitants). The dominance of this transport mode is unique to the city. Thus, transferability of transport planning principles and modelling tools that are based on western's principle must be checked for relevance. **Alongside this a high increase in car ownership over the recent years is observed.**

The motorcycle is currently the main mode of private motorised transport in Chiang Mai, but this is set to change. The proportion between motorcycle and car numbers (Chapter 4.3.3) suggests that **car ownership has increased more rapidly than that of motorcycles** over recent years and is set to overtake the number of motorcycles in the future. This will severely aggravate the city's transport problems as a car consumes up to four times more energy (Kongboontiam & Udomsri, 2009) and uses twice as much road and parking space than a motorcycle (Emberger, 2009). Moreover, cars emit more pollution. A study by M. J. Bradley & Associates (2007) evaluated the environmental performance between twelve different modes of transport. The study concluded that the one-passenger car emits the third highest CO₂ per passenger mile after ferry boat and demand response mode⁵¹. A single occupant car is also the third least energy efficient mode of transport.

This trend suggests that the city's transport problems will be aggravated at a much more rapid rate in the coming years.

c) Rapid motorisation

Comparison with Vienna revealed that Chiang Mai has a high rate of motorisation (689 vehicles per 1000 inhabitants, compared with Vienna's 484), and a higher average annual rate of increase (8.3% annually, compares with Vienna's 4.1%). This trend emphasises transport planning for Chiang Mai city must take account of a **high rate of increase in motorisation**. This also points to the need to proceed with caution in considering the transfer of policies and mitigations that work in an environment with lower motorisation, such as Vienna.

Moreover, the analysis of AADT on two highways also shows that growth of motorisation and traffic will occur where capacity is available.

d) Other trends

The analysis shows that the city's average household spends 25% of its monthly income on transport (Chapter 4.4). By comparison, an average American family spends 19%, while an average household in auto dependent Exurb suburbs spend 25% (Clements,

⁵¹ Shared-use transit service operating in response to calls from passengers to a transit operator, who schedules a vehicle to pick up the passengers to transport them to their destinations

2011). This suggests that **residents of Chiang Mai city spend a high proportion of monthly income on transport, equal to an American suburb with high auto-dependence**. This also points to an opportunity to provide measures that will decrease the residents' spending on transportation.

Household expenditure data also shows that most of **the respondents estimate the cost to use a car or motorcycle as zero other than the cost of fuel**. This perception needs to be taken into account in designing any transport measure that seeks to compete with private vehicles. Measures to increase the awareness of local residents about the true cost of owning and using private vehicles must be included.

Informal observations

Informal observations during the field trips included: the variation of density within the city area; closeness of parking space to accommodation; type of road classification; use of the motorcycle and non-motorised mode in low income group; land use within the city; and shared-taxi as a way of life. These empirical observations provided useful inputs into the analysis.

Socio-demographic and transport indicators presented in this chapter have been combined to analyse the overall trends of the city's transport system. It provided the basis and background for the in-depth analysis of the next chapter, which focuses on the mobility behaviour of the city's residents.

5. Mobility analysis

5.1. *Introduction*

The focus of this chapter is to understand the mobility behaviour of Chiang Mai city's residents by analysing the trip data gathered by the CM-MTS. The descriptions of the analyses are built on the context of the city's transport system revealed in the previous chapter. Concise information concerning the data is included here, and further detail is available in the full version of the CM-MTS report. The aim of this chapter is to understand unique mobility characteristics of the city which may give clues as how best to unravel its complex transport problems. Special focus is given to the motorcycle and shared-taxi.

Chapter 5.2 presents the limitations of the dataset and the steps taken to improve it. Chapter 5.3 contains the trip distribution analyses to identify correlations between mobility indicators (trip length and trip time) and six other indicators: 1) trip purpose, 2) trip mode, 3) sex, 4) registration status, 5) household location, and 6) monthly household income.

Chapter 5.4 focuses on the analysis of walking time to/from embarking points for each mode. Chapter 5.5 looks at the correlations between urban sprawl and several factors, such as household income, vehicle ownership, and vehicle use. It also estimates the magnitude of the motorcycle-led urban sprawl in relation to car-led. Chapter 5.6 summarises the implications of this chapter's findings and sets out a number of conclusions.

5.2. *Limitation and validation of the data set*

The limitation of the CM-MTS data can be found in the survey report. The CM-MTS data was checked prior to any analysis. It was found that a proportion of trips have disproportionate trip distance and time (i.e. long distance with short time duration.) It is thought these errors stem from inaccurate estimation of trip distance and time. These trips must be removed as they will affect the analysis, especially walking trips that generally have a shorter distance. Thus, calculated trip speeds were used to screen out these anomalies. A maximum speed allowable was set for each mode and trip, and where speed exceeded the set limit these results were omitted. The maximum speed values were set based on expert considerations. Table 5-1 shows the maximum speed for each mode, the number of valid and invalid trips and the percentage of valid trips.

Table 5-1 Trip speed validation

Mode	Max. speed allow (kph)	Total trips	No. of valid trip	No. of invalid trip	% of valid trips
Walking	5.0	2,892	1,607	1,285	56%
Bicycle	15.0	1,082	892	151	82%
Private car - driver	150.0	3,644	3,302	341	91%
Private car - passenger	150.0	1,451	1,314	137	91%
Motorcycle - driver	90.0	7,859	7,280	579	93%
Motorcycle - passenger	90.0	1,267	1,154	113	91%
Shared-taxi	90.0	235	217	18	92%
School/work private van	90.0	334	303	31	91%
Other	90.0	276	196	80	71%
Total	-	19040	16265	2775	85%

15% of the total number of trips have a higher speed than the limits set. A high proportion of the invalid trips are walking trips (46% of the total invalid trips), which also equated to half of all the walking trips surveyed. This suggests *respondents are less likely to estimate walking trips correctly in comparison to other modes*.

The omission of these invalid trips affected the mode share significantly, as shown in Table 5-2.

Table 5-2 Mode share before and after validation

Mode	Before Trip speed validations (%)	After Trip speed validations (%)	Different
Walking	15 %	10 %	-5 %
Bicycle	6 %	6 %	0 %
Private car	27 %	28 %	1 %
Motorcycle	48 %	52 %	4 %
Public transport (Shared-taxi only)	1 %	1 %	0 %
Other (Other + School/work private van)	3 %	3 %	0 %

Source: CM-MTS

It is clear that the proportion of walking trips is significantly decreased. However, it is considered that the mode share value before trip speed validation is the real representation of mode share as it is the numbers of trips made by the respondents, even though the perceived time and distance of some trips may be invalid. The validated dataset is used in this chapter and in the MARS model.

5.3. Trip distribution analyses

Analyses of trip time and distance distribution against different types of variables are made here. It should be noted that the initial trip time distributions had prominent steps between 5, 8, and 10 minute for all areas. These steps suggested that most respondents estimated their trip time in 5 minute interval between 5 and 10 minutes. All trip time graphs were revised to provide smoother transitions.

5.3.1. Trip purpose

The percentage of trip purpose is shown in Chapter 4. The mode shares of the respondents' trips are classified here by their trips' purpose, as shown in Table 5-3.

Table 5-3 Mode share by trip purpose

Mode (n=16,264)	Trip purpose						
	Work trip	School/Univ ersity trip	School run	Shopping	Going home	Other	All trips
Walking	12% (+2%)	3% (-7%)	0% (-10%)	12% (+2%)	9% (-1%)	20% (10%)	10%
Bicycle	3% (-2%)	3% (-2%)	1% (-4%)	10% (+5%)	6% (1%)	8% (3%)	5%
Car	31% (+3%)	26% (-2%)	46% (+18%)	24% (-4%)	27% (-1%)	24% (-4%)	28%
Motorcycle	50% (-2%)	53% (+1%)	53% (1%)	51% (-1%)	54% (+2%)	46% (-6%)	52%
Shared-taxi	1% (0%)	3% (2%)	0% (-1%)	2% (+1%)	1% (0%)	1% (0%)	1%
Other	2% (-1%)	12% (+9%)	1% (-2%)	1% (-2%)	3% (0%)	1% (-2%)	3%
	100%	100%	100%	100%	100%	100%	100%

Note: the percentages in parenthesis are the differences between all trips value and each trip's purpose
Source: CM-MTS

Variations of the mode share can be observed; School/university and school run trips have significantly less proportion of non-motorised transport. School run also has much higher ratio of car trip. These may stem from inability of children to drive themselves, and the perception of safety the car provides as a mode of transport. Surprisingly, shopping trip has higher bicycle and lower car ratios, even though the latter is far more convenient a mode for transporting purchased goods.

There are only slight variations between the motorcycle and shared-taxi across different trip purposes. The motorcycle proves to be less popular for the 'Other' purpose, while shared-taxi is used extensively by students for school/university trips and shopping.

The variation in trip proportions suggests **there are correlations between trip purpose and trip mode selection**. Further analysis is made to reveal the average trip time and distance by each trip purpose, as shown in Table 5-4.

Table 5-4 Average trip time and trip distance by trip purpose

Indicators	Trip purpose						
	Work trip	School/University trip	School run	Shopping	Going home	Other	All trips
Mean trip time (min.)	17.2	21.4	18.3	12.1	16.9	13.7	16.5
Mean trip distance (km)	6.6	7.5	6.7	3.9	5.9	4.5	5.8

Source: CM-MTS

Trip purposes with high proportions of non-motorised modes; such as, Shopping and Other, tend to have a shorter trip time and trip distance (i.e. average distance of a shopping trip has 27% less travel time and 34% lower travel distance than average.)

However, this pattern is not universal; the school run trip has the highest proportion of trips made by private motorised modes but does not have the highest trip time and trip distance. It is suspected that other factors, such as convenience and perceived safety required for the purpose of such trips, are keys for the selection of this mode for this purpose.

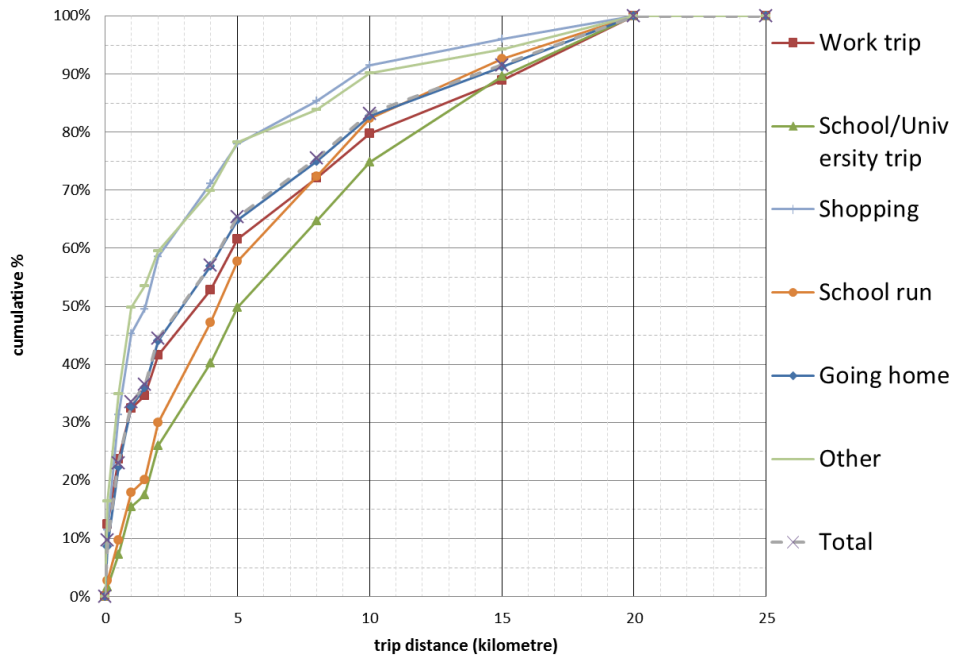
Thus, these findings imply that although trip time and trip distance may have some influence on trip mode selection, the magnitude of these influences is not clear. Other factors, such as perceived safety and convenience also seem to be significant, especially in school runs.

Next, the correlations between respondents' trip purpose and trip distance and time distributions are examined. The trip distance and time taken distributions, classified by trip purpose, are shown in Graph 5-1 and 5-2.

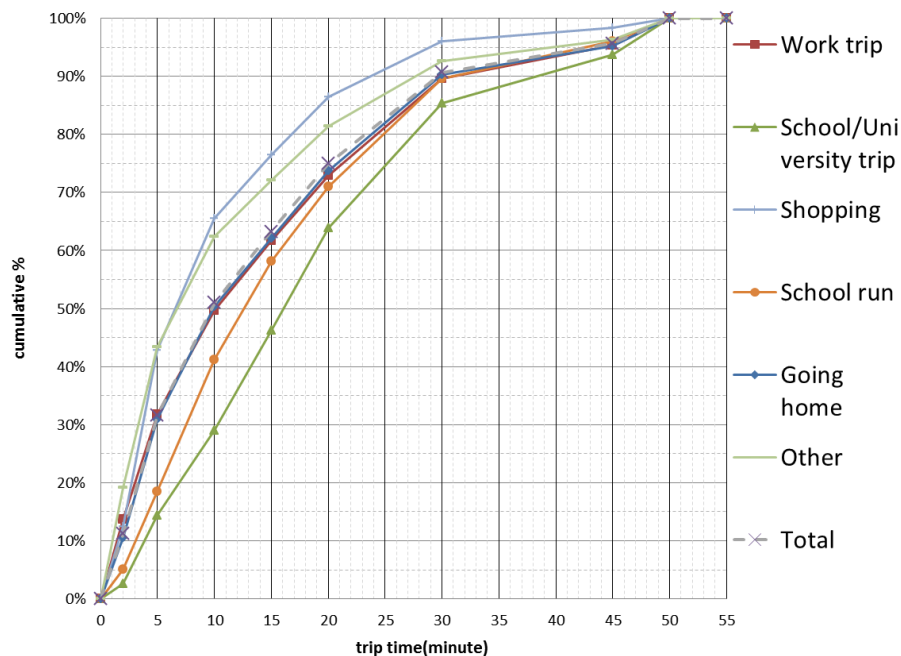
The trip distance and time distributions show the data aggregated into 3 groups: shorter trips (Shopping and Other), longer trips (school/university), and medium distance (the rest). School run trips show interesting patterns, starting in the region of high trip distance and time before moving across to join the medium distance group at 5 km and 15 minutes. This suggests that school run trips have distances that are aggregated more tightly than school/university trip (around 5-10kilometre or 10-20 minutes).

Overall, trip purpose seems to have some influence on trip distance and time distribution.

Graph 5-1 Trip distance distribution, classified by trip purpose

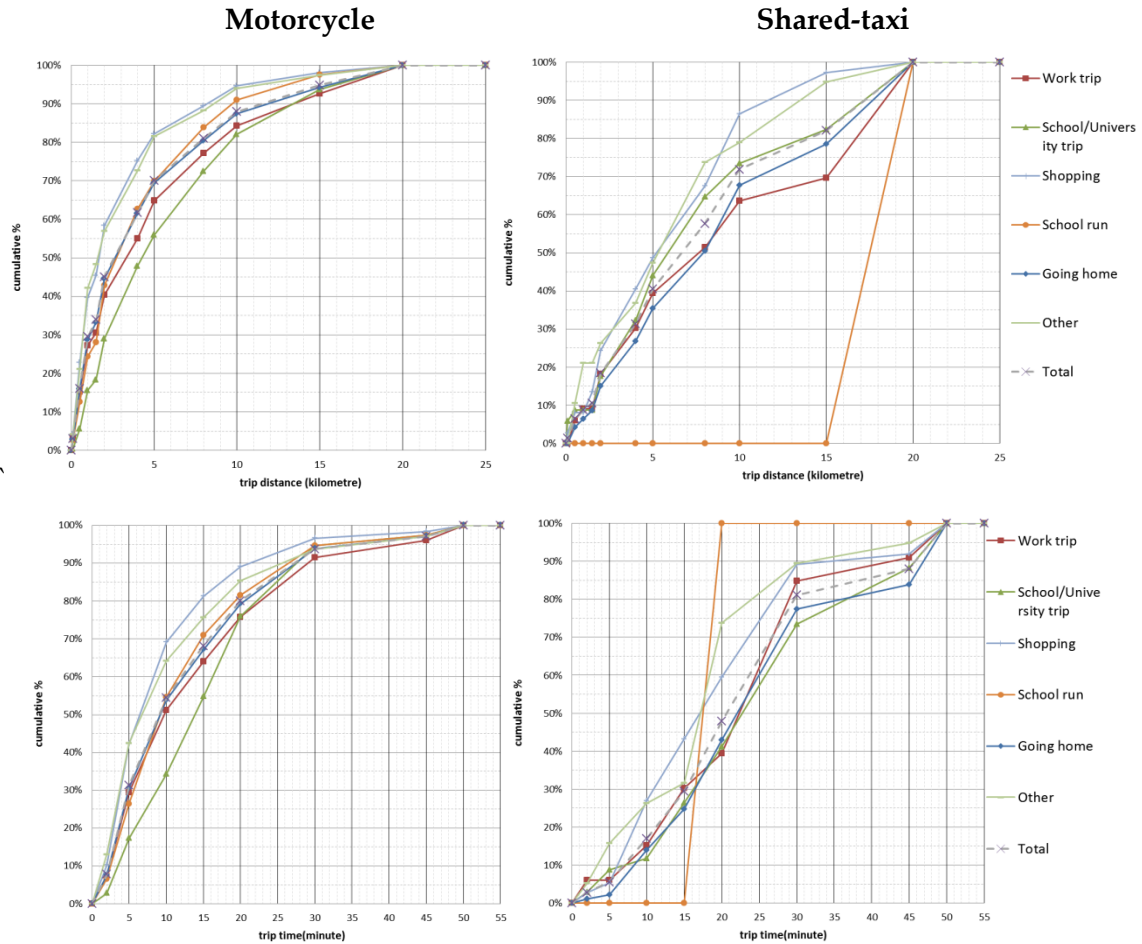


Graph 5-2 Trip time distribution, classified by trip purpose



Additional analyses are made on trip distance and time distribution for motorcycle and shared-taxi trips. The results are shown in Graph 5-3 below.

**Graph 5-3 Trip distance and time distributions, by trip purpose
(Motorcycle and shared-taxi trips only)**



The distance and time distributions of the motorcycle are similar to those of all traffic combined, with a slightly steeper gradient (shorter distance trips). The noticeable difference is the pattern of the school-run trips. Motorcycle school run trips have distributions that are more similar to the mean.

The distributions of the shared-taxi trips have a distinct pattern. They show a high proportion of trips that are long distance trips (e.g. 70% of trips are within 10 km in comparison with motorcycle data of 5 km) with a higher trip time (25 minutes compared with the motorcycle's 15 minutes, again for 70% of the trips). Some anomalies can also be observed, which may stem from the small sample size of the shared-taxi trips.

5.3.2. Trip modes

The mode share of the respondents is shown in Chapter 4. The trip data is classified by modes and the two statistical values presented here are mean and standard deviation, See Table 5-5.

Table 5-5 Statistical analysis of CM-MTS trip data by trip modes

Trip mode	Trip time taken (min.)		Trip distance (km)		Trip average speed (kph)	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Walking	4.6 (1.0)	7.8	0.2 (1.0)	0.4	2.1 (1.0)	1.2
Bicycle	7.7 (1.7)	8.7	0.8 (4.0)	1.1	6.4 (3.0)	3.4
Private car	23.3 (5.1)	17.4	10.0 (50.0)	12.0	26.0 (12.4)	17.5
Motorcycle	14.9 (3.2)	13.3	5.0 (25.0)	5.7	19.1 (9.1)	13.6
Shared-taxi	27.2 (5.9)	17.4	9.2 (46.0)	7.8	20.8 (9.9)	14.2
Other	29.2 (6.3)	20.4	8.5 (42.5)	7.5	17.3 (8.2)	11.9
All trips	16.5 (3.6)	15.6	5.8 (29.0)	8.4	18.7 (8.9)	15.5

Note: the number in parenthesis is ratio to walking's value in that column.

Trip time

Average trip times range between 4 and 29 minutes. Trips made by car can be up to five times longer than walking and bicycle. Other mode has the highest absolute standard deviation value and the non-motorised modes have the highest standard deviation values in relation to their averages. This mean walking and cycling trips can take up to 110%-170% more or less time than average. For the motorised modes, this variation is less, ranging between 50%-90% of their averages.

It is perhaps not surprising that four-wheeler modes (Private car and shared-taxi) have comparable trip time ratio, followed by the motorcycle, then the bicycle, and lastly walking. The standard deviations also follow the same pattern.

Trip distance

The averages range between 0.2 and 10.0 kilometres. Walking trips have the lowest value; with up to 50 times shorter than car trips. Shared-taxi trips have the highest average, slightly higher than the car. The motorcycle's average is roughly between the car's and non-motorised values; it has a medium range between non-motorised and four-wheeler modes.

Private car trips have the highest absolute standard deviation, which suggests a high variation in trip distance; i.e. cars are used for shorter trips as well as longer ones. However, in relation to the mean values, walking trips have the highest standard deviation; the

distance can vary up to 220% from the mean value. This suggests there may be a high variation in the respondents' threshold on walking distance.

Trip Speed

Trip speed is calculated for each trip from its estimated trip distance and trip time. Motorised modes' speeds range between 14.7 and 26.3 kilometres per hour. The car is the fastest mode. Motorcycle and shared-taxi's speeds are comparable. The average speeds show that the motorcycle's is lower than the car's, which is contradictory to the common believe that the motorcycle is faster than a car in the city. However, several points may prevent this observation from being conclusive. Firstly, the motorcycle has an advantage over a car in a saturated network, as it can weave between vehicles. The road network of the city, although congested, is observed to be far from fully saturated. Secondly, the area cover by CM-MTS contains a large proportion of non-built up areas with long stretches of highways passing through them. It is believed that cars can travel at higher speed than motorcycles in such near free-flow condition. Lastly, the trip time and distance of the survey are estimated values, thus, several factors can affect their accuracy

Car trips also have the highest absolute standard deviation; however, walking trips have the highest relative values. A particular walking trip can have up to 200% higher or lower speed from the mean value, which may be because of high inaccuracy in estimating the time taken for walking trips.

The mobility data of motorcycle trips in Chiang Mai is compared with data from other sources. The number of sources included here is small due to the limited number of motorcycle mobility surveys. Additionally, several data are also missing. The scale of data is also different; while Shanghai, Athens, and Chiang Mai are city-scale data, Taiwan and France are national data. Data for France is classified by the propulsion power with # motorcycles of more 50cc and mopeds with an engine size less than 50 cc. The comparison is shown in Table 5-6.

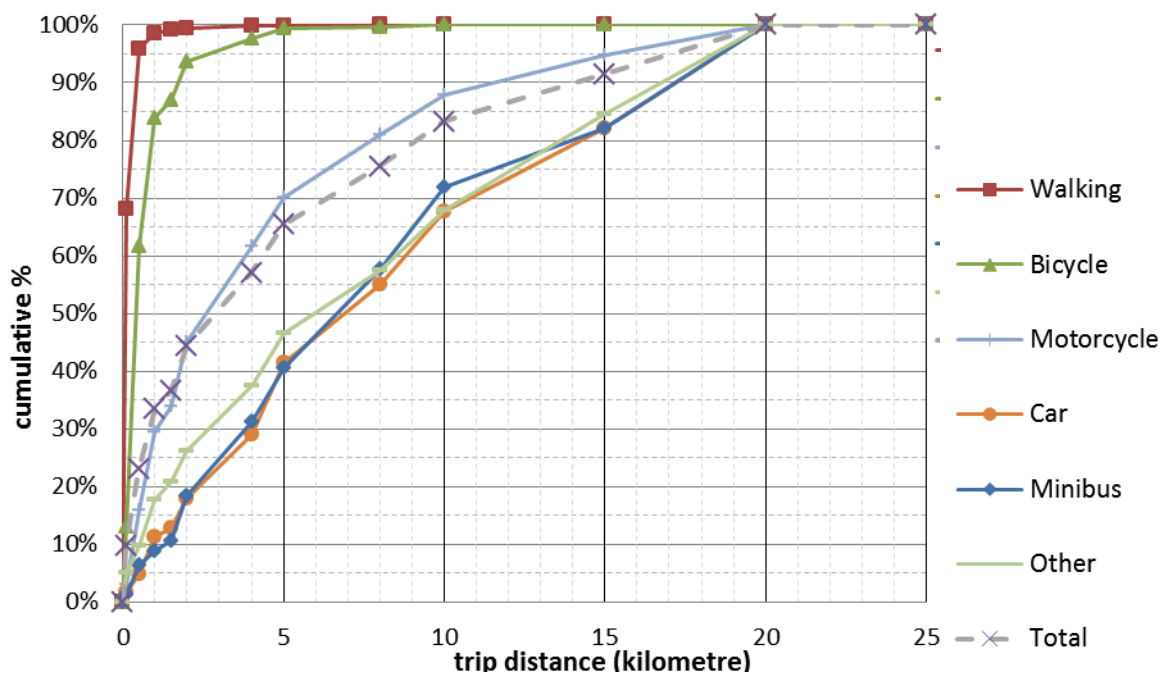
The data shows that Chiang Mai data has average trip time comparable to Athens but less than half of Shanghai. Its average trip length is also comparable to most cases, but Shanghai and Taiwan stand out. Chiang Mai has the highest average trip speed.

Table 5-6 Average trip distant, time, and speed for motorcycle users in different cities

Area	Type of motorised 2-wheeler	Average trip length(km)	Time (min)	Speed (km/hr.)
Chiang Mai (2012)	All Motorised 2-wheeler	5.0	14.9	19.1
Shanghai (2006)	Electric Bike	4.8	25.6	13.0
	LPG Scooter	6.6	28.8	14.6
Kunming (2006)	Electric bike	3.6	20.3	11.9
12 French urbanised areas (2010)	Moped	4.7	n/a	n/a
	Motorcycle	6.3	n/a	n/a
Melbourne (2012)	Scooter	15.5	n/a	n/a
Athens (2011)	Scooter	4.3	16.0	16.3
Taiwan (2001)	Motorcycle	10.8	n/a	n/a

Source: Solere (2010) – France, Cherry (2007) – China, Hsu, Sadullah, & Dao, (2003) – Taiwan, Kepaptsoglou & Milioti (2011) – Greece, and Rose, Thompson, Amani, & McClure (2012) – Australia.

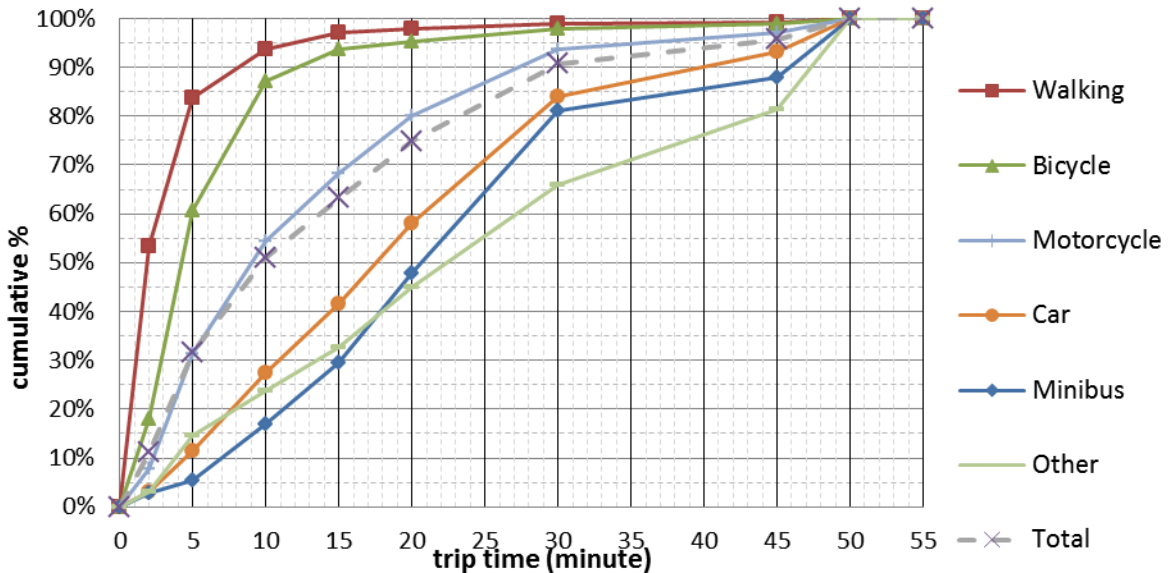
Next, the correlations between respondents' trip mode and trip distance and time distributions are examined. The trip distance and time taken distributions classified by trip mode are shown in Graph 5-4 and 5-5.

Graph 5-4 Trip distance distribution, classified by trip modes

The trips distance distributions by mode reveal an interesting pattern with three distinct distributions observed. The non-motorised modes are clustered on the top left corner; these are trips with shorter distance (95% of them are within 1km). Trips made by car, shared-taxi, and other modes (the motorised four-wheelers) are clustered together, making a diagonal line across the chart area; these are trips with longer distances (95% of

them are within 18.5km). Motorcycle trips' distribution lies roughly in the middle between the two (95% of them are within 15km).

Graph 5-5 Trip time distribution, classified by trip modes



The trip time distribution demonstrates similar trends to the trip distance distribution, although the clustering of the motorised four-wheelers is looser. The pattern of the motorcycle trips' distribution sits in between non-motorised mode and motorised four-wheelers. Another interesting feature is that the shared-taxi and the Other mode's trip times are, in general, higher than car trips even though the previous chart shows that the distribution of their trip distances are roughly the same. This suggests car trips have higher speed than the other two modes and take a more direct route toward their destinations. The distinguishable patterns depicted here suggest that trip mode has a strong influence on trip time.

Further analysis is made to compare the effects of trip mode and household location by plotting the distribution patterns of trip made by different mode for different household locations. The results are shown in Graph 5-6.

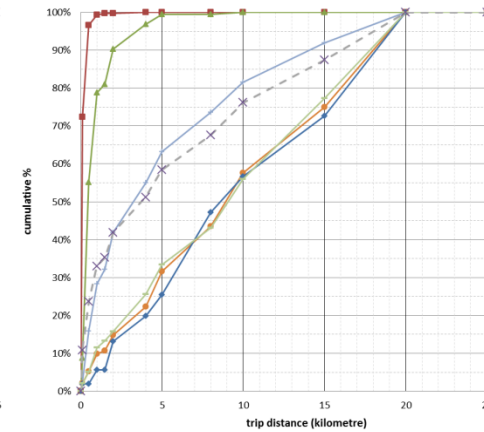
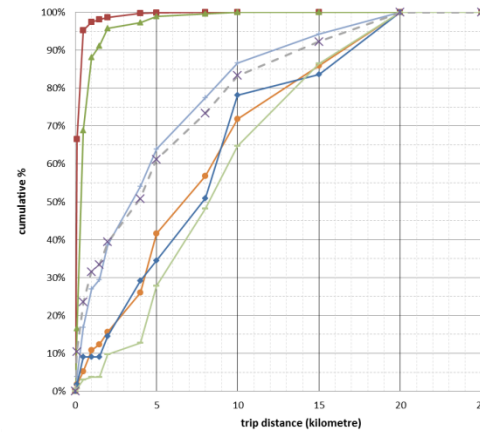
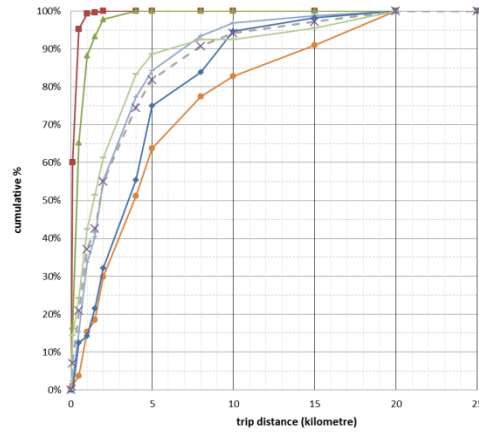
Graph 5-6 Trip distance and time distributions, classified by trip modes and household location

Hh location:

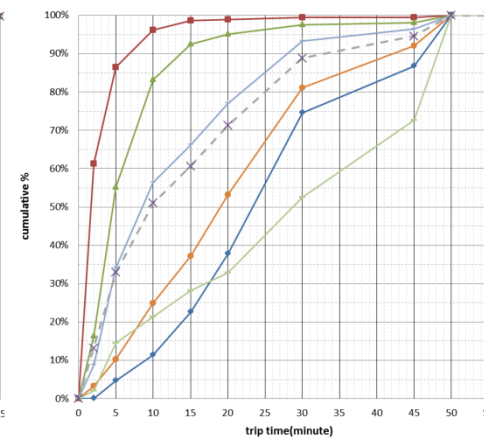
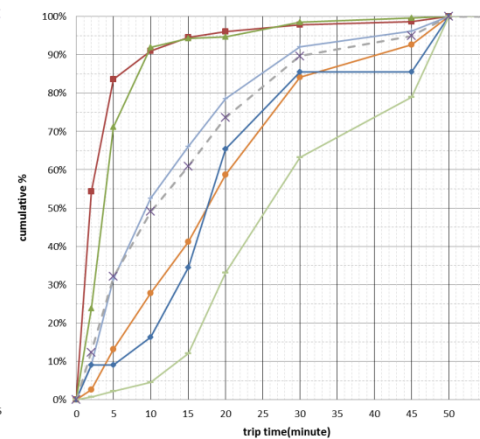
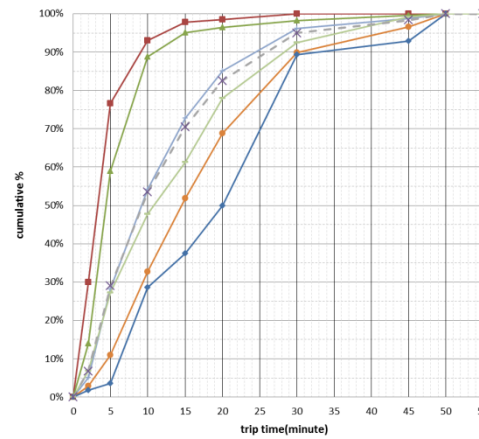
Municipality

Aumpor Muang

Outer districts



Walking
Bicycle
Motorcycle
Car
Minibus
Other
Total



Walking
Bicycle
Motorcycle
Car
Minibus
Other
Total

The following points can be observed from the charts above:

- The effect of trip modes on trip distance distribution becomes stronger as household location moves away from the city centre; the distinct three line pattern becomes more defined in the outer area than the municipality. The gaps between non-motorised modes, motorcycles, and four-wheeler vehicles are more prominent in the outer district than others.
- Similar observations can be made with trip time, although the distribution patterns are less defined and less aggregated. The Other mode in particular seems to clearly separate out from the four-wheeler group. The separation between walking and cycling is also more apparent in the outer districts, perhaps because cycles are used more to cover a longer trip (as shown by higher average trip distance and time).
- Nevertheless, the distribution patterns of trip distance and time of non-motorised, the motorcycle, and 4-wheeler modes show a strong consistency across different areas. Thus, **the mode of transport seems to have a stronger influence on trip distance and trip time than location of trip origin.**

5.3.3. Sex

In this analysis, the effects of gender on mobility behaviours are examined. The proportions of respondents in each sex with their corresponding trips are shown in Table 5-7.

Table 5-7 Proportion of respondents and trips by sex

Classification		Person		Trips	
Sexes	Male	2,782	45%	7,345	46%
	Female	3,347	55%	8,771	54%
	Total	6,129	100%	16,116	100%

The proportion of females is slightly higher; the number of trips made by females is also slightly higher but by a similar ratio. Table 5-8 shows how mode share correlates with each sex.

The female respondents made a much higher number of non-motorised trips (19%, compared with 11% in the male group) and also utilised the shared-taxi service more (2%, compared with 0%). The male group made more trips with private motorised modes, especially by motorcycle (55%, compared with 49% in female).

Table 5-8 Mode share by respondents' sex

Mode	Sex		All
	Male	Female	
Walking	7%	12%	10%
Bicycle	4%	7%	6%
Car	30%	27%	28%
Motorcycle	55%	49%	52%
Shared-taxi	0%	2%	1%
Other	3%	3%	3%

Next, the mobility indicators of each sex are shown in Table 5-9.

Table 5-9 Mobility indicators by sex

Indicators/Sex	Male	Female	All
No. of trips per day	3.1	3.2	3.1
Trip distance (km)	6.4	5.4	5.9
Trip time taken (minute)	17.3	15.8	16.4
Trip average speed (km/hr.)	20.1	17.5	18.7
Daily trip distance (km)	19.5	16.4	17.8
Daily trip time (minutes)	51.7	47.1	49.2

Although, female respondents made slightly more trips per day, their trips are closer and shorter. Moreover, they also travel at lower speeds and, on a daily basis covered less distance using less time. Additional analysis below looks into the influence gender has on mobility indicators of the motorcycle and shared-taxi, shown in Table 5-10.

Male respondents have higher average trip distance, trip time, and trip speed in both their use of motorcycles and shared-taxis. It is interesting to see the difference in trip speed of the shared-taxi service. The differences may stem from dissimilar perceptions of time and distance for male and female or simply because of the low sample size.

Table 5-10 Mobility indicators of the motorcycle and shared-taxi by sex

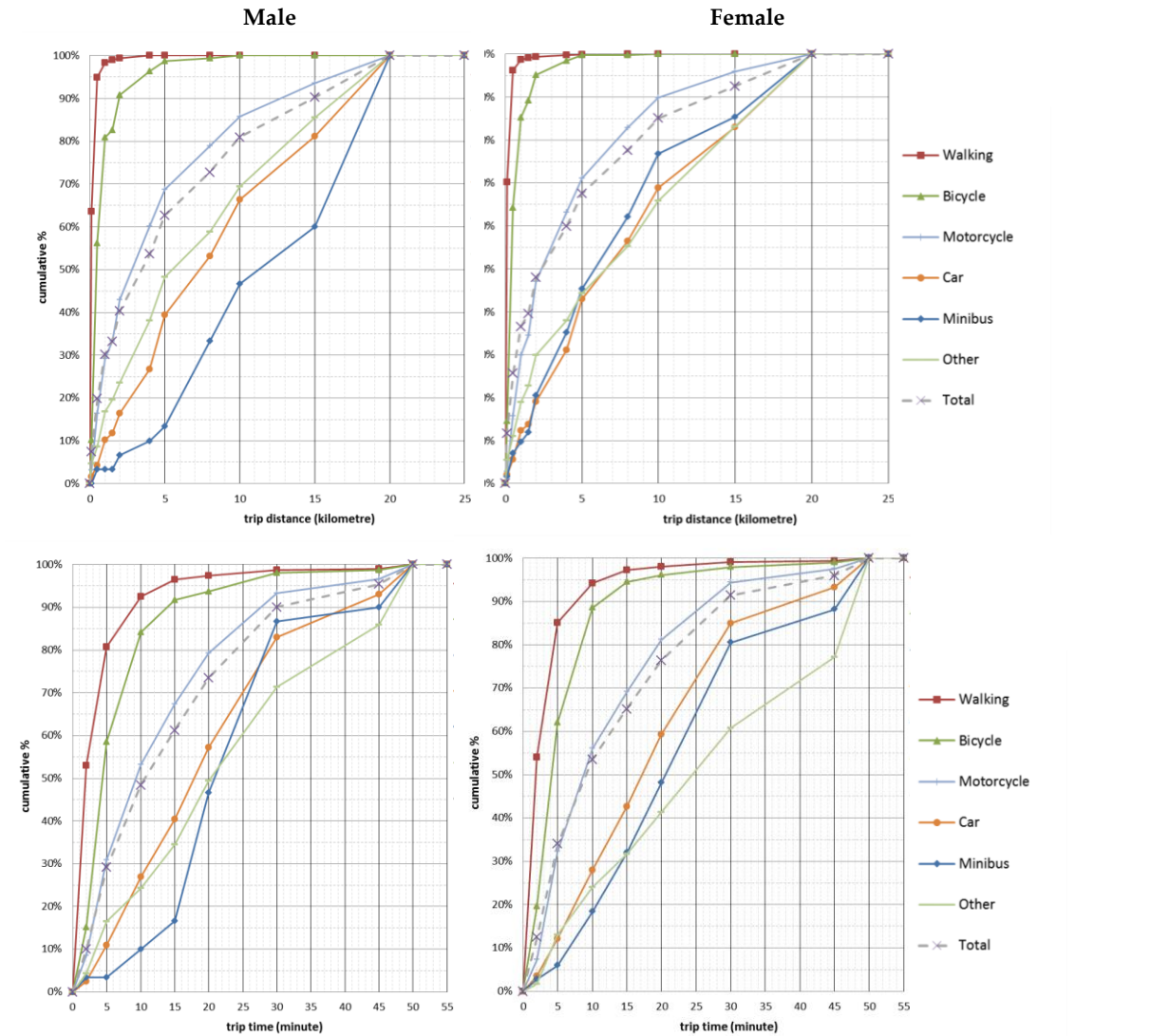
Indicators	Motorcycle			Shared-taxi		
	Male	Female	All motorcycles	Male	Female	All shared-taxi
Trip distance (km)	5.3 (1.07)	4.7 (0.94)	5.0 (1.0)	13.4 (1.47)	8.4 (0.92)	9.1 (1.0)
Trip time (min.)	15.3 (1.03)	14.5 (0.97)	14.9 (1.0)	28.2 (1.05)	26.6 (0.99)	26.9 (1.0)
Trip speed (km/hr.)	19.9 (1.04)	18.5 (0.97)	19.2 (1.0)	32.3 (1.56)	18.9 (0.91)	20.7 (1.0)

Note: numbers in parenthesis are the ratio of the value in the box in relation to all respondents' value of the same indicator

Further analysis is made to identify the influence respondents' gender may have on their relative distance and time distributions. The results are shown in Graph 5-7.

Graph 5-7 Trip distance and time distributions, classified by trip modes and sex

Sexes:



The respondents' sex seems to have slight effects on the trip distance distribution; the male respondents travelled further than the female. In trip time distribution the influence of respondents' sex can be observed although more subtle.

Male motorcycle riders seem to make longer distance trips (90% of trips are within 12.5 km.) than their female counterparts (90% of trips are within 10 km). However, their trip time distributions are similar, which suggests that the male respondents ride faster in general.

The distributions of shared-taxi trips for both genders seem to be similar, although there are some differences in the patterns. This is because of the small sample size of the

male shared-taxi riders. Thus, the data should be read with care as it is more sensitive to anomalies.

Overall, the respondents' sex has some influence on mode selection and mobility indicators but its effects are less prominent in trip distance and time distributions.

5.3.4. Registration status

Details of population registration are discussed in Chapter 4. The analysis in this chapter looks for correlations between the registered status of the respondents and their mobility behaviour. Table 5-11 displays number and proportion of respondents and trip made by each group.

Table 5-11 Number and proportion of respondents and trip made by registration status

Classification		Person		Trips	
Registration at residing address?	Yes	4,988	85%	13,012	84%
	No	899	15%	2,522	16%
	Total	5,887	100%	15,534	100%

Note: respondents without registration data is omitted from further analysis

The proportion of respondents who are not registered at their place of residence is around 15%. The number of trips made by this group is slightly higher. Table 5-12 shows the mobility indicators of the two groups.

Table 5-12 Mobility indicators by registration status

Indicators/status	Registered	Not registered	All
No. of trip per day	3.1	3.4	3.1
Trip distance (km)	5.8	5.9	5.9
Trip time taken (minute)	16.4	16.8	16.4
Trip average speed (km/hr.)	18.8	17.8	18.6
Daily trip distance (km)	17.5	19.7	17.8
Daily trip time (minute)	48.5	54.4	49.4

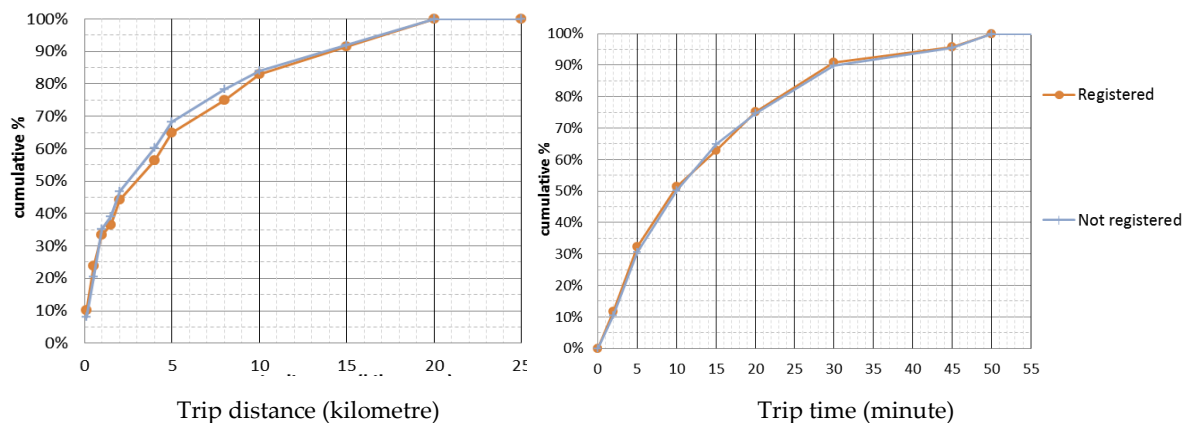
Unregistered respondents have a slightly higher average of daily trips, trip distance, trip time taken, daily trip distance, and daily trip time than those who are registered. In particular, the higher daily trip distance (2 km more than the average) and daily trip time (5 minutes more than average). However, the unregistered group has slightly slower average speed. Table 5-13 shows the mode share of each group.

Table 5-13 Mode share by registration status

Trip mode	Register status		
	Registered	Not registered	All
Walking	11%	7%	10%
Bicycle	6%	3%	6%
Car	29%	25%	28%
Motorcycle	50%	61%	52%
Shared-taxi	1%	1%	1%
Other	3%	3%	3%
Sum	100%	100%	100%

The registered group seems to have higher proportion of trips made by non-motorised trips and (17%, compared with unregistered group's 10%). They also made more car trips (29% compared with 25%) and a lower proportion of motorcycle trips (50%, compared with unregistered groups' 61%). It seems that the unregistered group is more dependent on the motorcycle.

Next, the trip distance and time taken distributions are analysed, the results are shown in Graph 5-8.

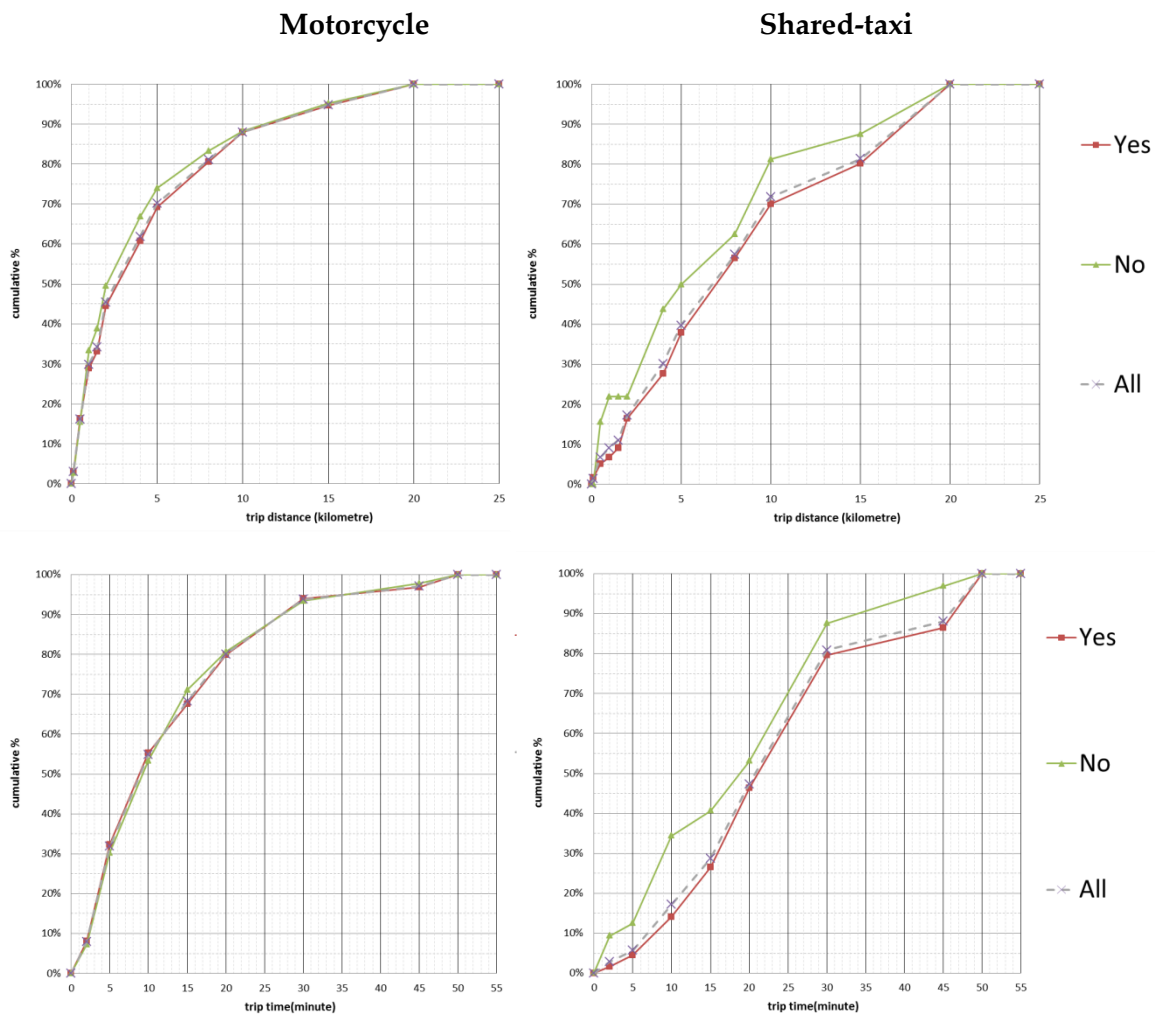
Graph 5-8 Trip distance and time distributions, classified by registration status

The effects of registration status on trip distance distribution seem to be weak; the two curves are nearly identical. Similarly, the trip time distribution seems to be unaffected by the trips makers' registration status. From these findings, it can be concluded that registration status seems to have some effect on the mode selection and mobility indicators. However, it has little effects on the trip distance and trip time distribution.

Additional analyses were carried out to identify the distribution pattern for registered and unregistered motorcycle/shared-taxi users. The results are shown in Graph 5-9.

Motorcycle users have similar distribution patterns to the overall respondents. However, distinctive patterns can be observed on shared-taxi distributions; longer trip distance and trip time. It should be noted that a large proportion of the shared-taxi trips are made by the registered respondents (177 out of 209 trips or 85%), which is likely to influence the pattern of the total respondents. The anomalies which are exhibited in Shared-taxi trips undertaken by unregistered respondents stem from its low sample size and can be discounted.

Graph 5-9 Trip distance and time distributions, classified by registration status for motorcycle and shared-taxi trips



5.3.5. Household location

In accordance with the classification of area by the CM-MTS (Figure 1-1), a mobility analysis of each location is made here. The proportion of household, persons, and trips made according to each household location are shown in Table 5-14.

Table 5-14 Proportion of households, persons, and trips surveyed classified by household location

Household location	Household		Person		Trips	
Municipality	641	28%	1,653	27%	4,201	26%
Aumpor Muang	787	34%	2,087	34%	5,495	34%
Outer districts	891	38%	2,449	40%	6,569	40%
Total	2,319	100%	6,189	100%	16,265	100%

In this analysis, the correlations between household location and mobility attributes are investigated. The mode share of trips made by households in each area is illustrated in Table 5-15, and their mobility indicators, such as average trip time and distance are depicted in Table 5-16.

Table 5-15 Mode share by household location (in % of total daily trip of each area)

Mode share/HH location	Municipality	Aumpor Muang	Outer districts	All
Walking	10%	16%	18%	15%
Bicycle	5%	5%	7%	6%
Car	20%	30%	29%	27%
Motorcycle	60%	45%	43%	48%
Shared-taxi	1%	1%	2%	1%
Other	4%	3%	3%	3%
Total	100%	100%	100%	100%

The respondents within Chiang Mai municipality have the lowest proportion of trips made by walking and cycling, despite its higher density,⁵² than the surrounding area. Those in the municipality also have a lower proportion of trips made by private car. Instead, it has the highest proportion of motorcycle trips (60% of trips). Those in the Aumpor Muang and

⁵² The municipality's density in 2012 is 3,426 persons per square metre, in comparison the Aumpor Muang district's is 1,546 persons per square metre.

the outer districts areas utilised non-motorised modes and the car more, and less use is made of the motorcycle than those in the municipality area.

Table 5-16 Mobility indicators by household location

Indicators/HH location	Municipality	Aumpor Muang	Outer districts	All
No. Of trip per day	3.0	3.2	3.2	3.1
Trip distance (km)	3.8	6.1	6.9	5.8
Trip time taken (minute)	14.3	17.1	17.4	16.5
Trip average speed (km/hr.)	14.0	19.7	20.7	18.7
Daily trip distance	11.2	18.7	21.3	17.8
Daily trip time	41.9	52.1	52.0	49.3

Source: CM-MTS 2012

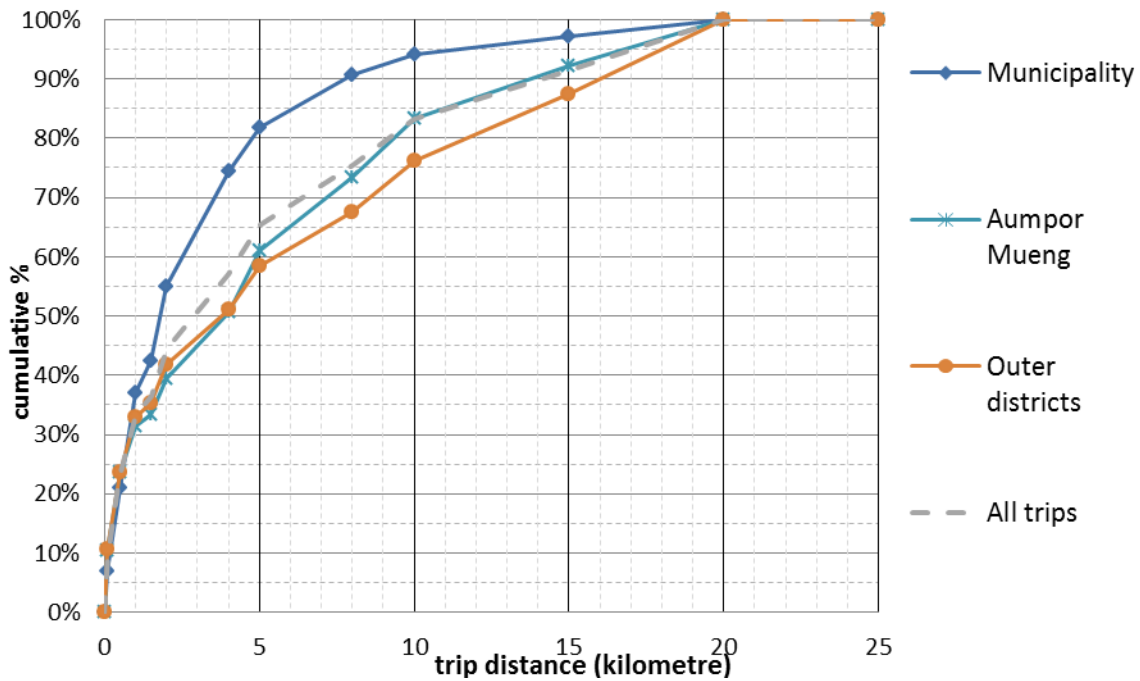
The average daily trip rates seem relatively similar across the three groups but the municipality group has a much lower average trip distance (30% less than average) and trip time (13% less) than other areas. Additionally, its average trip speed is also 25% slower than other areas.

Those within the municipality households also have lower average daily travel time and distance than the average values. The municipality group has 15% lower daily travel time and 37% lower daily travel distance than the averages. Those within the outer district household travel the longest, furthest, and fastest. This suggests that although density has no apparent effects on mode selection, it seems to have some influence on the average trip distance, time, and daily trip distance and time. There are correlations between household location and mobility behaviour.

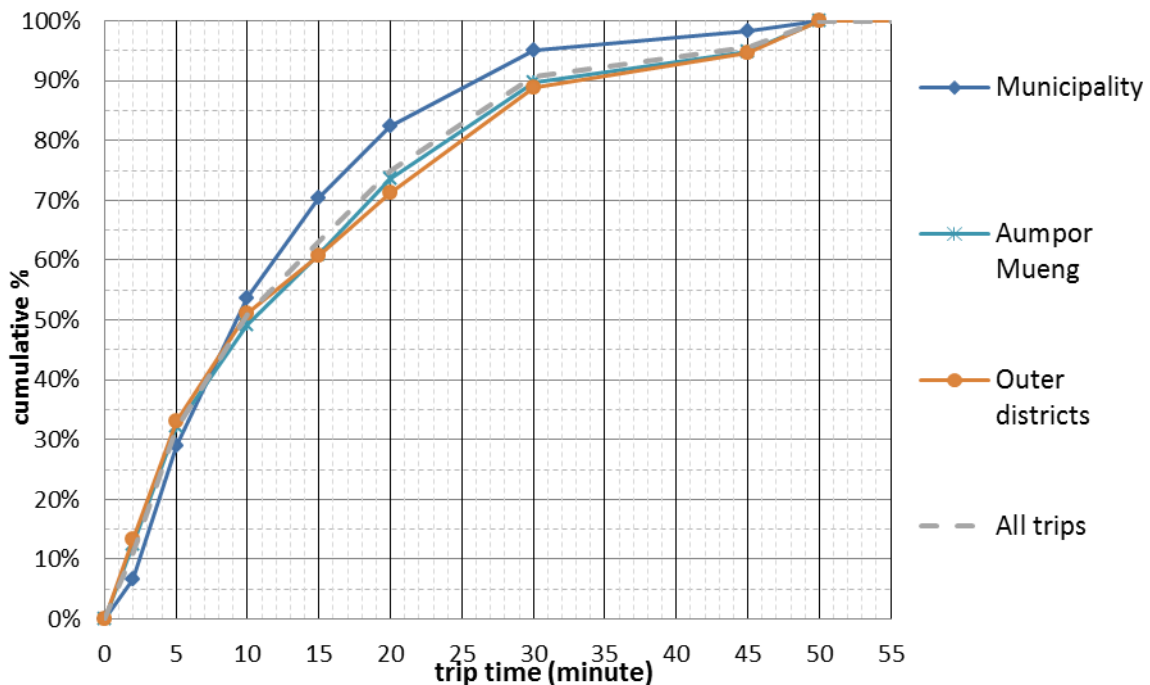
The trip distance and time taken distributions classified by the household location are shown in Graph 5-10 and 5-11.

Graph 5-10 suggests that household location has some influence on the distributions of trip distance; municipality respondents make much shorter trips, while Aumpor Muang and Outer Districts are comparable. The differences are less prominent in trip time, which shows that the trip speed in the municipality area is generally lower. This is perhaps due to congestion and road layout. It can be concluded that household location has some effects on trip distribution, especially in the municipality area.

Graph 5-10 Trip distance distribution, classified by household location



Graph 5-11 Trip time distribution, classified by household location



An analysis of motorcycle and shared-taxi trips for different household locations has been included in Chapter 5.3.2.

5.3.6. Household monthly income

The classification of respondents by their household monthly income is dealt with here in two separate approaches. The first approach is the conventional one of sorting each respondent according to their household monthly income. The seven income bands of CM-MTS are aggregated into three income bands for ease of analysis. The second approach attempts to take into account household size. In each respondent's case the mean of their monthly income band is calculated and then is divided in accordance with the respondent's household size. The result is then multiplied by 100 to give a percentage and finally, aggregated into three groups, which are divided by equal percentiles based on the number of cases. Two cut points were used with an equal width of 33.33%. It is considered that this percentile method better represents the actual income of trip makers, because a larger household also tends to have a larger income⁵³. The classification was carried out in the same way for trips. Table 5-17 compares the sample size of the two classification methods.

Table 5-17 Sample distributions by income group and income/family size methods

Classification		Person		Trips	
Household income	0-9,999	1,165	19%	3,120	19%
	9,999-19999	2,131	35%	5,590	35%
	20,000+	2,829	46%	7,381	46%
	Total	6,125	100%	16,091	100%
Income and family size index	Lower percentile	2,268	37%	5,758	36%
	Middle percentile	2,125	35%	5,455	34%
	Higher percentile	1,681	28%	4,893	30%
	Total	6,074	100%	16,106	100%

Note: 1) The total numbers are different due to omission of some samples without family size information

2) 40 Baht = 1 Euro

It is evident that the two classifications yield different distributions of the sample groupings. The income and family size index yields a more balanced spread of data, while the household income method resulted in a more 'top heavy' distribution or higher proportion of higher income group. Table 5-18 shows the mode share of each sample group.

⁵³ A separate analysis of the survey data shows that a household with more than 20,000 Baht per month has an average household size of 4.14, while a household with 0-9,999 Baht income per month has an average household size of 2.90

Table 5-18 Mode share by trip makers' household income (Baht)

Mode share/HH Income group	0 - 9,999 (n=3,120)	10,000 - 19,999 (n=5,590)	20,000+ (n=7,381)	All (n=16,091)
Walking	16%	9%	7%	10%
Bicycle	10%	5%	4%	5%
Car	9%	22%	42%	29%
Motorcycle	59%	59%	44%	52%
Shared-taxi	2%	1%	1%	1%
Other	4%	3%	3%	3%
Total	100%	100%	100%	100%

Mode share/HH size and income index	Lower percentile (n=5,758)	Middle percentile (n=5,455)	Higher percentile (n=4,726)	All (n=15,939)
Walking	13%	8%	8%	10%
Bicycle	8%	5%	3%	5%
Car	16%	29%	43%	29%
Motorcycle	58%	53%	43%	52%
Shared-taxi	2%	1%	1%	1%
Other	4%	3%	2%	3%
Total	100%	100%	100%	100%

Note: 1) 40 Baht is 1 Euro 2) the respondents' mode share here is different from the values quoted elsewhere due to omission of some samples without household income

A consistence pattern can be observed across the two sets of data; the lower income group made more non-motorised modes trips and motorcycle trips, the middle income group utilised more cars than the lower income group and slightly less motorcycles; and the higher income group utilised the car most of all. The choices made regarding transport mode across the low-high income group can be summarised:

Lower income group

Non-motorised and **motorcycle**.

Middle income group

Motorcycle and Car.

Higher income group

Car and **motorcycle**

Note: Bold letters indicate higher weighting. The motorcycle and car have similar weighting in the higher income group

In each income group, there seems to be two additional sub-groups:

- Lower income, non-motorised user
- Lower income, motorcycle user
- Middle income, motorcycle user
- Middle income, car user
- Higher income, motorcycle user
- Higher income, car user

The majority of these groups also do not overlap, i.e. they use a single mode throughout the day (CM-MTS reports that 52% of the respondents made their daily travel by a single mode of transport in CM-MTS report, Chapter 7). Table 5-19 shows the mobility indicators for each group.

The patterns of the data also seem to be consistence across the two sets, except the number of trips per day. The lower income group seem to have the highest number of daily trips (3.4 trips per day); but using the percentile method of analysis the highest number of daily trips (3.3 trips per day) is linked to the higher percentile group. Among different possible reasons, the difference may lie in how the data was aggregated into groups.

Apart from the difference mentioned above, a consistent pattern can be observed; respondents in the lower income group tend to make closer and shorter trips, with slower speed. They also have lower average daily trip distance and trip time.

Table 5-19 Mobility characteristic of each income groups

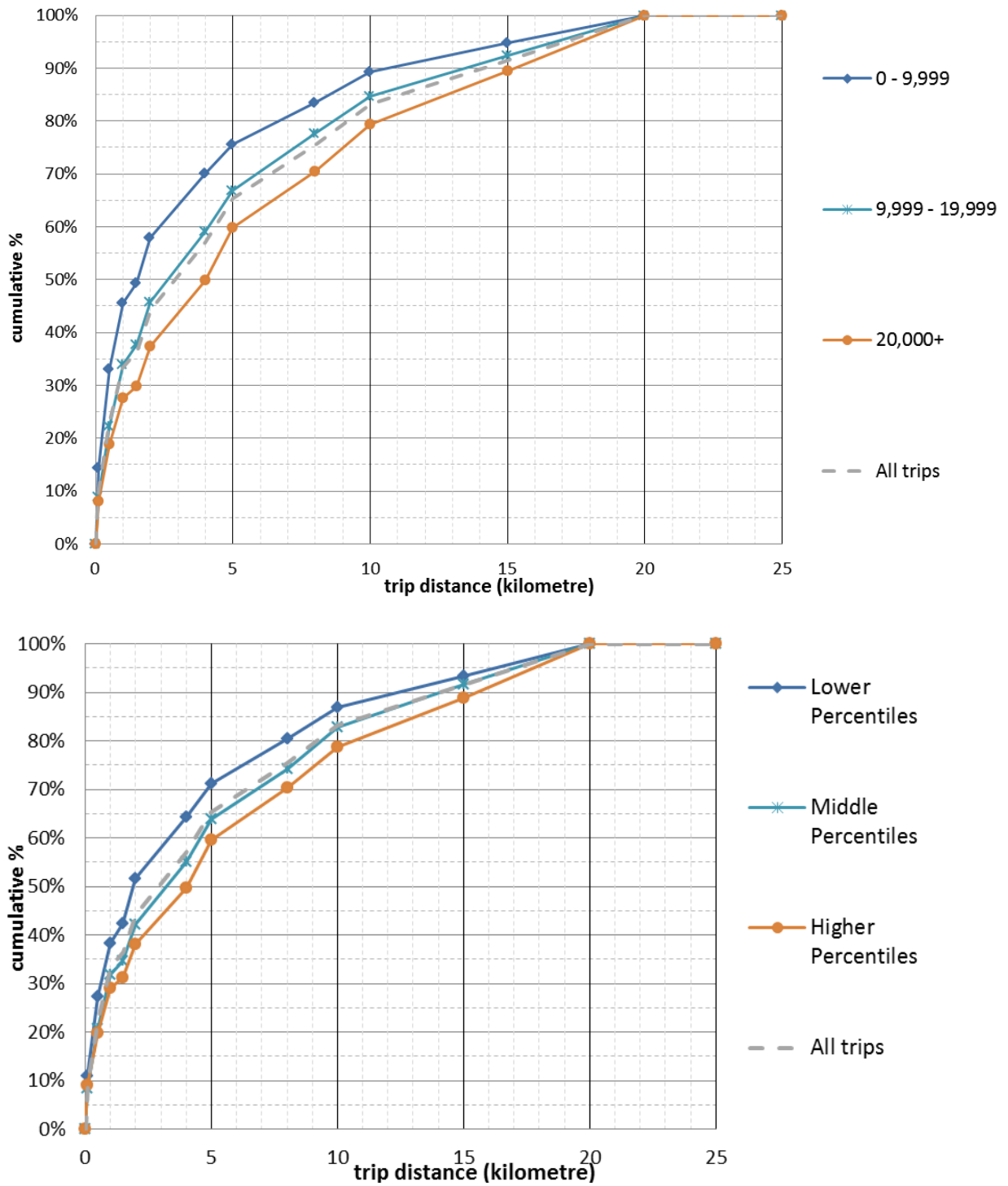
Indicators/Income group	0-9,999	10,000-19,999	20,000+	All
No. of trips per day	3.4	3.1	3.1	3.1
Trip distance (km)	4.2	5.6	6.8	5.9
Trip time taken (minute)	13.5	15.8	18.4	16.5
Trip average speed (km/hr.)	15.5	18.3	20.4	18.7
Daily trip distance (km)	13.6	16.6	20.4	17.8
Daily trip time (minute)	43.8	46.3	54.0	49.4

Indicators/Income-hh size index	Lower percentile	Middle percentile	Higher percentile	All
No. of trips per day	3.1	3.1	3.3	3.1
Trip distance (km)	5.0	6.0	6.8	5.9
Trip time taken (minute)	14.8	17.0	18.1	16.5
Trip average speed (km/hr.)	17.0	19.1	20.5	18.7
Daily trip distance (km)	14.7	18.1	21.7	17.8
Daily trip time (minute)	43.6	50.3	55.9	49.4

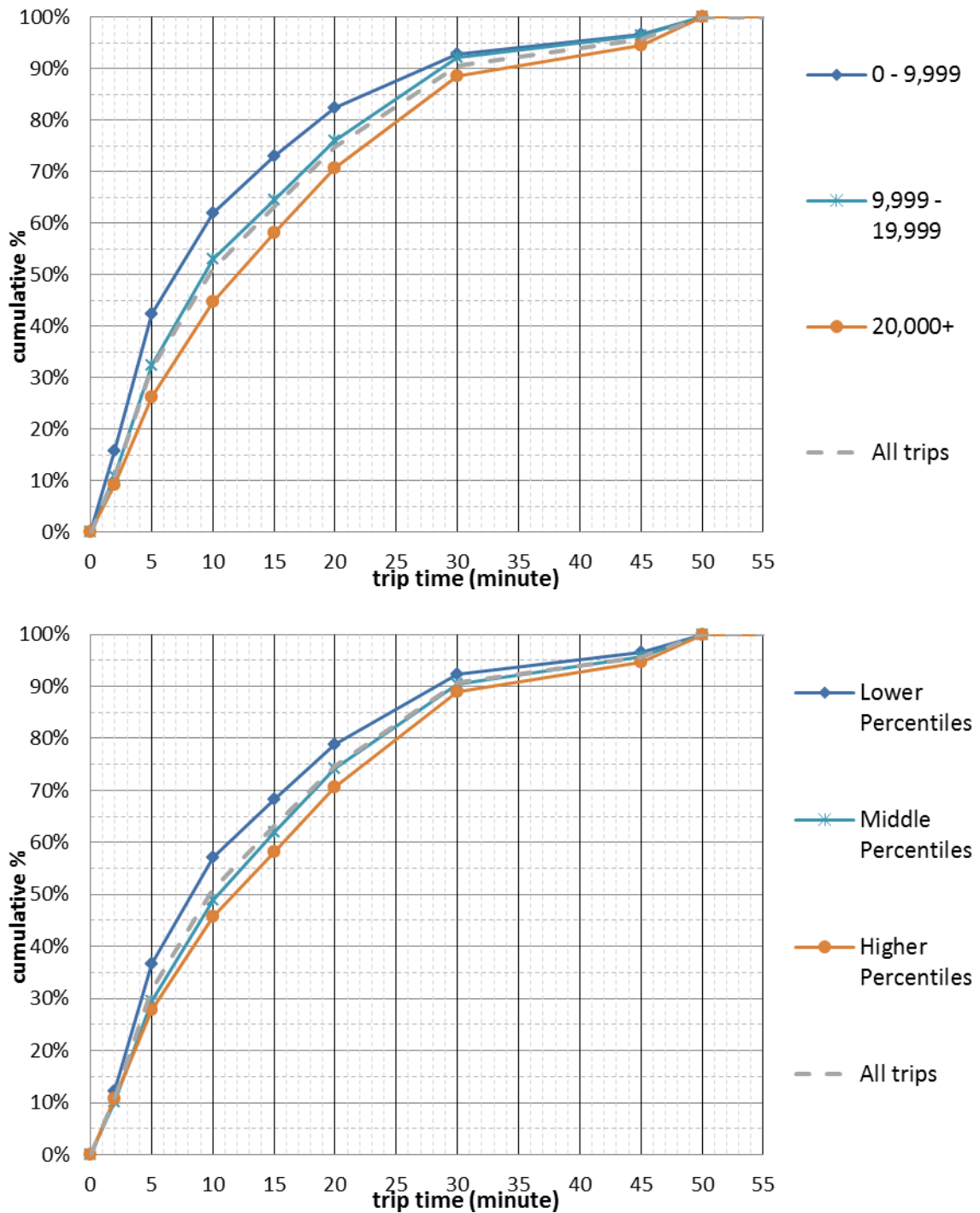
Further analyses looked at the trip distance and trip time distributions. The results of the analyses are shown in Graph 5-12 and 5-13.

The trip distance distributions of the two data sets are similar. They also reflect the observations made previously; respondents from lower income group tend to make closer trips, while the higher income group tends to make trips with higher distance. Thus, household monthly income has a positive correlation with trip distance.

Graph 5-12 Trip distance distribution, classified by trip makers' household income and income percentiles



Graph 5-13 Trip time distribution, classified by trip makers' household income and income percentiles



A similar pattern to trip distance distribution can be observed for trip time distribution; household income also has a positive correlation to trip time (i.e. richer household make longer trips). However, the effects are more subtle. Thus, household income has lower influence on travel time than travel distance.

Further analysis compared the effects of trip mode and household monthly income on trip distribution patterns, and the results are shown in Graph 5-14 and 5-15.

The following observations can be extracted from these set of graphs:

- Both sets of data show a similar distribution pattern with some slight differences. For example, the shared-taxi trip distance distribution in the higher income percentile group follows the average line closer than the higher income group.
- The differences in trip distance distribution between each mode are quite well-defined; the three distinct groups of transport modes of non-motorised, motorcycle, and four-wheeler usage are clearly visible.
- The differences in trip time distribution are more subtle than in trip distance distribution.
- Overall, the effects of household income seem to be minor, yet, household monthly income has a positive correlation with trip time and time distance.

Motorcycle focus

- Motorcycle trip distance and time distributions of the three income group groups are fairly similar. However, there seems to be a positive correlation between percentile index and motorcycle trip distance. Yet the difference is less clear in trip time distribution.
- Household income has little effect on the trip time and distance distribution of motorcycle trips. Although, it is apparent that the higher income group has slightly higher trip distance.

Shared-taxi focus

- Similarly, there is little apparent difference between the household income groups. However, the higher percentile seems to make shorter trips than others. Nevertheless, the difference is less apparent in trip time distribution.
- Household income has little effect on the trip time and distance distribution of shared-taxi trips.

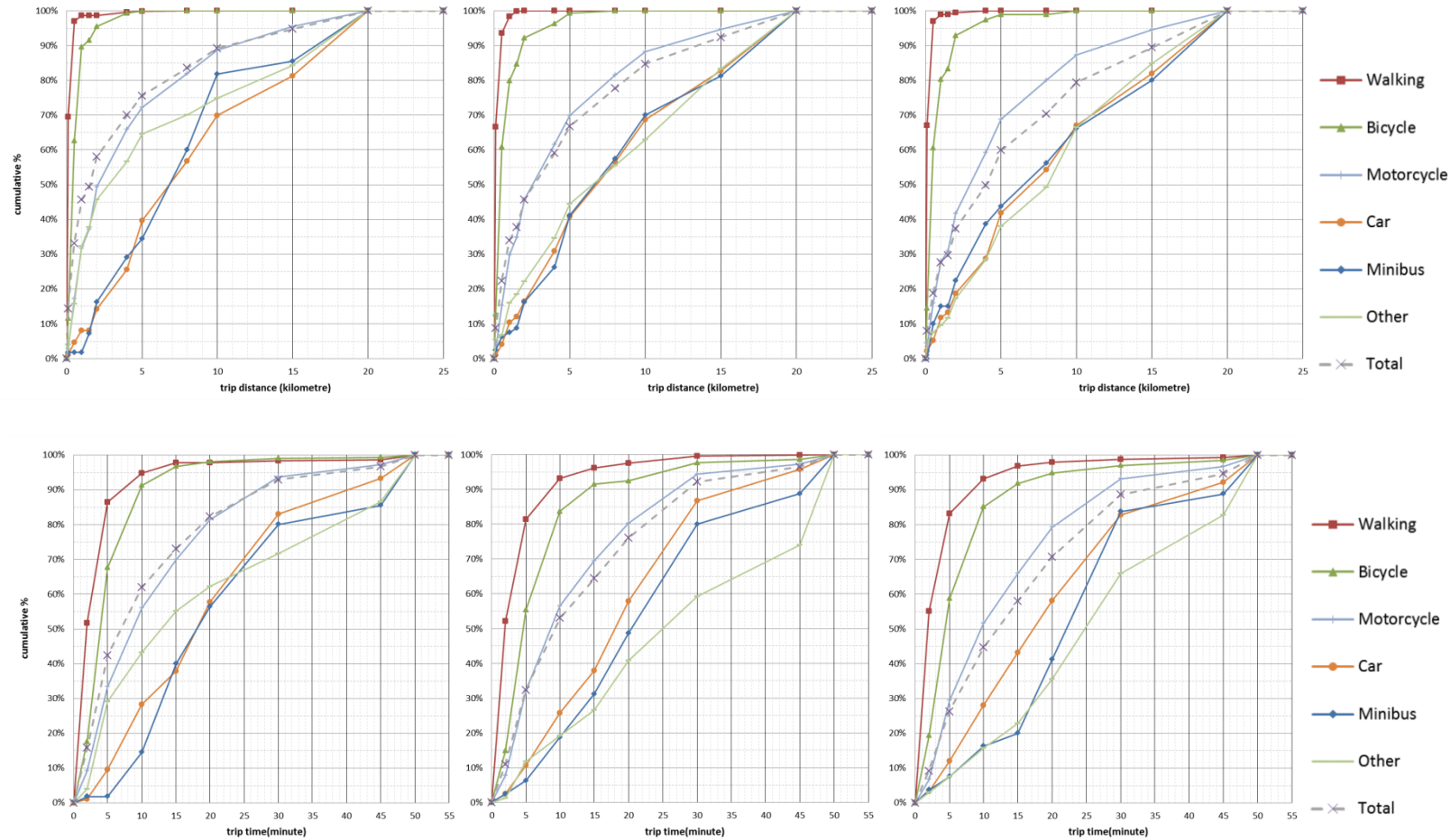
Graph 5-14 Trip distance and time distributions, classified by trip modes and monthly household income

hh income:

0-9,999 Baht

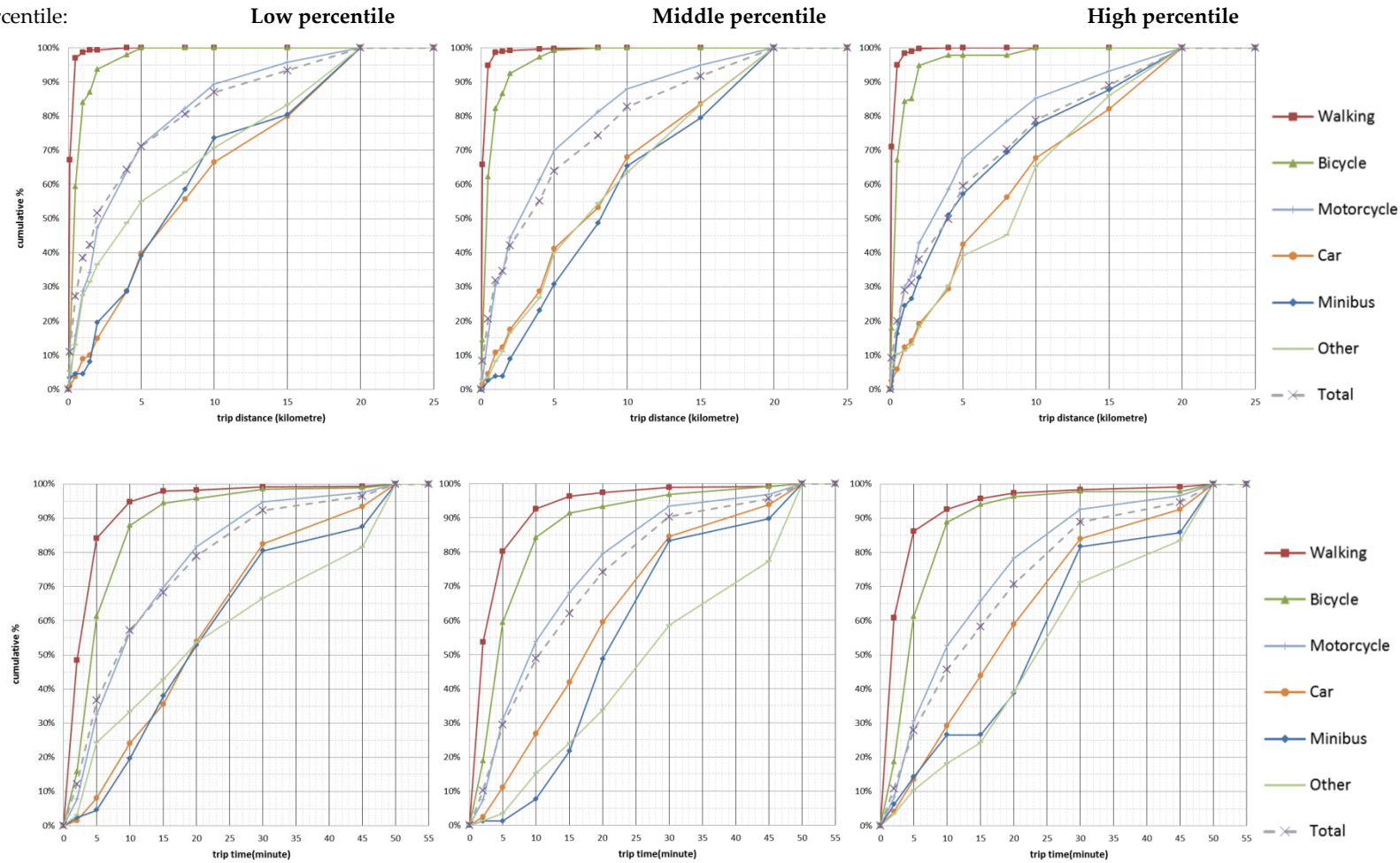
10,000-19,999 Baht

20,000+ Baht



Graph 5-15 Trip distance and time distributions, classified by trip modes and monthly household income percentiles

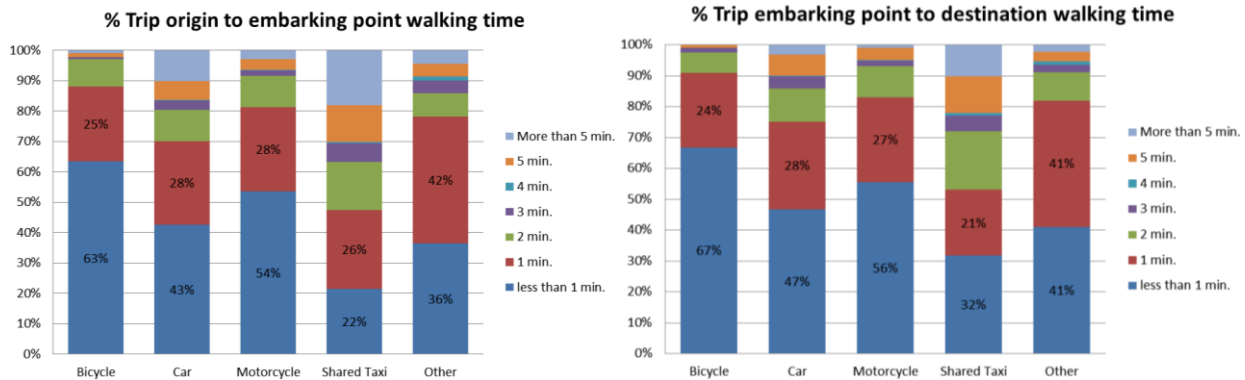
hh income percentile:



5.4. Walking time to/from embarkation points

Knoflachner (2006) proposed a theorem that walking distance to/from parking space can influence mode choice selection. An analysis on walking time to and from embarking point of different modes is made here. The data is from the CM-MTS survey. The results are shown in Graph 5-16.

Graph 5-16 Walking time to/from embarking point of different modes



Analysis of walking time to/from embarking points show the motorcycle can be parked close to their origins and destinations. 82-83% of motorcycle trips can be parked within 1 minute walking time of the starting/finishing point of the journey. By contrast, walking time for the car is 71%-75% within 1 minute. Thus, in accordance to the Equidistance Parking Principle proposed by Knoflachner (2006), the motorcycle has a potentially higher penetration (or ease of access) than the car, as the shorter walking distance makes this mode of transport more convenient. According to Knoflachner's research, it also suggests that the motorcycle may have a stronger 'lock in' or captive effect on drivers than the car as they save more body energy in accessing their vehicle.

Interestingly, the bicycle has the highest penetration (88% and 91% within 1 minute walking and shared-taxi has the lowest penetration rate (48% and 53% within 1 minute walking) among all modes. This means bicycle users utilise the least energy to access their 'vehicle' and using a shared-taxi requires the most energy.

In Table 5-20 the average walking time from origin to embarkation point and from disembarkation point to destination are shown for different areas.

Table 5-20 Average walking time between origin/destination and embarkation points**Walking time from Origin to Embarkation point (min.)**

Mode	Trip origin in			Average Mode
	Municipality	Aumpor Muang	Outer Districts	
Bicycle	0.90	0.76	1.06	0.93
Car	2.20	2.14	1.98	2.12
Motorcycle	1.32	1.35	1.17	1.28
Shared-taxi	2.71	4.13	3.52	3.30
School/work private van	1.67	2.06	1.29	1.65
Other	1.15	2.73	1.53	1.51
Average area	1.58	1.53	1.32	

Walking time from Disembarkation to Destination (min.)

Mode	Trip Destination in			Average Mode
	Municipality	Aumpor Muang	Outer Districts	
Bicycle	0.77	0.72	0.88	0.80
Car	1.62	1.50	1.39	1.52
Motorcycle	1.21	1.10	1.01	1.11
Shared-taxi	2.02	2.32	3.75	2.55
School/work private van	1.49	1.48	1.13	1.36
Other	1.22	0.80	1.32	1.18
Average area	1.32	1.17	1.07	

The results confirm the trends observed previously, the bicycle has the lowest access time at both origin and destinations. The motorcycle has less access time than the car and the shared-taxi has the highest access time among all modes. Additionally, the data also shows that trips originating or finishing in the municipality area have the highest access time than those in Aumpor Muang and Outer District. The lack of parking areas in the central area of the city may have forced the respondents to park further away from their origin/destination. However, in the case of the shared-taxi it is the opposite. Trips with origin/destination outside the city have higher walking time, because the share-taxi only operates on the main roads. Respondents who live away from the main road must walk to hail the shared-taxi along the main roads, which can be quite a journey. Whereas, the road network is denser within the city centre area, thus walking time to reach a point where a shared-taxi can be hailed takes less time. In addition, there are also more shared-taxis within the city centre area.

5.5. *Mobility and Urban sprawl*

Urban sprawl is one of the consequences of an unsustainable transport system. It leads to a longer trip distance and a higher travel time. It makes public transport inefficient and hence it promotes the use of motorised transport. Two analyses made here are related to urban sprawl.

5.5.1. *Urban sprawl and the richer household*

The mobility results presented in this chapter show respondents with higher income have the following mobility trends:

- 1) make more motorised trips,
- 2) have higher average trip distance, trip time, and trip speed,
- 3) have higher average daily trip distance and daily trip time, and
- 4) have slightly higher average number of trips per day

These trends suggest higher income respondents are more mobile. This analysis seeks to examine whether there is a correlation between household income and household location. It is apparent that wealthier respondents were more likely to take advantage of the cheaper land price at the outer area of the city and thus make longer trip distances with faster modes of transport. In other words, the analysis here investigates whether the richer respondents have a higher influence than other income groups in encouraging urban sprawl outside the city.

First, the average land price for each the three areas of Chiang Mai city was determined. Data was obtained from two sources: the internet and information provided by the ICM. Attempts were made to obtain more accurate data from the treasury office but the procedure required was too complicated. This exercise is to provide the probable relative different in land price across the three areas. To this end, the data available from the two sources should be sufficient. Comparison of the two sources of data is made in Table 5-20.

Table 5-21 Average land price for different area of Chiang Mai city

Area	Average Price per sq. m. (Euro)	
	Internet (index)	ICM (index)
Municipality	554 (11.7)	496 (13.7)
Aumpor Muang	271 (5.8)	240 (6.7)
Outer areas	47 (1)	36 (1)

Note: 1 Euro = 40 Baht (2012 rate)

Source: <http://www.ddproperty.com> , <http://www.teedinchiangmai.com/> and ICM

The two sets of land price data show a similar trend: the land price in the municipality area is most expensive and the outer area is the cheapest. The difference between the highest price and the lowest price can vary by a factor of up to 14 times. Thus, it may be thought that the lower land price in the outer areas would prove a strong incentive to move away from the city centre

Next, the proportion of household income percentile in each area is analysed. The analysis between household income and household location is shown in Figure 5-1.

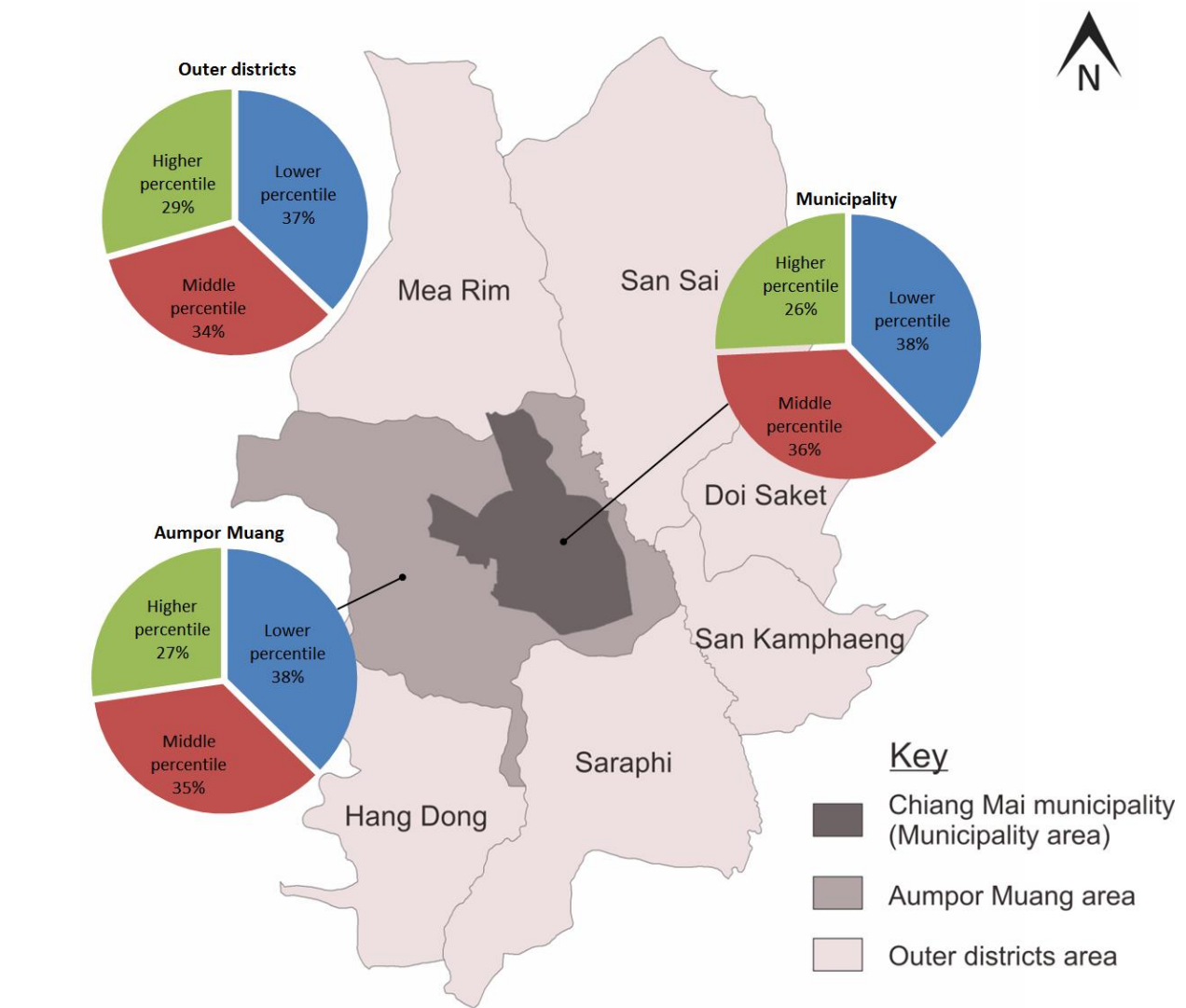


Figure 5-1 Household location and Income percentile of respondents

The figure shows that there are similar distributions of income percentile across the three areas, with the outer area has slightly higher proportion of richer households (29%) than other areas considered. The result provides some support for the hypothesis that the rich drive urban sprawl; however, the percentage differences are not sufficient enough to

draw a definitive conclusion on the matter. Moreover, there are limitations on the CM-MTS survey, especially in its ability to gain access to gated communities situated in the outer districts area. Thus, additional data on the distribution of household based on its income will improve this analysis and enable a more definitive conclusion to be made.

Lastly, the mobility pattern of the three income groups is analysed to find any further evidence that may support the hypothesis. Table 5-21 shows the average trip time and trip distance by trip purpose for different income percentiles.

Table 5-22 Average trip time and distance of different income percentiles (by trip purpose)

Trip purpose	Income percentile	Trip time (min)	Trip distance (km)
Work trip	Lower	15.3 (1.0)	5.5 (1.0)
	Middle	17.9 (1.2)	6.9 (1.3)
	Higher	18.5 (1.2)	7.5 (1.4)
School/University trip	Lower	21.1 (1.0)	7.0 (1.0)
	Middle	21.7 (1.0)	7.5 (1.1)
	Higher	21.5 (1.0)	8.4 (1.2)
School run	Lower	16.9 (1.0)	6.0 (1.0)
	Middle	18.4 (1.1)	7.1 (1.2)
	Higher	20.0 (1.2)	7.1 (1.2)
Shopping	Lower	10.4 (1.0)	3.1 (1.0)
	Middle	12.9 (1.2)	3.9 (1.3)
	Higher	13.6 (1.3)	4.8 (1.6)
Going home	Lower	15.2 (1.0)	5.0 (1.0)
	Middle	17.4 (1.1)	6.0 (1.2)
	Higher	18.8 (1.2)	6.9 (1.4)
Other	Lower	11.7 (1.0)	3.7 (1.0)
	Middle	13.0 (1.1)	3.7 (1.0)
	Higher	16.5 (1.4)	6.2 (1.7)

Note: the numbers in parenthesis are indexes to the lower group of each trip purpose and bold text signify the highest values in each trip purpose

The differences across the three income percentiles have a consistent pattern for most trip purposes; the higher income group has higher average trip length and trip time. In only one trip purpose (school/university trip) can a different pattern be observed.

The trend of the trip distance suggests the higher and middle income groups tend to travel between 20%-70% longer distance and 10-40% longer time than the lower income group. Another interesting pattern observed is that for school/university trip, the travel time seems to be similar across the three income groups. Nevertheless, the trip distances for this purpose follow the same pattern with other trip purposes. This suggests that the choice of school/university is govern strongly by travel time budget. The higher average distance

of the higher income groups also suggests that these groups utilise transport modes with higher speed.

The findings of the analyses here seem to present evidence that support the hypothesis that the richer residents have higher contribution toward urban sprawling than other groups. However, further analysis should be made to affirm this suggestion, as the analyses have several limitations inherent in its data.

5.5.2. Relationship between urban sprawl, vehicle ownership, and vehicle use

Newman & Kenworthy (1991) made a well-known demonstration that increases in petrol use decreases the urban density exponentially. Here, similar analysis is attempted to ascertain the relationship between transport and land use by examining vehicle ownership in the urban area and vehicle use within Chiang Mai city. In this analysis, the urban areas are those designated as such by the city authorities. The designation may not reflect the actual urbanised area, but it does reflect, with a high degree of accuracy, the city's built-up area. The vehicle ownership values are calculated from the number of vehicles registered within Chiang Mai province. The vehicle use values are the VKT on highways within the province only, as VKT on other type of roads has not been recorded. The data starts in 1951 being the year the first highway in Chiang Mai was opened for use.

Firstly, a simplified analysis is made, to demonstrate the need for a motorised mode of transport capable of travelling at higher speed, as the size of the city increased. The analysis looks at the travel time and speed of a return trip from home to the city centre of an imaginary resident who always lives at the edge of the city. The official area of Chiang Mai city is converted to a circle of the same geographical area. The radius of the circle is calculated and converted to walking time. The walking time taken for a round trip along the radius of the circle to and from the centre of the city in the year 1923 is used as the base point. From this the travel speed necessary to maintain travelling time at the same level, has been calculated. To keep it simple, the calculation assumes the increase in city area does not affect its land use, i.e. the residents continue to travel to the centre as the crow flies. In addition, it is assumed that average walking speed is 3 km per hour, a conservative value, which takes into account the hot climate of Chiang Mai city. Table 5-22 details the result of these calculations.

Table 5-23 Speed required to contain travel time from the edge of the city area to its centre at 40 minutes as urban area expands

Year	Urban area (Sq. km.)	A round trip distance from the edge of the circle to the centre or 2 x Radius (km)	Walking time (min)*	Speed needed to maintain travel time at 40min (km/hr.)
1296	3.2	2.0	40.4	3.0
1923	3.2	2.0	40.4	3.0
1935	17.5	4.7	94.4	7.0
1965	29.2	6.1	121.9	9.1
1975	29.2	6.1	121.9	9.1
1982	29.2	6.1	121.9	9.1
1983	40.2	7.2	143.1	10.6
1983*	106.3	11.6	232.6	17.3
1990	430.0	23.4	467.9	34.8
2012	430.0	23.4	467.9	34.8

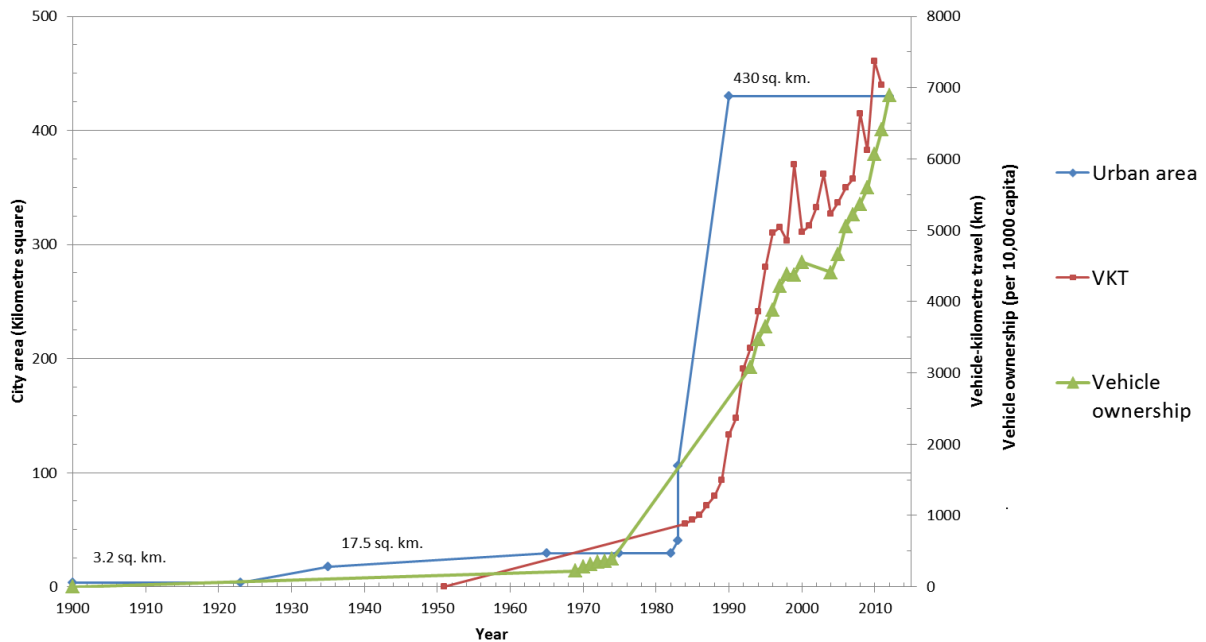
Note: Assumes a conservative 3 km/hr. walking speed to take account of walking in average temperatures of 30C

* the official city area expanded twice in 1983

The result shows that beyond 1965, it became impossible to cover the distance within the given time by walking. The bicycle provided a viable transport mode in 1923 with its average speed of 15.5 km/h. However, from 1983 motorised modes are the only viable option. In other words, motorised vehicles become an essential for residents from 1983 onwards. This simple analysis demonstrates a probable correlation between the increased urbanised area of the city and motorised vehicle ownership from 1990 onwards.

Next, three sets of data - the official urban area, the VKT, and vehicle ownership - are plotted together in Graph 5-17. Vehicle ownership data needs to be adjusted to fit on the same scale by use a multiple factor of 10, thus ownership values are shown as the number of vehicles per 10,000 capita. The graph starts at the beginning of the motorised period (1900) until the present. It is assumed that vehicle ownership within Chiang Mai province is 1 in 1900, the year Thailand imported its first car. The provincial data is used here because of the lack of vehicle ownership data at the city level.

Graph 5-17 Official urban area, vehicle-kilometre travel (VKT) on the national highways, and vehicle ownership (per 10,000 capita) of Chiang Mai province



Note: In 2004, the DLT introduced a regulation to deregister vehicles when the registered owner failed to pay tax for three years or more. As a result the DLT records between 2001 and 2003 are not included here as the records in this transitional phase, within which the new regulation was implemented, created a considerable amount of ambiguity in the administrative system.

Source: Data from Department of land transport and (Nimnual, Srisakda, & Satayopas, 1980; Pintapun, 2002)

Graph 5-17 suggests a positive correlation between the two entities; the increase in the urbanised area increases vehicle ownership. The pattern of the graph suggests that there are indeed positive correlations between the three sets of data. They increase exponentially in the period 1970-1990 with an estimated time lag of around 6 years between land use and transport changes.

This result supports the land use – transport theorem but the missing data makes it difficult to carry out further analysis and to establish the causation between the entities. Inclusion of VKT data between 1950-1984 and vehicle ownership data between 1974-1993, will help to identify the exact period at which the exponential growths occurred and provide an improved estimation of the time-lag between the changes of the two entities.

5.5.3. Urban sprawl in the motorcycle dominated city

High automobile dependency and urban sprawl are two entities which are widely believed to be connected. Several studies, such as Batty, Besussi, & Chin (2003); Glaeser & Kahn (2004); Melosi (2004); Newman, Kenworthy, & Vintila (1995); and Salingaros (2006)

purport the causal relationships between increased car ownership and urban sprawl. One of their common standpoints is that a reduction of transport costs derived from owning motorised vehicles enables urban residents to maintain their accessibility to their places of employment, even when these become quite distant. Thus, it encourages a city's residents to move away from the central area toward the urban fringe where ample amount of land is available at a cheaper price, which consequently causes the city to sprawl.

For a city with high motorcycle domination like Chiang Mai, it is questionable whether the attributes of urban sprawl here will be different from those observed elsewhere. The analyses of trip distance and trip time distributions made in this chapter have shown that non-motorised transport, motorcycles, and motorised four-wheelers have unique trip distance and trip time distributions. These differences point towards the possibility that urban sprawl in a motorcycle dominated city should be different from those dominated by car. However, a brief literature review found no relevant reference covering this subject. Nevertheless, some pragmatic estimation can be made by considering the nature of motorcycle trips revealed earlier. Some mobility indicators of the car and the motorcycle are compared in Table 5-23.

Table 5-24 Mobility indicators comparison between car and the motorcycle

Indicators/Trip mode	Motorcycle	Private car	Different ratio (mc : car)
Average trip time taken (min.)	14.9	23.3	0.6
Average trip distance (km)	5	10	0.5
Average trip average speed (kph)	19.1	26	0.7

The comparison shows that the mobility indicators of the motorcycle and the car differ by the magnitudes of 0.5 to 0.7. If we assume that 1) the relationship between transport and land use is linear and 2) the urban sprawl and speed of travel has a direct correlation, a motorcycle-driven urban sprawl should have around 30-50% less magnitude than a car driven sprawl. However, it is difficult to isolate the effects of the motorcycle as the presence of the car is inevitable. Moreover, sprawling is believed to be driven by richer members of the population who utilise cars more than other income groups. The pragmatic approach made here provides only a rough estimate of the effects of urban sprawl from the high dependency on motorcycles alone.

5.6. ***Analyses findings and discussions***

The following findings can be drawn from the analyses in this chapter:

- a) *Trip purpose influences trip mode selection*; there is a clear correlation between the two entities; certain trip purposes are more motorised than others. For example; School run trips have the highest proportion of motorised transport trips (98%), even it does not have the highest average trip distance nor trip time. It shows there are social and other factors that are linked with a particular trip purpose. For example, the need for children to travel in a degree of comfort and perceived safety influences the school run transport mode selection. These factors are subjective but seem to receive a higher weighting than objective factors, such as trip time and trip distance. The perceived safety and convenience are perhaps prioritised here as parents are taking their children with them on their way to work.
- b) *Residing in an area with higher density may not lead to a lower number of private motorised trips, but it reduces trip distance and trip time*. This finding is in contrast to a generally held belief that residents in high density area encourage non-motorised trip's utilisation, such as that suggested by Lawson (2007). Yet the respondents living within the municipality area, which has highest density, were found to have the lowest proportion of non-motorised transport trips (15%, compared with the outer districts' 25%); 60% of their trips are made by motorcycle. The high use of motorcycles within the municipality is thought to be the result of numerous factors, such as lack of quality footpaths and the need to substitute travel speed/time for lower rent cost and the need for flexible trip range (See Chapter 4.5d). The analysis also finds that those living in the municipality made shorter and closer trips to home than respondents in other areas. In addition, they also have lower average daily trip distance and trip time.
- c) *Trip mode has a strong correlation with trip distance and time and the motorcycle is preferred for intermediate trip ranges*. Trip distance and trip time distributions analysis reveals that motorcycle trips have an intermediate distance range in relation to non-motorised and motorised four-wheelers modes. The distributions show a well-defined pattern that separated out non-motorised

modes, the motorcycle, and motorised four-wheelers. The results also suggest that trip distance and time has a strong correlation to trip mode, i.e. non-motorised trips have lower average trip distance and trip time than car trips, while motorcycle trips lie in the middle between the two.

- d) *Shared-taxi has similar trip distance and time distributions to car.* Several analyses above show that shared-taxi trips' distributions closely resemble those of the car. It is also apparent there are anomalies within the shared-taxi data, which stem from its small sample size.
- e) *Household income affects mode choice and mobility behaviour.* Respondents with higher household monthly income seem to utilise more private motorised modes. For instance;
- the lower income group made more trips with non-motorised mode and by motorcycle,
 - the middle income group utilised motorcycles the most and cars to a lesser extent,
 - the higher income group uses cars and motorcycles in equal proportion

Household income also seems to have positive correlations with several mobility indicators; such as, 1) trip distance, 2) trip time, 3) trip speed, 4) daily trip distance, and 5) daily trip time. However, household income seems to have minor effects on trip distance and trip time distributions.

- f) *Registration status has an effect on trip modes but to a lesser extent on other mobility indicators.* Non-registered respondents seem to utilise more of the motorcycle mode (61%, compared with 50% by registered respondents). However, the differences between the two groups are more subtle across other types of mobility indicators.
- g) *Female respondents made shorter, closer, and slower trips.* Female respondents made trips that are 15% closer to home, 9% shorter in distance and 13% slower in time than their male counterpart. They also cover 16% less distance and overall use 9% less trip time daily. Additionally, they made more non-motorised trips and used shared-taxi more.

h) Trip mode and trip distributions have strong correlations

Among the various factors considered in the trip distribution analyses, the effect of trip mode is the most prominent. The ranking of the six factors considered according to their influence is: trip mode, trip purpose, monthly income, household location, sex, and registration status (strong to weak).

i) Motorcycle driven urban sprawl may have a lower magnitude than car-driven urban sprawl

Based on the generally held assumption that urban sprawl has a linear relationship with mobility attributes, it can be estimated motorcycle-driven urban sprawl will have between 30-50% less magnitude than car-driven sprawl.

j) Richer households drive urban sprawl

A cross analysis between household income and its location suggests that richer households take advantage of cheap land in the outer districts and accept increased travel distance and time as a trade-off.

k) Interconnectedness between urban area, vehicle ownership, and vehicle use

Analysis on urban area, vehicle ownership, and vehicle use of Chiang Mai city shows motorised transport became a necessity in 1983. The analysis also reveals a positive correlation between the three elements. In addition, a time lag of 6 years is estimated between urban area and transport infrastructure developments.

l) High convenience of the motorcycle and potential of the bicycle

Analysis of walking time to and from embarking points shows motorcycle trips have lower access time than using a car. Thus, the motorcycle can potentially save more body energy than the car, i.e. it is more convenient to use. Nevertheless, this convenience is also a threat to the environment as the motorcycle competes with non-motorised modes causing more carbon emissions.

The analysis also shows that the bicycle has the lowest access time. This finding is logical given the smaller form factor and lighter weight of the bicycle, thus it can be parked closer to home and easily stored. Based on Knoflacher's principle (2003), the lowest access time already gives the bicycle an advantage over other modes. The low percentage of bicycle riding in the city has to be explained by other factors, such as the perception of safety

or the desire to ride in comfort. Efforts must be made to improve road conditions to promote more use of the bicycle, e.g. creation of more bicycle lanes.

k) Accuracy in walking time/distance estimation

The validation of trip data shows that walking trips have the lower percentage of valid trip speed; only 56% of them are within a valid speed range (under 5 km/hr.), compared with the average of 85% for all modes. This inaccuracy may be due to the rounding errors which have more significant effects on trips with shorter distance and time. Additionally, it is also likely that there are stronger resistances that distort the perception of space and time in walking trips than other modes.

The observations in this chapter reveal interesting characteristics of the city's transport system. It provides many findings both in the form of correlations and isolated attributes. These provide valuable inputs into finding solutions to the city's transport problem.

Up until this point, the focus of my thesis has been on understanding the development path and the present status of the city. In the next chapter, the city's transport problems are looked into from a system perspective.

6. Understanding Chiang Mai city's transport problems

6.1. *Introduction*

In this chapter a system approach analysis of the city's transport problem is carried out to complement the detailed analysis of the previous chapters. The system approach is used here to gain a new line of enquiry and new insights into finding different transport solutions other than the reductionist approach taken by previous studies.

In Chapter 6.2, the conventional definitions and meanings of urban transport problems are studied to provide a starting point. A concise literature review is carried out to provide a catalogue of transport problems and their likely causes and effects. The interconnections between the categorised entities are then mapped using the Causal Loop Diagramming (CLD) technique. In Chapter 6.3, the understanding gained in the previous chapter is applied to Chiang Mai city by using the city's data to validate the generic CLD. Chapter 6.4 describes the process used to interview decision makers who have responsibility for transportation services in Chiang Mai. The aim is to gain an insight into their understanding of the transport and sustainability issues and to compare it with the understandings gained in the previous chapters. The interviews focused on these decision makers because of their influential roles in shaping the city. Additionally, the comparison should reveal any improvement required to improve the decision makers' understanding of the issues. Chapter 6.5 provides a brief conclusion to this exercise.

6.2. *Conventional definitions of urban transport problem*

Transport problems in urban areas have a long history. They can be traced back as far as the time of the Roman Empire when traffic delays and congestion was common in ancient towns and cities such as Rome. Early attempts to legislate for a solution to these traffic problems are found in many documents from the period, including *Lex Julia Municipalis*, the best-known set of Roman traffic regulations. *Lex Julia Municipalis* was introduced between 90 and 45BC, and limited the times during which wagon traffic could access the streets of Rome. In addition, it formalised the segregation of pedestrians and "vehicular" traffic, with the introduction of sidewalks and roadways (Tilburg, 2007).

It is likely that there was already a high amount of transportation activities in Chiang Mai city in its early period. Historic records show that the Mangrai code, a set of civil law

and regulation established by King Mangrai shortly after he founded Chiang Mai city, contains traffic regulations. It entails enforcements, regulations, and conflict resolutions specifically for pedestrianisation, travel and movement of goods using animals, and river transportation (na Chiangmai, 1995; Siri, 2007).

Many cities today suffer transport problems. Some of these problems are ancient ones, such as traffic congestion and insufficient parking space. Others are more contemporary, such as the effect of transport on the environment, increases in commuting distance, and high dependency on the use of private vehicles. Various measures and 'tools' have been devised to solve urban transport problems, yet the number of cities suffering from such conditions is on the rise and with increased severity. This situation provides sufficient grounds to review our understanding as to why this should be the case.

This chapter begins by defining the term: "urban transport problem". An urban area or a city can be defined either by reference to an area's demographic characteristics (size and density) or by its function (wideurbanworld, 2011). However, there are variations in the size and density thresholds used to define a city. For example, Japan defines its urbanised area as contiguous areas of densely inhabited districts with a density of 4,000 inhabitants per square kilometre (Statistics Bureau, 2013), while China's threshold is 1,500 inhabitants per square kilometre (S. Liu, Li, & Zhang, 2003). Nevertheless, an urban area or city can be defined broadly as an area with a higher population density and a greater variety of functions than its surrounding area.

The term "transport" is generally used in relation to the means by which goods, people and/or animals are moved or carried from one location to another (Dictionary.com, 2012b). Transport is rarely a goal in itself; it is a means of travelling over distances in order to undertake intended activity. The conventional modes of transport are aviation (plane), road (car, motorcycle, bicycle, walking), rail (train), and maritime (boat and ship). In the modern age, pipeline, cable, and telecommunication might also be considered as another means of transporting and delivering information and services.

A problem can be defined as "any question or matter involving doubt, uncertainty, or difficulty" or "a question posed for solution or discussion" (Dictionary.com, 2012a). Although it is often stringed with a negative connotation, a problem can also be presented as an opportunity for change, innovation, and advancement.

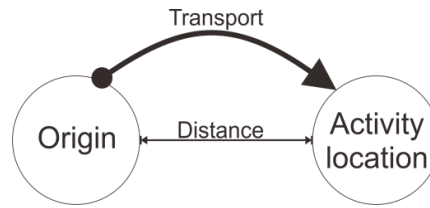


Figure 6-1 Transport – a means to overcome distance

Combining the meanings of these three terms produces the following definition of urban transport problem: *a condition whereby the act of transporting something from its point of origin to the desired location is hindered by time lags and physical constraints characteristic of a densely populated area.*

6.2.1. Transport problems catalogue

In this chapter a brief literature review is carried out to catalogue transport problems, their likely causes, and their effects. Table 6-1 summarises the results of the review, which includes additional comments from the author.

Table 6-1: Conventional urban transport problems

Transport problem	Likely causes	Likely effects
Traffic congestion (decreased travel speed)	<ul style="list-style-type: none"> • Demand exceeds supply of transport or a random event that disrupts traffic flows 	<ul style="list-style-type: none"> • Make vehicle use unattractive • Increase travel time • Decrease effectiveness of energy usage
Insufficient parking space	<ul style="list-style-type: none"> • Demand exceeds supply for parking space 	<ul style="list-style-type: none"> • Make vehicle use unattractive • Increase travel time and distance
Increased travel distance	<ul style="list-style-type: none"> • Urban sprawl – decrease of city density and parking space 	<ul style="list-style-type: none"> • Increase travel time
Increased travel time by vehicle	<ul style="list-style-type: none"> • Increase in travel distance • Decrease in travel speed (congestion) 	<ul style="list-style-type: none"> • Increase fuel consumption and externalities • Increase trip generalized cost (i.e. time and money) • Induce stress and other health related problems
Inadequate public transport and service quality	<ul style="list-style-type: none"> • Lack of investment • Increase in congestion/unpunctuality 	<ul style="list-style-type: none"> • Increase vehicle use • Decrease public transport ridership
Hindrance of non-motorised transport modes (walk/cycle)	<ul style="list-style-type: none"> • Worsening of walking environment • Increase trip distance (i.e. urban sprawl) 	<ul style="list-style-type: none"> • Increase private vehicle use • Increase health related problems
Land consumption by the transport sector	<ul style="list-style-type: none"> • Increase demands for parking space and road infrastructures 	<ul style="list-style-type: none"> • Reduce land for other activities, such as housing and public space, • Increase land price
Environmental impact (i.e. air pollution and noise)	<ul style="list-style-type: none"> • Increase vehicle use 	<ul style="list-style-type: none"> • Reduce quality of life in the area • Decrease walking and cycling mode trips
Energy consumption (fuel and other substances)	<ul style="list-style-type: none"> • Increase vehicle use 	<ul style="list-style-type: none"> • Increase energy dependency (if import) • Transport cost • Transport externalities

Table 6-1: Conventional urban transport problems (continue)

Transport problem	Likely causes	Likely effects
Accident and fatality	<ul style="list-style-type: none"> • Increase of average network speed, • Increase in vehicle use • Decrease in motorist's discipline • Badly designed infrastructure 	<ul style="list-style-type: none"> • Increase social and economic costs
Political hindrance (decision makers are obliged to support provision of private vehicle facilities)	<ul style="list-style-type: none"> • High vehicle use 	<ul style="list-style-type: none"> • Increase in vehicle infrastructure, such as road and car parking spaces

Source: based on (Rodrigue, 2012; Zavitsas, Kaparias, Bell, & Tomassini, 2010)

It is apparent from the results in Table 6-1 that different entities within urban transport problems are interconnected. These connections are examined next.

6.2.2. Interconnectedness between transport problems

The Causal Loop Diagram (CLD) technique⁵⁴ is employed here to illustrate the relationships between different transport problems and entities summarised in Table 6-1. Figure 6-2 shows the CLD of the Transport problem, which reflects the accounts of Rodrigue, (2012); Zavitsas, Kaparias, Bell, & Tomassini, (2010) and the author's views of the subject.

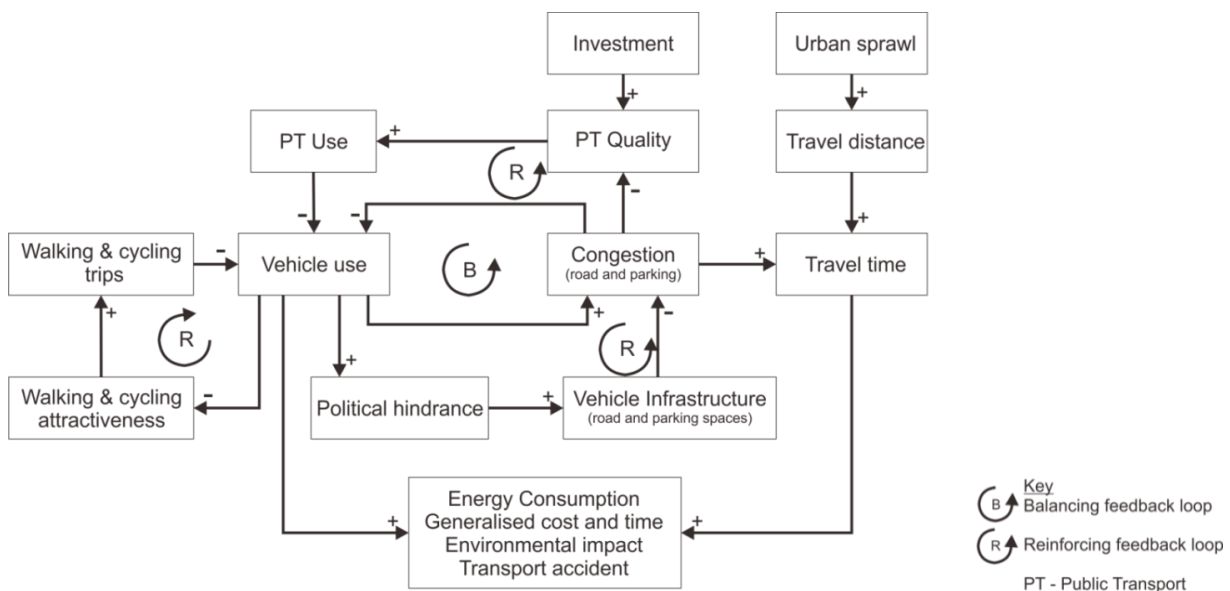


Figure 6-2 Transport problem CLD (First version)

⁵⁴ Causal Loop Diagram (CLD) is a comprehensive thinking tool which, when applied in a systematic manner aids decision making. It helps provide a deeper understanding of complex cause-effect relationships, hence enabling more effective problem solving.

The CLD shows that the entities form four feedback loops; one balancing and three reinforcing loops.

Further comparison of the CLD above with that presented by (Morichi & Acharya, 2012, p. 61) in Figure 6-3 demonstrates several possible improvements, such as the inclusion of urban sprawl and vehicle ownership into the feedback loops. Figure 6-4 shows the author’s revised transport problem CLD.

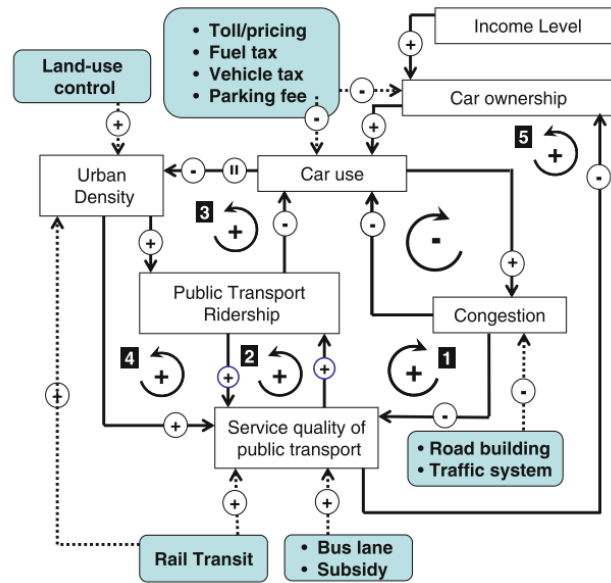


Figure 6-3 Transport problem CLD by Morichi & Acharya, (2012, p. 61)

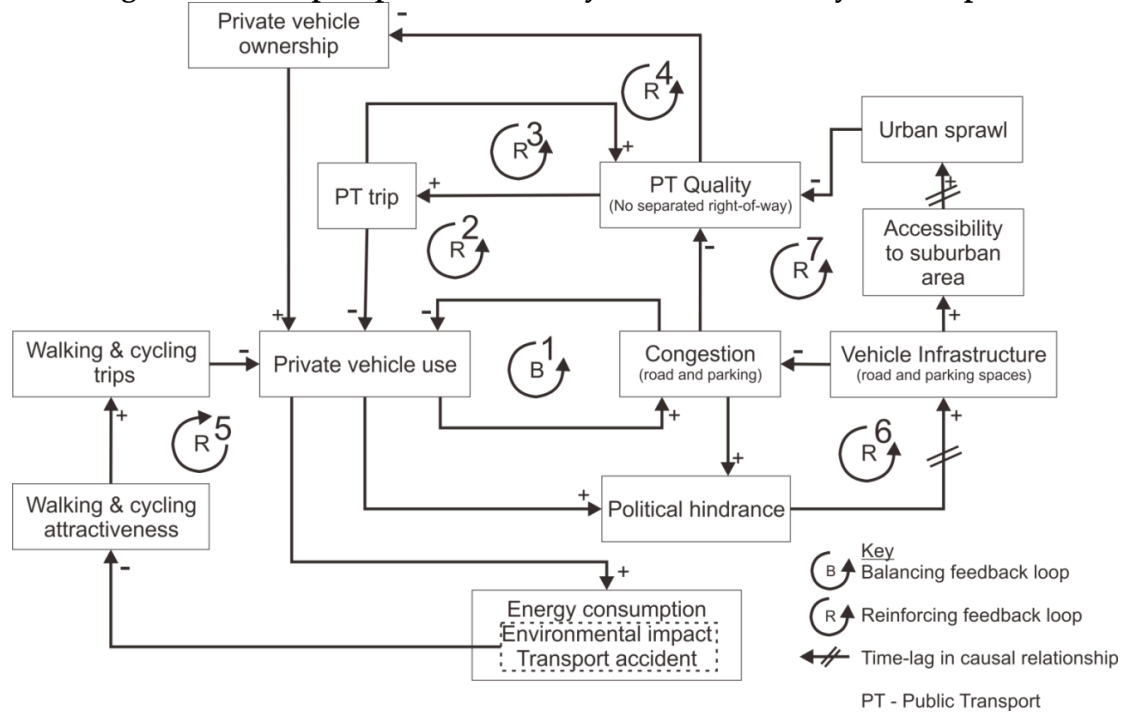


Figure 6-4 Revised transport problem CLD

Several assumptions were made to simplify the CLD, they are:

- The boundary of the CLD is the urbanised area of a city
- The public transport system is exclusively a road-based system, without a separated right-of-way.
- Private vehicle is comprised of the motorcycle and the car
- Public transport is comprised of the public bus and also the shared-taxi
- Punctuality is the only aspect of Quality of Public transport considered here.
- Accessibility to the suburbanise area of the city is the main factor that induces urban sprawl
- There is no 'lock-in' factor that prevent modes shift, i.e. residents can freely shift their modes of transport.
- External factors, such as income level are not included

The reading of this CLD should begin at *Private vehicle use*. Under a level of transport supply, increased *Private vehicle use* will increase *Congestion* i.e. a condition which exists when demand exceeds supply in road and parking spaces. The increase of *Congestion* may in turn reduce the *Vehicle use* as it increases travel time, making the private vehicle a less attractive means of travel. These two entities form a balancing feedback loop (Loop B1), which seeks to achieve or maintain a goal (Sherwood, 2002; Sterman, 2000).

An increase in *Congestion* will decrease the frequency and punctuality of public transport services (PT), i.e. it reduces the *PT Quality* of service. The decrease in the *PT Quality* of service will decrease *PT use* and encourage an increase in *Private vehicle use*, as users seek a more reliable mode of transport. This forms a reinforcing feedback loop (Loop R2). This type of feedback loop drives either an exponential growth or exponential decline, depending on what triggered it in the first place (Sherwood, 2002; Sterman, 2000). Additionally, a decrease of *PT use* will decrease *PT quality* as the income from fares declines along with a subsequent decrease in the amount of cash available to reinvest into the PT system (Loop R3).

In similar fashion, an increase in *Private vehicle ownership*, as a result of deteriorating *PT Quality*, will increase *Private vehicle use* (Loop R4). An increase in *Private vehicle use* will increase the level of *Energy Consumption*, *Environmental impact* and *Transport accidents*. An increase in these entities will decrease the *Walking and cycling attractiveness* and the *Walking and cycling trips*, hence further increasing *Private vehicle use* (Loop R5).

An increase in *Private vehicle use* also increases *Political hindrance* or put pressure on the city's decision makers to provide additional vehicle infrastructure to maintain support from their voters. An increase in *Vehicle infrastructure*, such as road or car park construction reduces *Congestion* by increasing the system's capacity. However, in the long run the level of *Private vehicle use* increases as the reduced congestion level induces more vehicle use (Loop R6).

The increase in *Vehicle infrastructure* over time will increase the *Accessibility to suburban area* around the city. This will encourage *Urban Sprawl* as residents move out of the urbanized area to seek cheaper land and housing. An increase in the *Urban sprawl* decreases the *PT quality* as public transport systems usually operate more effectively in denser areas (Loop R7).

The CLD shows six balancing loops and one reinforcing loop, the choices made by travellers determine how these loops interact and how strong each one is in relation to the other. The analyses of conventional transport problems, as defined, and their interconnectedness in this chapter illustrates the complexity of the subject. There are a wide range of conditions that can be defined as being a transport problem. Moreover, there is multifaceted connectivity between these different conditions (or the entities that cause them). An attempt to improve certain conditions in the short term may lead to a worsening of the overall condition in the medium or long term. Rigorous application of the CLD by transport decision makers leads to greater understanding of the complexities involved in the problem. This in-depth situation analysis would result in decisions that transform undesirable transport conditions effectively and efficiently.

6.3. Validation of the CLD using Chiang Mai city data

In this chapter, the CLD constructed in the previous chapter is validated with the aim of adopting the CLD as a qualitative model. Four entities within the CLD have been selected for this validation process, namely, *Private vehicle use*, *Private vehicle ownership*, *Urban sprawl*, and *Vehicle infrastructure*. The selection is based on the availability of relevant data and the importance of each these entities within the model's mix. The positions of these entities within the CLD are shown on Figure 6-5.

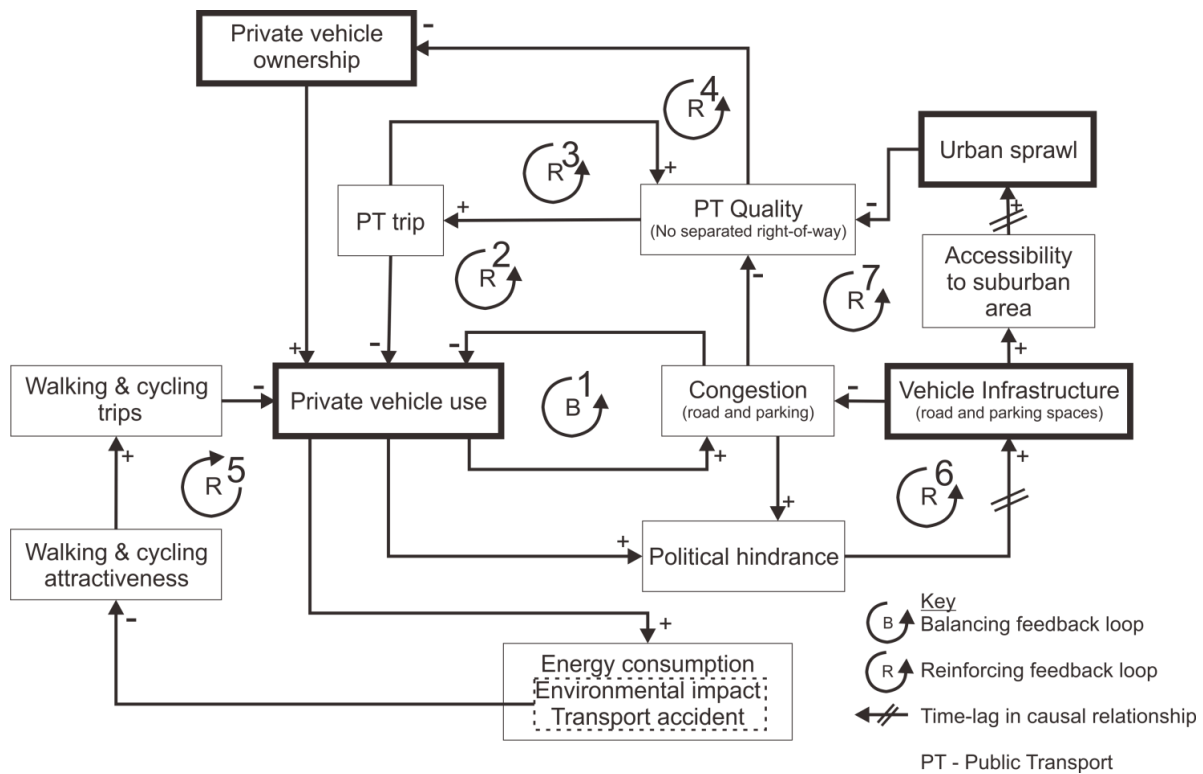


Figure 6-5 Four entities considered in the analysis (in bold border)

In summary, the examinations in this chapter concentrate on validating the causal relationships between the following entities:

- Private vehicle use and vehicle infrastructure
- Vehicle infrastructure and urban sprawl
- Urban sprawl and private vehicle ownership
- Private vehicle ownership and private vehicle use

The data presented in this chapter specifically relates to Chiang Mai province and is sourced from publicly available information within the Province and national government departments/agencies.

Private vehicle use and vehicle infrastructure

Vehicle-kilometre travel or VKT is a measurement of traffic flow, determined by multiplying the number of vehicles on a given road or traffic network by the average length of their trips measured in kilometres.⁵⁵ It is used here to arrive at an aggregated level of vehicle use. VKT data for roads within Chiang Mai city was not available at the time of

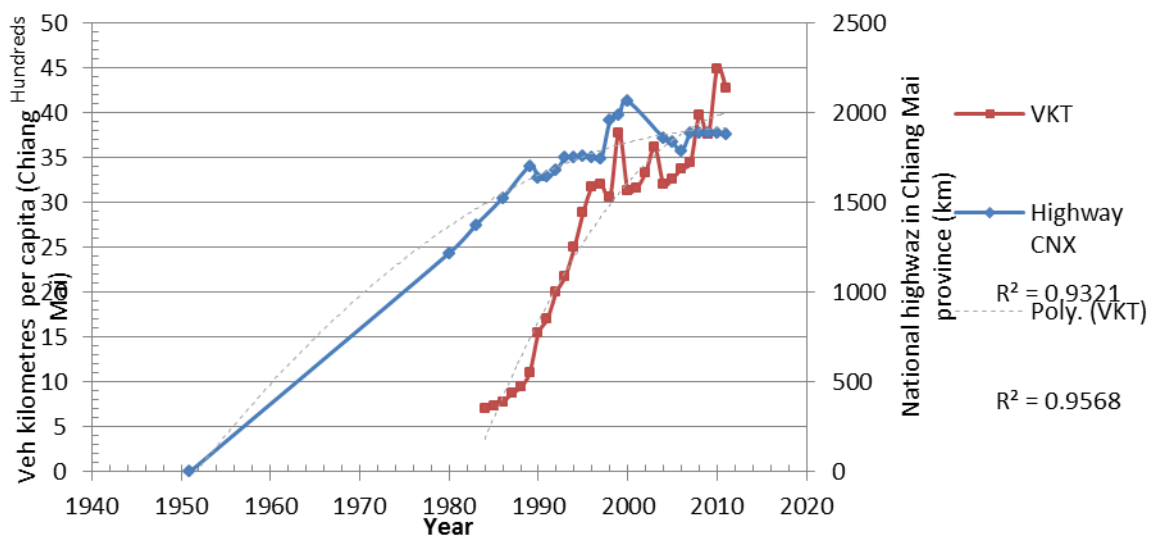
⁵⁵ [Adapted from Eurostat, ECMT, and UN/ECE. 1997. Glossary for Transport Statistics. Document prepared by the Inter-secretariat Working Group on Transport Statistics, Second edition]

writing, therefore the VKT values of the national highways within Chiang Mai province is used instead to represent the city's vehicle use.

It is assumed in this analysis that the national highway's length prior to 1951 was equal to zero, because the technology to construct modern highway was imported into Thailand in this year (Pintapun, 2002). In 1952, the government introduced National Highway construction legislation that led to a rapid increase in the total length of national highways. The reductions in the national highway's length in 2000-2005 were due to the government's policy of transferring ownership of highways to their local administrations. However, further transfer of ownership appears to have been delayed after several of these highways were found to be deteriorating. This is because local administrations do not have adequate skills, knowledge and/or resources to maintain them.

Graph 6-1 shows the relationship between the VKT per capita on the national highways and the national highway's length within Chiang Mai province. The graph shows that the total length of all highways within the province stabilised after 2007, while the VKT value has continued on an upward trend. It shows a positive correlation between the two entities. In addition, it implies that an increase in the highway's length results in an increase in VKT with some time lag. It was not possible to estimate this time lag with any precision because of the lack of accurate information on the VKT and the highway's length data at city level.

Graph 6-1 Annual VKT per capita on the national highways within Chiang Mai province and the highway's length



Source: VKT and National Highway length from Department of Highway and population from CM-NSO

Vehicle infrastructure and urban sprawl

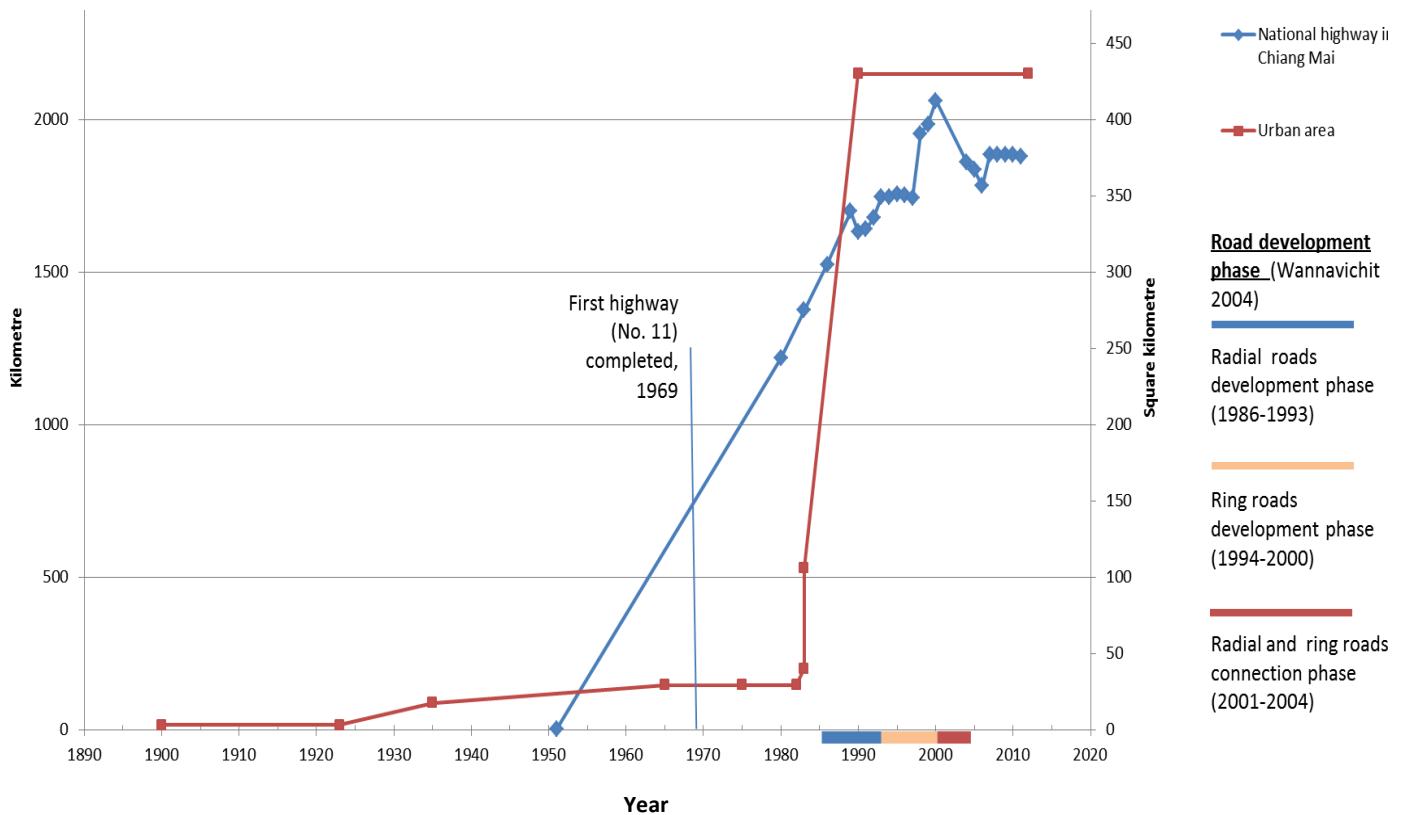
The causal relationship between the Vehicle infrastructure and the urban area is observed in this chapter. Table 6-2 contains a summary of the official area of urbanised development of Chiang Mai city.

Table 6-2 Timeline of Chiang Mai city urbanised area

Year	Description	Urban area (km ²)	Index
1296	Established as the Capital of Lanna Kingdoms	3.2	1
1923	Became a dominion of Siam, promoted to Sanitary district	3.2	1
1935	Became part of Thailand, promoted to municipality	17.5	5.5
1965	Created First City Plan (began 1965, finished 1968)	29.2	9.1
1975	Created the Principle City Plan 1975-1989?	29.2	9.1
1982	Designated a primary city by 5th NESDP	29.2	9.1
1983	Expanded the municipality boundary	40.2	12.6
1983	Revised and enforced The Principle City Plan	106.3	33.2
1990	2nd revision of the Principle City Plan	430	134.4
2012	3rd revision of the Principle City Plan	430	134.4

Source: modified from (D. Charoenmuang, 2007)

Graph 6-2 National highways length within Chiang Mai province and the city area



Source: Highway length data obtained from Department of Highway

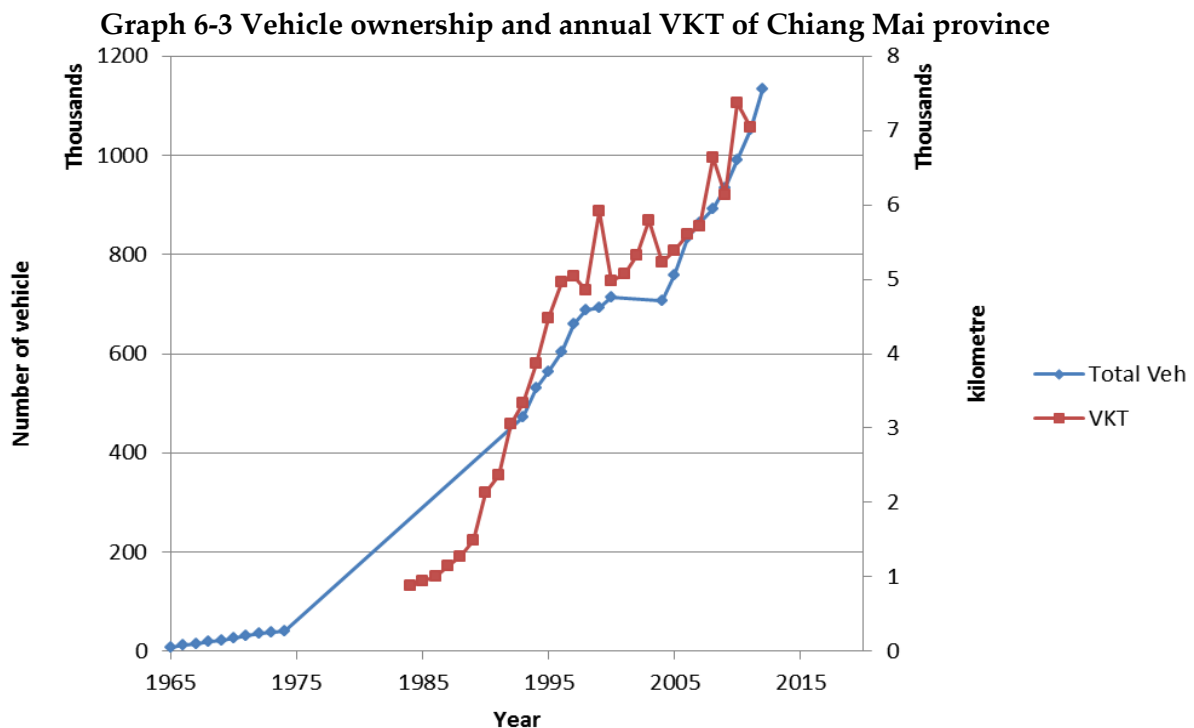
Graph 6-2 shows a positive correlation between the two entities. It includes the road development phase as put forward by (Wannavichit, 2004). The graph suggests that highway construction accelerates the expansion of the urbanised area after a short time lag. It appears that the urbanised area expanded to its current state in 1991, mid-way through the development of the radial roads (1986-1993) phase.

Urban sprawl and vehicle ownership

Under a constant travel speed, an increase in travel distance will increase travel time. Thus, the need to travel at higher speed must arise from an increase in travel distance and the desire to maintain the same travel time. The present area of Chiang Mai city is 134 times bigger than its original size. This expansion has impacted on residents' mobility, as demonstrated in Chapter 5.2.2. The analysis shows positive correlation between the city area and increased vehicle ownership.

Vehicle ownership and vehicle use (VKT)

The ownership of a vehicle is most likely to increase dependence on, and usage of, the vehicle rather than walking or using public transport. Graph 6-3 depicts the level of vehicle ownership and annual VKT of Chiang Mai province. The two sets of data overlap from year 1991 onward, demonstrating a close positive correlation between the two entities.



Source: Data from Department of land transport and (Nimnual, Srisakda, & Satayopas, 1980; Pintapun, 2002)

The calibration shows that relationships of the CLD and the correlations of data concur. The credibility and accuracy of the CLD can be enhanced by including city level data and provision of vehicle ownership between 1974 and 1993. Figure 6-6 illustrates the correlations between the four entities observed in this analysis.

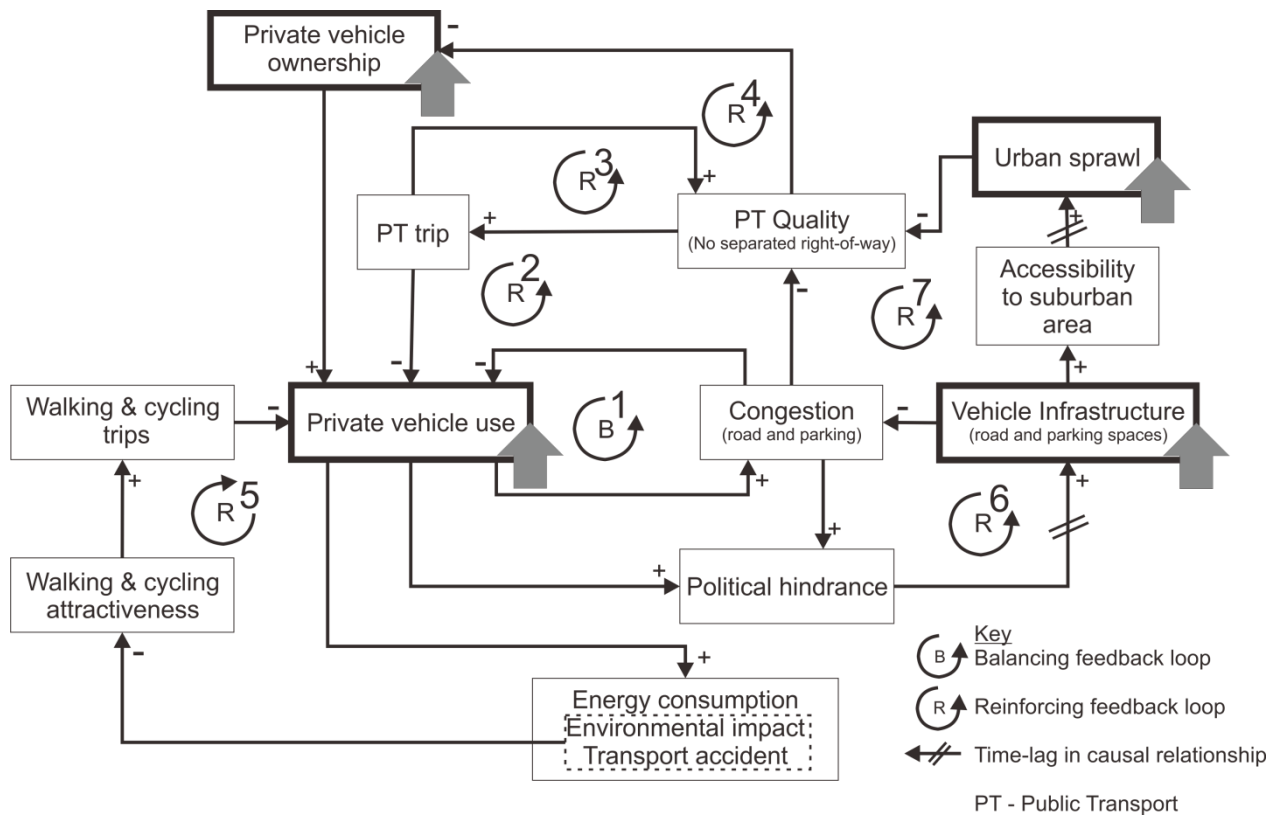


Figure 6-6 Correlations between the calibrated entities

6.4. Perspectives of the decision makers

In this sub-chapter, an analysis is carried out to review the perceptions of the city's transport decision makers. The objective of this exercise was to gain an insight into their views of the city's transport problems and their ideas about what sustainable solutions would provide the best answers. The information gathered by this exercise helps to provide a more complete understanding of the system. It will also contribute toward devising effective future development measures to solve the transport problems and lead the city towards a sustainable state. In addition, it aims to capture and compare policies that these decisions makers believe will alleviate the transport problem of the city with the CLD constructed in Chapter 6.3.

Chiang Mai Province Land Transport System Management Subcommittee

In Thailand, the development of transport infrastructures of a city are traditionally guided by a group of decision makers or a team of advisors that serve an elected politician. For Chiang Mai city it is the members of Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS) who are responsible for the land transport related policies and improvement activities that are taking place within Chiang Mai Province area. In recent years, the severity of Chiang Mai city’s transport problems is increasing despite various efforts of the CM-LTSS and other government bodies to alleviate the problems. Table 6-6 contains detailed information on the CM-LTSS.

Box 6-1 Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS)

Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS)

The CM-LTSS is a subsidiary body of the National Land Transport System Management Committee (LTSC). The LTSC is chaired by the prime minister and is endorsed by the LTSC Royal Decree Revision 2, 1992 national law. The CM-LTSS is responsible for the land transport related policies and activities with in Chiang Mai Province area. The duties of CM-LTSS can be summarised as:

- form land transport related policy,
- consider the feasibility of transport and traffic projects in the area,
- stipulate the land transport management and traffic mitigation standards, and
- propose laws, regulations, and any amendments to manage and mitigate transport and traffic problems

The CM-LTSS is also responsible for the implementation of transport and traffic related measures in accordance with the National Cabinet's policies (Kodmhai.com, 2012).

6.4.1. Methodology

A set of questions provided a framework for the interviews. The questionnaire contained three parts. In part one, the questions posed related to sustainability in the context of transport and the Sufficiency Economy⁵⁶. Part two presented the respondents with questions related to the transportation problems of the city. In the final part, the respondents were asked for their fields of responsibility and the impact of their work. Most

⁵⁶ a term coined by H.M. King Bhumibol Adulyadej for more detail see Appendix E

of the questions in the questionnaire are open-ended; only three are closed “Yes/No” type questions.

The interview requests were sent to a targeted 19 members of CM-LTSS out of a total 23 members. The requests were not sent to every member because of the limited time to carry out the exercise. Each request contained a formal cover letter and the interview questionnaire. Follow-up phone calls were made one week after the letters were submitted. In total, 14 CM-LTSS members were available for interviews. Other committee members were contacted but were not available or declined the request to take part because of other commitments. Nonetheless, those who agreed to participate represent a broad cross-section of the CM-LTSS. The interviews were carried out between 21st and 29th May 2012. Figure 6-7 lists the members of the CM-LTSS and the types of organisations to which each member belongs. The job titles of those members of CM-LTSS who were interviewed are highlighted in **bold letters**.

Each respondent was systematically asked all questions contained in the questionnaire. Their responses were recorded in short note format; no audio recording apparatus was used. The short notes were transcribed and translated into English narrative data and the information presented in Appendix D in the form of interview summaries. The narrative data from the interviews was catalogued and analysed to identify the frequency, the pattern, and the relative importance of the respondents' replies, as detailed in Chapter 6.4.2. The consistency of the interviews' theme is checked and matched in Chapter 6.4.3. The suggested policies are ranked to define the priority in Chapter 6.4.4. Policy measures are grouped together and assessed as to whether they will yield the intended goal of alleviating the city's transport problems. The assessment employs the CLD construct detailed in Chapter 6.3. It should be noted that the analysis of the CM-LTSS members' responses are treated as a whole, rather than individually, to reflect the assumed consensus-based operation of the group.

Members of Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS)

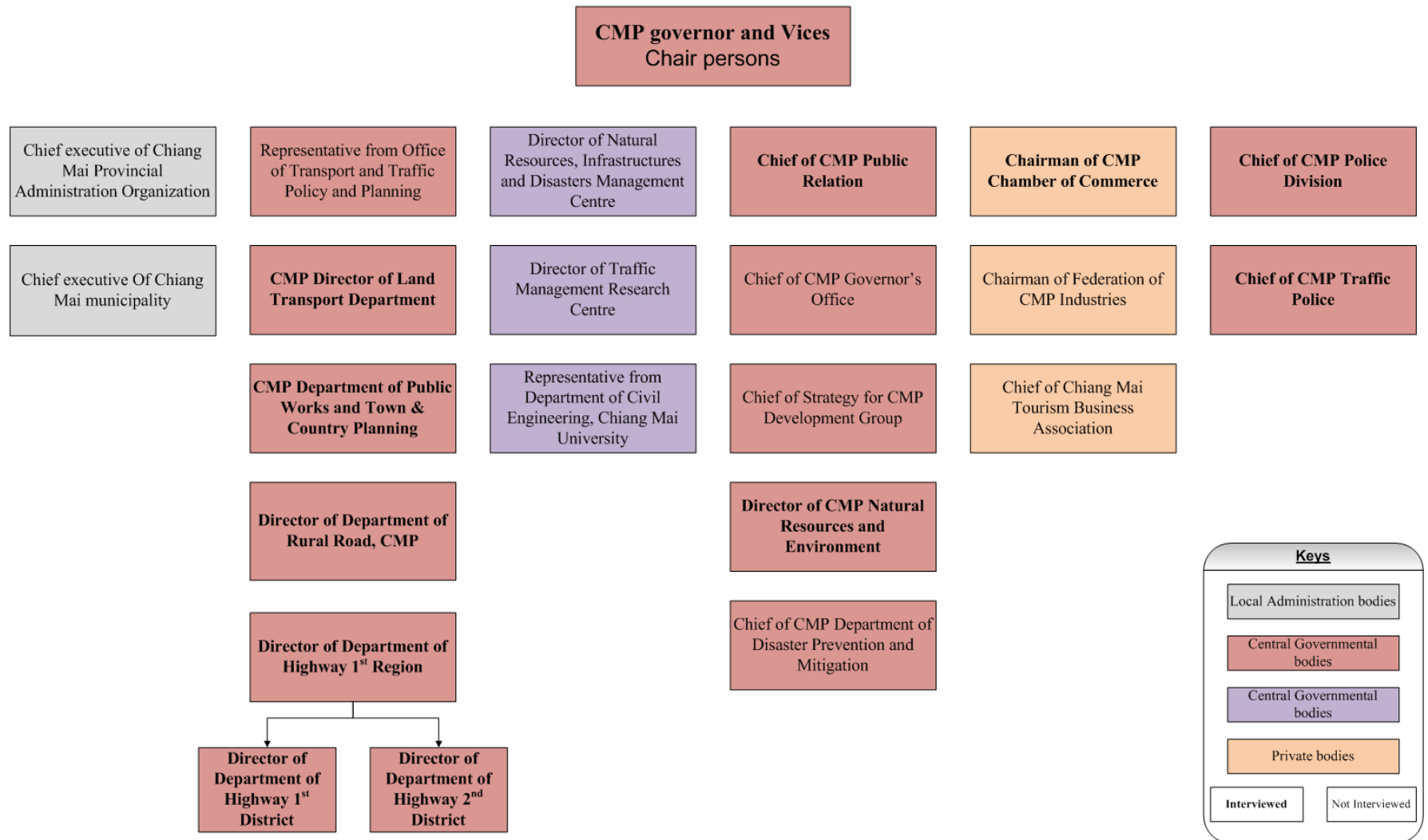


Figure 6-7 Members of Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS)

Note: CMP: Chiang Mai Province

6.4.2. Content categorisation

The interview transcripts were categorised into narrative data to identify the themes and the coherencies of the respondents' responses. Firstly, an identification number was added to each transcript. Secondly, the transcripts were read through to check for consistency and to define and classify the themes of each response. The frequency of each theme was recorded to illustrate its relative importance. It is recognised that the frequency count method employed, provides a rough estimate of the themes' relative importance and is not statistically significant. After categorising all the responses, the transcripts were read through again to re-check the frequency counts. The final results of this analysis are described in this chapter. The item listings are ranked in order of their scores. Table 6-3 shows the respondents' replies when asked about their definitions of a sustainable city.

Table 6-3: The respondents' definition of a sustainable city

Q 1.1: Concept of Sustainability: A sustainable city is a city that...

Respondents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Count
a. has a good transportation system with a good plan and sufficient road infrastructures	x	x	x		x	x	x	x			x		x		9
b. has a good city plan and an effective land use management		x	x		x		x				x				5
c. has unique culture and tradition				x					x	x		x		x	5
d. is liveable and has a good living standard	x	x										x			3
e. has a high environmental quality	x			x											2
f. has a high attractiveness for investment and a stable economic	x		x												2
g. has a good distribution of public services/resources		x													1
h. has a good law enforcement											x				1
i. is governed locally														x	1

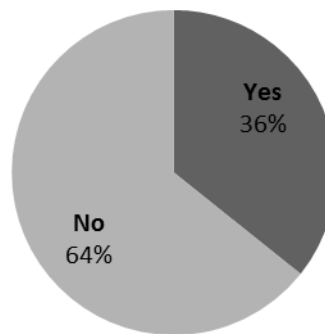
A large proportion (9 out of 14) of the respondents considers that the quality of the transportation system and road infrastructure will contribute positively to the sustainability of a city. This domination is suspected to be influenced by the nature of the group (CM-LTSS) and the theme of the interview.

It can be concluded from the ranking that the respondents give a high priority to the following items as characteristics of a sustainable city: a good transportation system, well-planned land usage, a strong local tradition, and a high level of living standard.

Graph 6-4 shows the respondents' replies when asked if they think Chiang Mai city is a sustainable city.

Graph 6-4: The respondents' view on Chiang Mai city's sustainability

Q. 1.2: Is Chiang Mai a sustainable city?



Note: based on 14 responses

A high proportion (64%) of the respondents think Chiang Mai city is not sustainable. Their judgements are perhaps in accordance with their definitions of a sustainable city from the forgoing. Table 6-4 ranks factors the respondents' beliefs to reduce the sustainability level of the city.

5 out 14 respondents consider that the lack of a public transport system is the main reason the city's sustainability is reduced. An equal number of respondents also think the lack of vision, long term goals and master plan is another of the causes. This shows that the respondents recognise the need for a long time horizon when considering sustainability. The contribution of human factors (negative human behaviour) and economic development are ranked equally (4 out of 14).

Table 6-4: Factors the respondents believe to reduce the sustainability of the city**Q 1.3: Factors that reduces the sustainability level of Chiang Mai city are:**

Respondents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Count
a. Lack of quality public transport system	x				x		x					x	x		5
b. Lack of long term goals/visions/master plans		x	x				x				x	x			5
c. Negative human behaviour (lack of discipline, insights, and responsibility)	x			x		x					x				4
d. Rapid and uncontrolled economic/development growth		x							x		x			x	4
e. Fragmentation of the responsible authority			x		x						x				3
f. Ineffective use of resources	x										x	x			3
g. Lack of social and environmental considerations in development and engineer projects				x					x	x					3
h. Immigration				x										x	2
i. Loss of local identity and traditions				x						x					2
j. Low quality of road infrastructure					x										1
k. A rapid increases of road vehicles							x								1
l. The negative influence by the medias										x					1
m. Illegal exploitation of public good									x						1

Table 6-5 rates the actions and instruments the respondents believe will preserve the sustainability level of the city.

Table 6-5: Measures the respondents believe will maintain the sustainability level of the city**Q 1.4: To maintain Chiang Mai city's sustainability, it will require:**

Respondents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Count
a. Measures to change human behaviours: through education and increased awareness	x			x						x	x				4
b. Promotion and implementation of PT and NMT system	x						x					x	x		4
c. Long term goals and holistic visions for the city			x		x							x			3
d. A development direction that originates from local people		x							x					x	3
e. A land use plan of the city					x						x	x			3
f. A strong enforcement for the implementation of transport and land use plan					x				x		x				3
g. Restriction of demand		x													1
h. Measures to prevent interference from politicians					x										1
i. Examples from leaders								x							1
j. Increase budget								x							1
k. promotion and preservation of local culture and tradition											x				1

Among the top six measures highly rated by the respondents to retain the city's sustainability, three are transport and land use related. The other three are measures to induce behavioural change, goal setting, and local-centric development policy.

Table 6-6 ranks the effects the respondents believe will result if the sustainability level of the city decreases.

Table 6-6: The effects the respondents believe will occur as the sustainability level of the city reduces.

Q 1.5: The effects of reduced level of sustainability to Chiang Mai city are:

Respondents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Count
a. Reduce the city's liveability and quality of life		x		x			X				x	x	x		6
b. Losing identity, culture, and tradition of the city				x				x	x	x		x			5
c. Increase related problems (energy consumption, environment, and social)					x		X	x			x		x		5
d. Reduced competitiveness of the city, business growth and its potential	x								x				x		3
e. Worsening of transport problems (congestion and accidents)					x		X						x		3
f. Increase public spending and mitigation cost			x		x										2

Two of the three top ranked effects are highly subjective entities (quality of life and local identity); their importance is widely accepted and appreciated, yet they are difficult to measure. The rest of the effects listed are more objective and measurable.

Table 6-7 shows the groups of people the respondents believe will gain and lose from the reduction in the city's level of sustainability.

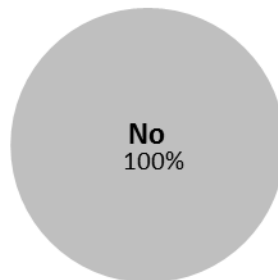
Table 6-7: The group of people the respondents believe will be affected by the reduction in the city's level of sustainability

Respondents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Count
Q 1.6a: People who will benefit from the reduction in the city's sustainability															
People who live outside the city	x	x	x	x	x	n/a	x	n/a	X	x	x	x	x	x	12
Q 1.6b: People who will be adversely effected by the reduction in the city's sustainability															
People who live in the city	x	x	x	x	x	n/a	x	x	X	n/a	x	x	x	x	12

All of the respondents who commented on this question believe that reduction in the city’s sustainability level will benefit those outside the city at the expense of people living inside the city. Graph 6-5 illustrates the proportion of respondents who believe that there is a difference between Sufficiency Economy and sustainability.

**Graph 6-5: The opinion of the respondents on the differences
between Sufficiency Economy and sustainability**

**Q 1.7: Is there a different between Sufficiency Economy
and Sustainability ?**

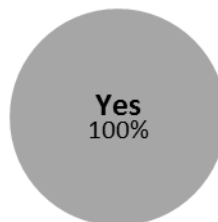


Note: based on 13 responses (one respondent did not comment)

Almost all of the respondents consider that the Sufficiency Economy is the same as Sustainability. Sufficiency Economy is a development principle coined by King Bhumibol Adulyadej (see Appendix E for detailed information on Sufficiency Economy). It is often referred to and used in governmental development policies such as the National Economic and Social Development plan (NESDP).

Graph 6-6 the respondents’ opinion on the city’s transportation problems

Q 2.1: Is there a transportation problem in Chiang Mai?



Note: based on 14 responses

Although there are differences in the respondents' replies to the question on the city's sustainability, all of them believe that there is a transport problem in Chiang Mai city.

Table 6-8 classifies what the respondents believe to be causes of the city's transport problems.

Table 6-8 Factors the respondents believe to be the causes of the city's transportation problems

Q 2.2: The cause of transportation problems in Chiang Mai are:

Respondents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Count
a. Lack of public transport system and management		x			x		x	x	X	x	x	x	x		9
b. Increased number of motorised vehicles and vehicle trips		x			x	x		x			x		x	x	7
c. Ineffective land use plan, car oriented development, and urban sprawl	x	x			x		x		X	x				x	7
d. Lack of road infrastructure both in terms of quantity and quality	x					x	x		X		x	x			6
e. Increased population and number of visitors		x		X	x	x								x	5
f. Lack of plan and long term vision								x	X	x		x			4
g. Negative human behaviours such as lack of discipline and ethics		x							X	x			x		4
h. Fast economic growth and development of the city				X		x								x	3
i. Fragmentation of responsible government sectors			x		x										2
j. The restriction of existing infrastructure and city layout		x								x					2
k. Lack of government's active participation e.g. in controlling private sector activities			x												1
l. Ineffective management of infrastructures			x												1

A majority of the respondents believe the lack of public transport and the ineffective land use plan are both causes of the city's transport problem, which are valid beliefs in accordance with the CLD. However, several other causes, such as an increase in motorised vehicles and the lack of road infrastructures, are not the 'true causes' of the city transport problem. They are undesirable conditions resulting from an increase in the need for private vehicle usage in the city as shown on the CLD. In addition, other proposed causes, such as increase in population, fast economic growth, and negative behaviour are factors that accelerate the worsening and undesirable conditions. Thus, these replies reflect the partial understanding of these respondents of the city's transport problem.

Table 6-9 lists the mitigation measures respondents believe will alleviate the city's transport problems, in accordance with their score count.

Table 6-9: Mitigation measures the respondents believe will solve the city's transportation problems

Q 2.3: Mitigation measures of transport problems in Chiang Mai city are:

Respondents	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Count
a. Provision of public transport system	x	X			x	x	x		x		x	x	x		9
b. Improve motorist discipline through education, information, and strengthened enforcement						x	x		x	x	x	x	x	x	8
c. Provision, construction, and enhancement of road infrastructures	x					x	x			x	x	x		x	7
d. Improved land use planning and management. Promote mix land use to reduce travel distance	x				x	x		x	x			x			6
e. Redistribution and relocation of traffic attractors to areas outside the city		x			x			x	x			x			5
f. Increase traffic capacity of the transport system by various TDM measures such as introducing flexible working hours	x		x		x	x									4
g. Promote sustainable transport by improving footpath, reducing private vehicle dependency, and building sustainable transport infrastructure	x		x		x	x					x				4
h. Improve transportation system management by cooperation, and distribution of responsibility	x		x									x		x	4
i. Vehicle access restriction, especially in the central area		x										x			2
j. Expansion of the city area		x													1
k. Protect and preserve the inner city from development		x													1
l. Migration control				X											1

The mitigation measures that received high scores are provision of public transport system (9 points), measures to improve human behaviours (8 points), and improvement to the road infrastructures (7 points). This ranking shows consistency in the respondents' perceptions of the causes of Chiang Mai's transport problems and also consistency in the best way to address these issues. In addition, land use planning (6 points) and the improvement in infrastructure management (4 points) measures also receive high scores. It is interesting that over one-third of the respondents believe that the transport problems can be solved by

relocation of traffic attractors, such as schools and hospitals outside the city (5 points). The measure suggested reflects the tendency to view transport problems in a reductionist way.

6.4.3. Theme consistency analysis

In this chapter, the different entities from the previous chapter are grouped together in accordance with their themes and are placed side-by-side. This analysis aims to check the consistency of the respondents' replies and to reveal the pattern of their responds within each theme. Responses on sustainability and transport problems were analysed separately. Table 6-14 shows results of this matching analysis for the questions related to sustainability.

The questionnaire contains four different questions on sustainability: the vision of a sustainable city, the factors that reduce its sustainability, the factors that maintain its sustainability, and the effect of the reduction in sustainability. The responses to these questions can be grouped into twenty different themes. It is apparent from Table 6-10 that the responses on certain issues appear more consistent across the four questions; only the transport and culture are the themes that appear in all questions. These preliminary observations suggest that these issues are imprinted in the mind of the respondents more strongly than others.

In addition, there is high consistency in the responses across the themes with high scores; e.g. negative human behaviour received a total score of 16. The high score suggests that the respondents have a high coherency in their vertical thinking¹ (or logical analysis) on the topic related to sustainability of the city as a group.

¹ See (Harris, 2002) and others by Edward De Bono

Table 6-10: Matching respondents’ answers on questions related to sustainability

Theme/Question	1.1 Vision of a sustainable city	1.3 Factors that reduce the city’s sustainability	1.4 Measures to maintain the city’s sustainability	1.5 Effect of reduction in sustainability
1.Transportation	a. has a good transportation system with a good plan and sufficient road infrastructure	a. Lack of quality public transport system	b. Promotion and implementation of PT and NMT system	e. Worsening of transport problems (congestion and accidents)
2.Land use plan and its enforcement	b. has a good city plan and an effective land use management h. has good law enforcement	d. Rapid and uncontrolled economic/development growth	e. A land use plan of the city f. A strong enforcement for the implementation of transport and land use plan	n/a
3.Culture and tradition	c. has unique culture and tradition	i. Loss of local identity and traditions	k. promote and preserve local culture and tradition	b. Losing identity, cultural, and tradition of the city
4.Life quality	d. is liveable and has a good living standard e. has a high environmental quality	g. Lack of social and environmental considerations in development and engineer projects	n/a	a. Reduce the city’s liveability and the quality of life c. Increase related problems (energy consumption, environment, and socials)
5.Economic competitiveness	f. has a high attractiveness for investment and a stable economy	n/a	n/a	d. Reduce competitiveness of the city, business growth and its potential
6.Distribution of services	g. has a good distribution of public services/resources	n/a	n/a	n/a
7.Locally governed	i. is governed locally		d. A development direction that originate from local people	
8.Long term goal	n/a	b. Lack of long term goals/visions/master plans	c. Long term goals and holistic visions for the city	n/a
9.Human behaviour	n/a	c. Negative human behaviour (lack of discipline, insights, and responsibility)	a. Measures to change human behaviours: by education and increase awareness	n/a
10.Fragmentation of the responsible authority	n/a	e. Fragmentation of the responsible authority	n/a	n/a
11.Ineffective use of resources	n/a	f. Ineffective use of resources	n/a	n/a
12.Immigration	n/a	h. Immigration	n/a	n/a

Table 6-10: Matching respondents’ answers on questions related to sustainability (Continue)

Theme	1.1 Vision of a sustainable city	1.3 Factors that reduce the city’s sustainability	1.4 Measures to maintain the city’s sustainability	1.5 Effect of reduction in sustainability
13.Quality of road infrastructure	n/a	j. Low quality of road infrastructure	n/a	n/a
14.Increase in road vehicles	n/a	k. A rapid increases of road vehicles	g. Restriction of demand	n/a
15.Influence by the media	n/a	l. The negative influence by the medias	n/a	n/a
16.Exploitation of public good	n/a	m. Illegal exploitation of public good	n/a	n/a
17.Examples from leaders	n/a	n/a	i. Examples from leaders	n/a
18.Budget	n/a	n/a	j. Increase budget	n/a
19.Interference from politicians	n/a	n/a	h. Measures to prevent interference from politicians	n/a
20.Public spending and mitigation cost	n/a	n/a	n/a	f. Increase public spending and mitigation cost

A similar matching analysis was carried out for the respondents' replies on the city's transport problems questions. Table 6-11 shows the results of this analysis.

Table 6-11: Matching respondents' answers on questions related to the city's transport problems

Theme	2.2 Cause	2.3 Mitigation
1.Public Transport provision and management	a. Lack of public transport system and management	a. Provision of public transport system
2.Private vehicle quantity	b. Increase number of motorised vehicles and vehicle trips	e. Increase effectiveness and efficiency of the transport system by various TDM measures i. Vehicle access restriction, especially within the central area
3.Land use planning	c. Ineffective land use plan, car oriented development, and urban sprawl	d. Improve land use planning and management. Promote mix land use to reduce travel distance
4.Road infrastructure quantity and quality	d. Lack of road infrastructures' quantity and quality	c. Provisions, constructions, and enhancements of road infrastructures
5.Population	e. Increase population and visitors	l. Migration control
6.Human behaviour effects	g. Negative human behaviours such as lack of discipline and ethic	b Improve motorist discipline by education, information, and strengthen enforcement
7.Development of the city	h. Fast economic growth and development of the city	f. Redistribution and relocate traffic attractors to area outside the city k. Protect and preserve the old inner city from development
8.Responsible organization	i. Fragmentation of responsible government sectors	h. Improve transportation system management by cooperation, and distribution of responsibility
9.City infrastructure and its boundary	j. The restriction of existing infrastructure and city layout	j. Expansion of the city area
10.Long term plan and vision of the city	f. Lack of plan and long term vision	n/a
11.Government participation	k. Lack of government's active participation e.g. in controlling private sector activities	n/a
12.Infrastructure management	l. Ineffective management of infrastructures	n/a
13.Promotion of sustainability Transport	n/a	g. Promote sustainable transport by improve footpath, reduce private vehicle dependency, and build sustainable transport infrastructure

The responses to the questions on the cause and mitigation measure of the city's transport problems can be grouped into 13 themes, out of which 9 themes have responses for both questions. The result shows a similar pattern as the foregoing analysis; a high level

of consistency across themes that received multiple responses. This further suggests that a high coherency of the respondents’ vertical thinking on these issues.

6.4.4. Priority analysis

The total counts of responses across each theme are summed up to quantify the respondents’ priority. The ranking of responding themes related to sustainability based on their scores is shown in Table 6-12.

Table 6-12: Ranking of category related to sustainability

Theme	Score	% of total score
1.Quality of Transportation	21	19%
2.Quality of living	19	17%
3.Land use plan with strong enforcement	16	14%
4.Cultures and traditions	13	12%
5.Human behaviour and responsibility	8	7%
6.Long term goals and vision	8	7%
7.Economic competitiveness	5	4%
8.Locally govern	4	4%
9.Fragmented responsible	3	3%
10.Use of resources	2	2%
11.Public spending and mitigation cost	2	2%
12.Immigration	2	2%
13.Road vehicles	2	2%
14.Interference from politicians	1	1%
15.Distribution of services	1	1%
16.Examples from leaders	1	1%
17.Quality of road infrastructure	1	1%
18.Influence from the medias	1	1%
19.Exploitation of public good	1	1%
20.Budget	1	1%
Total	112	100%

The ranking shows that 75% of the total scores are assigned to 6 out of 22 themes. This indicates the respondents’ concentrate their concerns on particular themes; i.e. quality of transport, quality of living, land use plan, culture, human behaviour, and long term goals

. This focus suggests that the decision makers have strong shared ‘visions’ on these themes. Nevertheless, the high number of themes with low score indicates that the decision makers’ concerns are also fairly diverse.

A similar analysis is carried out for the responses on Chiang Mai’s transport problems; Table 6-13 shows the results of this analysis.

Table 6-13: Ranking of category related to Chiang Mai transport problems

Theme	Score	% of total score
1.Public Transport provision and management	18	18%
2.Land use planning	13	13%
3.Road infrastructures' quality and quantity	12	13%
4.Human behaviour effects	12	12%
5.Private vehicle quantity	11	11%
6.Development of the city	9	9%
7.Population	6	6%
8.Responsible organisation	6	6%
9.Promotion of sustainability Transport	4	5%
10.Long term plan and vision for the city	4	4%
11.City Infrastructure and its boundary	3	3%
12.Government participation	1	1%
13.Infrastructure management	1	1%
Total	100	100%

The result shows a similar pattern to the previous analysis; 67% of the total scores are assigned to 5 out of 13 themes. The number of themes is significantly lower than the previous analysis, which indicates an increase in the respondents' focus in this subject. It is suspected that the specific nature of the questions may have contributed toward this increase.

6.4.5. Causal analysis

The analysis in this chapter focuses on measures to mitigate transport problems suggested by the respondents (Question 2.4). The aim of this analysis is to evaluate whether the decision makers' proposed methods of mitigation will result in the improvement of the city transport problem or not. Firstly, the number of different ways to mitigate transport problems is condensed by grouping them according to their types. Secondly, the CLD constructed in Chapter 6.3 is used to assess the proposed solutions against the intended goal. Table 6-14 shows the grouping of the proposed solutions according to their types.

Table 6-14: Proposed mitigation to solve the city's transport problems

Types of mitigation proposed	Time delay	Mode specific
1. Promotion of non-personal vehicles mode a. Provision of public transport system g. Promote sustainable transport by improving footpaths, reducing private vehicle dependency, and building sustainable transport infrastructure	Medium to long term	Mode specified (walking, cycling and public transport)
2. Road capacity expansion b. Improve motorist discipline by education, information, and strengthened enforcement c. Provision, construction, and enhancement of road infrastructures f. Increase traffic capacity of the transport system by various TDM measures such as flexible working hours	Short to medium term	Mode specified (Private vehicle)
3. Road capacity reduction i. Vehicle access restriction, especially within the central area	Short to medium term	Mode specified (Private vehicle)
4. Relocation of traffic attractors and expansion of city e. Redistribution and relocation of traffic attractors to area outside the city j. Expansion of the city area	Long term	Non-mode specified
5. Land use planning d. Improve land use planning and management. Promote mixed land use to reduce travel distance k. Protect and preserve the inner city from development	Long term	Non-mode specified
6. Population control l. Migration control	Long term	Non-mode specified
7. Improve transport organization h. Improve transportation system management by cooperation, and distribution of responsibility	Long term	Non-mode specified

The proposed mitigation measures are grouped into seven types. The table includes the time delay and the mode of transport affected by each measure. The time delay refers to the relative duration of time taken between the point, when the measure is implemented and the point it at which it becomes effective. Long term refers to 10 years or more, medium term is 5-10 years and short term is less than 5 years. The mode specific column indicates whether the measure aims to address specific modes or all modes of transport in the system. It is apparent that the mitigations proposed by the respondents are mostly long term and non-mode specific measures.

The inclusion of the motorist discipline measure in the road capacity group may seem an obscure choice. However, in accordance with the respondents' thinking, an increase in drivers' discipline will reduce accidents, and address driving behaviours that obstruct traffic flows, hence improving the capacity of the road network.

Next, the mental model presented in the previous chapter (Figure 6-4) is employed to assess the effects of these seven measures against their intended goals. Figure 6-8 depicts an example of the assessment of the mitigation measure number 2: Road capacity expansion.

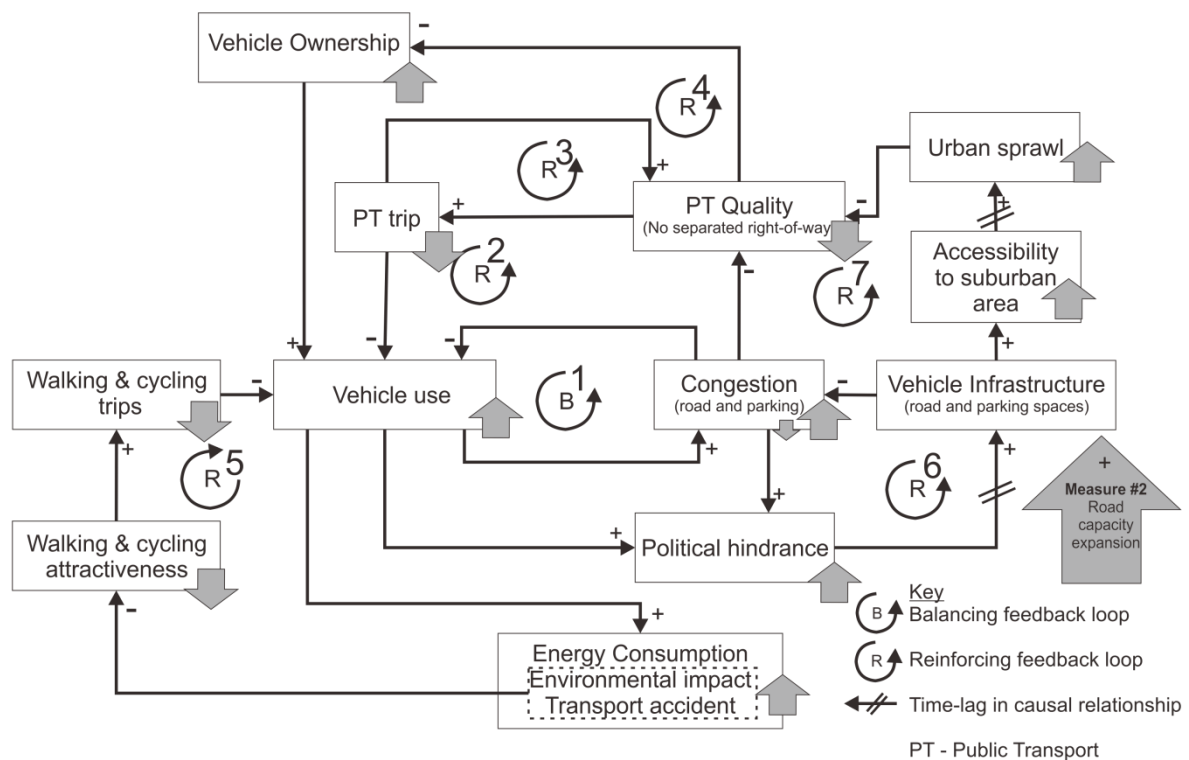


Figure 6-8 Impact assessment of the road capacity expansion measure

The assessment adopts the assumptions made for the CLD in Chapter 6.2.2. The evaluation of each measure is detailed below and summarized in Table 6-20

Measure 1: Promotion of non-personal vehicles mode

This measure includes the provision of infrastructure, and other soft measures, such as advertising and education that will increase the mode share of the public and non-motorised modes. An increase in the share of both modes will decrease the number of trips made by private vehicles, hence reducing the demand for further infrastructure, which will reduce urban sprawl and consequently reduce the number of private vehicle trips.

Measure 2: Road capacity expansion

Generally, an increase or decrease in road capacity is derived mainly from infrastructure construction. Demand management and other 'soft' measures (such as implementation of an Intelligent Transportation System (ITS)) will also increase road capacity but by a relatively lower amount. An increase in road capacity by private vehicle infrastructure construction will reduce congestion in the short term. The reduced congestion will attract more private vehicle trips, and hence increase the number of private vehicle trips, in the long run. The construction of such infrastructure will also induce urban sprawl as accessibility into the suburban area increases. This will increase vehicle ownership and consequently, vehicle use. It can be concluded that a measure to increase road capacity will exacerbate the transport problem, instead of solving it.

Measure 3: Road capacity reduction

In contrast to the forgoing, measures that reduce road capacity (such as road closure) will reduce the attractiveness to use private vehicles, due to increase in congestion (reduced capacity) and reduced accessibility by vehicles. In contrast accessibility by walking and cycling of the area considered will increase. This will consequently, reduce the private vehicle mode share. This measure will affect the transport system in an opposite manner to the foregoing; hence it will alleviate transport problems

Measure 4: Relocation of traffic attractors and expansion of city

The expansion of the city area and the relocation of traffic attractors to area outside the city are assessed together. These two measures are, in effect, measures to artificially create urban sprawl. They will increase the need to use and own private vehicles and, will eventually lead to the worsening of transport problems. Unless an appropriate public transport system, which provides quality connections between the traffic attractors and their traffic sources (i.e. residential area), is put into place prior to the relocation.

Additionally, the relocation of traffic attractors from the core city area will result in a localised degeneration of the area as there are often economic and social activities associated with these traffic attractors. However, these aspects are not covered by the current CLD.

Measure 5: Land use planning

The respondents suggested two different approaches to introducing land-use measures to increase the sustainability of Chiang Mai, i.e. the promotion of mixed land use and the restriction of further development of the inner city area. They are assessed separately here. Firstly, the promotion of mixed land use to reduce travel distance is evaluated. Although, this measure is beyond the scope of the mental model, its principles can still be applied for assessment.

In most cases, the development of mixed land use normally takes place outside the core city centre where there is more flexibility in land use within abundant space. Thus, this kind of development will initially increase the private vehicle mode share, unless they are well-connected with public transport to the surrounding area. However, as the mixed usages of the area develop, the needs that previously were fulfilled by long trips or private vehicle trips should be replaced by local trips or public transport and non-motorised transport trips. It is presumed that this replacement will occur when the sum of travel-cost and benefit-gain within the local area exceeds that of the core city. However, in reality this shift is more complex. The quantification of the objective benefits (such as fuel and time saving) may be estimated, but it is more difficult to measure the subjective benefits gained (such as social interaction and business opportunity). In addition, the multifaceted interactions between different entities within the urban area give rise to emergent properties that cannot be measured from evaluating individual entities. From the system point of view, it is therefore difficult to evaluate the effects of mixed land use development as a mitigating factor for transport problems in the long term. However, it will most likely increase the number of private trips in the short term.

Secondly, the land use measures to protect and preserve the inner city from being developed are assessed. The core area of Chiang Mai city consists of a historical part which should be preserved for its legacy. A measure to limit land use change should define its boundary and the limitations appropriately, allowing the area to regenerate and develop to maintain its 'usage'. Otherwise, the core city area will degenerate as urban sprawl expands. The latter will consequently cause an increase in private vehicle usage and aggravate the transport problem.

Measure 6: Population control

The population controls considered here are measures that affect the rate of population change by influencing the birth rate and the immigration rate of the city. It may also affect the direction of population change (i.e. decrease the population) if the net rate is negative. Therefore, population control does not directly alleviate transport problems; it simply affects the rate of accumulation (or loss) of other parameters. In other words, population determines the rate of increase/decrease in parameters that are associated with it, such as the number of private vehicles and the number of households. The current CLD cannot evaluate the effects of population change explicitly; nevertheless, mathematical formulas can be included to enable assessment of such measures.

Measure 7: Improve transport organisation

An improvement of transport organisation in the city will increase the effectiveness and efficiency in its utilisation of resources (monetary and spatial) to provide transport services. This improvement is normally focused on particular modes of transport according to the policy of the organisation. It will increase the attractiveness of the modes concerned and induce a stronger shift to these modes from others. Although, this measure cannot be evaluated with the current CLD, it can be assessed by inclusion of mathematic formulas and additional variables.

6.5. Results

The results from the causal analysis of the 7 measures are shown in Table 6-18. The assessment shows that only two out of seven policies proposed will result in some improvements to the city's transport system. Three will aggravate the condition further, two measures are implementation dependent and one has indirect effects. Thus, based on this assessment the policy makers have less than a 30% chance to improve the system with any certainty. In other words, they are more likely to aggravate the problem further with their suggested policies. This exercise demonstrates the decision makers' inaccurate assessment of the system and stresses the need for a tool to educate the policy makers about the root causes of the city's transport problems

Table 6-15: Summary of results from the mitigations causal analysis

Types of mitigation measure proposed	Effects
1. Promotion of non-personal vehicles mode a. Provision of public transport system g. Promote sustainable transport by improving footpaths, reducing private vehicle dependency, and building sustainable transport infrastructure	Alleviate transport problem Promotion of this measure will increase the attractiveness of the PT and NMT modes hence, reduces PV trips and transport problems associates with them such as congestion
2. Road capacity expansion b. Improve motorist discipline by education, information, and strengthen enforcement c. Provisions, constructions, and enhancements of road infrastructures f. Increase traffic capacity of the transport system by various TDM measures such as flexible working hour i. Vehicle access restriction, especially from the central area	Aggravate transport problem This measure will increase the attractiveness of PV, hence increases the PV mode shares in expense of other modes. It will trigger urban sprawl which increase PV dependency and further increase PV mode shares.
3. Road capacity reduction i. Vehicle access restriction, especially from the central area	Alleviate transport problem Promotion of this measure will decrease the attractiveness of the PV as the level of congestion will increase. In contrast, it will increase area available for PT and NMT modes hence, increases their mode shares
4. Relocation of traffic attractors and expansion of city e. Redistribution and relocate traffic attractors to area outside the city j. Expansion of the city area	Aggravate transport problem Measures e. and j. will produce urban sprawl and increase car dependency, hence aggravate transport problems.
5. Land use planning d. Improve land use planning and management. Promote mixed land use to reduce travel distance k. Protect and preserve the inner city from development	Impacts depending on measures Measure d. will increase PV trips in an initial phase. In long run, it is uncertain whether the needs previously fulfilled by long distance trips can be met in local area. The effectiveness of measure k. depends on the development limitation and area of the protected zone.
6. Population control l. Migration control	Indirect effects. Increase or decrease in the birth and the in migration rates do not have a direct effects on transport problems. They affect the rate of accumulation of entities related to population (such as number of private vehicles)
7. Improve transport organization h. Improve transportation system management by cooperation, and distribution of responsibility	Impacts depending on measures Improvement will increase the effectiveness and efficiency of the city transport provision. It will increase the attractiveness of the targeted transport modes which is set by the organization’s policy. The mode share of the targeted mode will increase.

7. Vision for Chiang Mai city transport system

7.1. *Introduction*

In this chapter, a vision of the city transport system is first established based on the definitions of relevant terms, such as “sustainability”, “sustainable transport”, and “sufficient economy”. The definitions of these terms are detailed in Appendix E. The vision is then used to derive a set of objectives from which are derived a set of tangible measures and indicators to evaluate our progress toward achieving the goals. A set of background indicators is also included to aid the understanding of the transport system. In Chapter 7.3 a set of scenarios⁵⁸ that will be assessed using the MARS model, is described.

7.2. *Sustainable transport vision for Chiang Mai city*

In a planning context, a vision is a desirable ideal state of the future set by an individual, groups of decision makers, or in consensus with other stakeholders. The vision can be broken down to provide specific goals and objectives that will deliver the desired results. In Thailand, local authorities are entitled to set their development vision and objectives, providing these are consistent with the policies of the central government. Although, there are several administrative organisations within the area of Chiang Mai city, three of them are most influential. They are Chiang Mai municipality (local level administrative organisation), Chiang Mai Provincial Administrative (local level administrative organisation), and Chiang Mai Province (provincial level administrative organisation)⁵⁹. The current visions of the three authorities are presented in Table 7-1.

The review of their infrastructure development strategies, which derived from these visions shows that the Chiang Mai Province’s focus is on providing infrastructures that support sustainable prosperity according to the Sufficient Economy principle (Chiang Mai Province, 2010). The Chiang Mai Municipality has derived four specific goals from its vision as follows (Chiang Mai Municipality, 2011):

⁵⁸ A scenario is a predefined background condition and a strategy

⁵⁹ Chiang Mai municipality is situated within the Chiang Mai Provincial Administrative area, thus their operations are connected. The Chiang Mai Provincial Administration represents central government. Its role is to ensure that the policies and day-to-day operation of the local administrative organisations within the province are in harmony with the government’s policies.

1. Development of land use in accordance with the principal plan
2. Development of road infrastructure to ensure good accessibility
3. Development of traffic system and public transport system
4. Improvement of cityscape, tidiness and beautification.

Table 7-1 Current visions of three administrative organisations in Chiang Mai city

Vision	Main points
Chiang Mai municipality “Chiang Mai municipality is a sustainable and liveable city, with a unique cultural tradition, and good quality of life. Strong communities with good governance”	Sustainable Liveable Unique tradition Quality of life Good governance
Chiang Mai Provincial Administrative Organization “Develop the quality of life of Chiang Mai’s citizens through efficient public service” (or Public Service Efficiency)	Quality of life Efficient public service
Chiang Mai Province “City of Life and Prosperity” – A city that provides happiness and valuable life for its residents and visitors alike, as a world-class liveable and tourist city, as well as a gateway toward international investment	Happiness Liveable city Quality tourism Economic development

Although the objectives of the provincial administrative organisation were not available, the reviews show that the relevant authorities have set visions and translate them into goals and objectives. These goals and objectives cannot be used to support decision making as they are non-specific and immeasurable. These findings highlight the **need for better vision and goal setting** for the city.

7.2.1. Sustainable transport visions

This vision for Chiang Mai city’s sustainable transport system is based on the definitions of relevant terms, which are included in Appendix E. Additionally, it also includes personal knowledge and the experience gained from undertaking the field work to gather household mobility data (CM-MTS 2012).

Box 7-1 Vision for Chiang Mai city’s transport system

A safe and sustainable transport system that supports a good standard of living for everyone.

The explanations of keys words of this vision are:

- *Safety* – to protect lives from direct and indirect hazard
- *Sustainable* – protection of environment by minimise use of non-renewable energy and emission of externalities

- *Support a good standard of living*– provide quality basic transport infrastructure that enables sufficient accessibility to work, leisure, and facilities
- *For everyone* – social inclusion for disabled persons, all genders, income levels, and nationalities

7.2.2. Sustainable transport objectives

Objectives provide guidelines toward goals and help to identify obstacles, challenges, and constraints that need to be overcome (May & Minken, 2003). In this sub-chapter, a list of objectives necessary to achieve the vision previously defined is made. The objectives also incorporate the information gained from the city's decision makers on their view about sustainability (Chapter 6). There are seven categories of the objectives:-1) Safety, 2) Protection of the environment, 3) Accessibility, 4) Quality of living standard, 5) Equity and fairness within generation and between generations, 6) Cultural heritage and traditions, and 7) Economy

These seven objectives can be broken down further to provide sub-objective and indicators for each one of them (Table 7-2).

Table 7-2 Objective and sub-objective of the city's sustainable transport planning

Sustainable transport planning	Aspect	Objective	Sub-objective
	Environmental	1. Efficient use of resources and protection of the environment	1.1 Efficient in the use of resources for transport activities 1.2 Reduce greenhouse gases to a reasonable level 1.3 Reduce other air pollution to a reasonable level 1.4 Reduce noise pollution to a reasonable level 1.5 Control proportion of green areas
	Social	2. Improve accessibility for all modes	2.1 Provide reasonable accessibility to goods and services 2.2 Reduce automobile dependency 2.3 Enable reasonable freedom of movement for each user 2.4 Control urban sprawl
		3. Improve transport safety	3.1 Reduce transport accidents, including non-vehicular
		4. Enhance living standard	4.1 Enhance social, cultural, and recreational activities
		5. Equity and fairness within generation and between generations	5.1 Accessibility for non-vehicular users 5.2 Accessibility for mobility impaired users 5.3 Compensation for today's and tomorrow's losers 5.4 Ensure a fair distribution of benefits derive from taxpayer's money
		6. Preserve cultural heritage and traditions	6.1 Retain the unique culture and tradition of the city (self-immunity)
	Economy	7. Promote economy	7.1 Promote Sufficiency Economy

Source: adapted and modified from (May & Minken, 2003, p. 38)

The seven objectives are integral parts of the vision towards achieving a sustainable transport system for the city. It is important that they should not be fragmented and focused on individually. Figure 7-1 provides an illustration to emphasise this point and how the seven objectives and its sub-objectives support the city's sustainable transport system

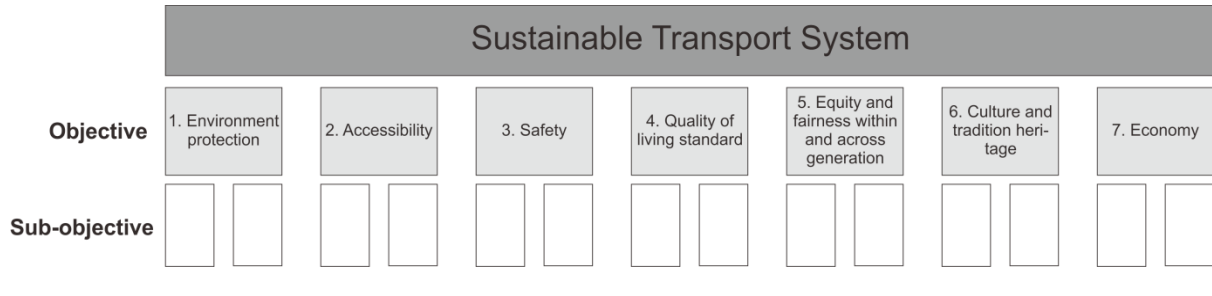


Figure 7-1 Sustainable Transport system and its seven objectives

7.2.1. Sustainable transport indicators and background variables

The main difference between conventional and sustainable transport indicators is that the latter seeks to provide measurement of transport quality beyond the private motorised transport realm (Litman & Burwell, 2006). Examples of conventional transport indicators are level of service, average traffic speed, and accident per vehicle distance travel. Sustainable transport, by contrast, aims to make visible elements that provide unbiased representative assessment of the transport system. Examples of such indicators are per capita motorised vehicle kilometre, energy or fuel consumption per trip, and percentage of the city's land mass dedicated to transport.

In the previous sub-chapter, sustainable transport objectives are defined to provide guidelines and directions toward the goals. Nevertheless, they cannot be used to evaluate progress toward the goals, thus indicators are needed. Nielsen (2009) purports three objectives of indicators:

“to map actual development, to clarify essential driving forces behind the development in urban transport and to evaluate appropriate policies and measures for a more sustainable urban transport.” (Nielsen, 2009, p. 1)

May & Minken (2003) advocate specifying the objectives and ‘break them down’ into a number of sub-objectives that are operational and measurable. For instance, the vision may be zero traffic accidents, but a reduction in the number of accidents by a certain

percentage within a certain time period represents a more realistic safety objective. The indicators of Chiang Mai city's sustainable transport planning is shown in Table 7-3.

Several of these indicators are taken from the list of indicators suggested by May & Minken (2003) and Litman & Burwell, (2006). The list of indicators was reviewed against the PROPOLIS project's list (Lautso & Spiekermann, 2004) and Sustainable Development indicators list⁶⁰ for Thailand (NESDB, 2004) to ensure its comprehensiveness. Moreover, these indicators were reviewed against the interview accounts of the planning experts who worked with the decisions maker of the city (Chapter 6). Thus, they are, to high degree, consistent with the decision makers' opinions.

There are 25 indicators in total. However, MARS can only produce 11 of these indicators. This is due to the limitation of the model and the nature of these indicators. For instance; walkability index requires a survey of footpaths in the area concerned to provide a baseline. Assumptions can then be made how different policies will affect this condition but this task is beyond MARS's capability.

In addition to the 25 indicators, a set of transport statistics variables is selected to provide a background data that will aid an understanding and explanation on the effects of the policies considered toward the behaviour of the transport system, shows in Table 7-4.

In this chapter, the vision for Chiang Mai city is established and broken down into objectives and measurable indicators. These indicators will provide input into the formation of MARS model for Chiang Mai city, which is detailed in the next chapter.

⁶⁰ NESDB (2004) is the first attempt to develop a Sustainable Development composite index for Thailand. The index comprises of 23 indicators within three categories (Economic, Social, and Environment). They are combined to for the composite index at equal weighting.

Table 7-3 Indicators of Chiang Mai city sustainable transport planning

Objective	Sub-objective	Indicators	Unit
1.Environmental protection	1.1 Efficient in the use of resources	1.1a* Consumption of fuel per trip 1.1b* Cumulative fuel consumption	(litre)
	1.2 Reduce greenhouse to a reasonable level	1.2a* Greenhouse gas emission per trip 1.2b* Cumulative greenhouse gas emission	(CO2 equivalent)
	1.3 Reduce air pollution to a reasonable level	1.3 Level of PM and No _x ⁶¹ emit from transport per trip	(tons/trip)
	1.4 Reduce noise pollution to a reasonable level	1.4 Transport noise emission above 60dbA	(Leq or Leu)
	1.5 Proportion and quality of green area	1.5 Percentage of Green area	(% of area)
2. Accessibility	2.1 Provide reasonable accessibility	2.1* Change in accessibility	(% to base year)
	2.2 Reduce automobile dependency	2.2* Percentage of trips made by non-private motorised transport	(%)
	2.3 Enable reasonable freedom of movement for vulnerable user	2.3 Walkability index	
	2.4 Control urban sprawl	2.4a* Average trip distance	(kilometre/trip)
		2.4b Average distance of housing units to city centre (assuming a single centre)	(kilometre/trip)
3. Safety	3.1 Reduce transport accidents, including non-vehicular	3.1a* Cumulative traffic injuries	(injuries)
		3.1b* Cumulative traffic deaths	(death)
4. Quality of living standard	4.1 Enhance the social, cultural, and recreation activities	4.1* Percentage of trips make by walking and cycling	(%)
	4.2 High housing standard	4.2 Residential area per capita	(sq. metre/inh.)
	4.3 Proportion and quality of public space	4.3 Percentage of public area	(%)
5. Equity and fairness within and intergeneratio n	5.1 Accessibility for non-vehicular users	5.1* Proportion of trips make by non-vehicular mode (i.e. waking and cycling)	(%)
	5.2 Accessibility for mobility impaired users	5.2 Walkability index	
	5.3 Compensation for today and tomorrow's losers	5.3 Equity impact tables	
	5.4 Ensure a fair distribution of benefits derive from taxpayer's money	5.4 Distribution of accessibility benefits by zone	
6. Culture and tradition heritage	6.1 Retain the unique culture and tradition of the city (self-immunity)	6.1a Unique culture and tradition of the city index from questionnaire	
7. Economy	7.1 Promote Sufficiency Economy in Economic dimension	7.1a Unemployment percentage	(% of population)
		7.1b Share of imported consumer goods	(% of total good consume)
		7.1c Average proportion of Household debt in relation to its monthly income	(average % of HH income)

Note: Indicators with * are indicators that **can** be produced by MARS model

Table 7-4 Background variables for Chiang Mai city sustainable transport planning

Type	Variables	Unit
Transport statistics	Average trip length by mode+	kilometre/trip
	Average trip time by mode+	minutes/trip
	Average travel speed by mode+	kilometre/hour
	Mode share by trip	share percentage

Source: modified from (Lautso & Spiekermann, 2004)

⁶¹ a generic term for mono-nitrogen oxides NO and NO₂ (nitric oxide and nitrogen dioxide)

8. Chiang Mai city MARS model

Since its inception, MARS has been applied successfully to a number of cities across Europe, Asia, North America, and South America, including a city in Thailand. These track records suggest the model has an adequate level of transferability. Nevertheless, a thorough examination on any generic model before applying it to a case study is essential, because each model is constructed for a specific purpose and to simulate a specific condition (Sterman, 2000). This is perhaps more relevant to a LUTI model, as each city has a unique land use pattern and transport systems. MARS was initially created to model Vienna, an ancient western city with over two thousand years of history. Although there may be similarities between Vienna and Chiang Mai city, it is likely that their land use and transport system have fundamental differences.

In this chapter, a critical inspection of the existing structure of MARS model and its principal assumptions will be undertaken. In the first part (Chapter 8.1), the fundamental principles of MARS and the model's structure are reviewed. The aim is to check the model's fitness for purpose and highlight any necessary modifications. Readers who are unfamiliar with MARS model should refer to Appendix F and Pfaffenbichler (2003), for comprehensive accounts on the model.

In the second part (Chapter 8.2), details of the Chiang Mai city MARS model development are described. It contains accounts on the model's principal assumptions, the quality of life indicator, and the calibration and testing processes. A concise conclusion is provided in the final part of this chapter (Chapter 8.4).

8.1. *Transferability of MARS and possible improvements*

In this section examinations of various principles and assumptions in MARS are made. The assessments aim to check the transferability of MARS and to put together a shortlist of potential improvements to the model. The list is then analysed to pick out the three most feasible enhancements to be carried to the model.

8.1.1. *Travel Time Budget (TTB)*

The Travel Time Budget (TTB) hypothesis suggests that people spend a certain amount of time on travel and will make alterations on their travel to minimise the difference from that time budget. The hypothesis appeared as early as 1961 ((Tanner, 1961), cited by

(Wee, Rietveld, & Meurs, 2006)) and has been the focus of lively discussions among transport scholars ever since (IET, 2010; Mokhtarian & Chen, 2004).

The constant TTB is one of the principal assumptions in the trip generation sub-model of MARS. The TTB principle is used together with the constant commuting trip rate (HWH) assumption to derive the total travel time and the non-work time per trip rate in the model. The adoption of this principle suggests that **MARS rejects the benefits derived from travel time saving.**

Travel time saving has been primarily used to in transport cost-benefit analysis and is based on one of the most fundamental theory of the conventional travel behaviour theory that "travel time is a disutility to be minimised" (Mokhtarian & Chen, 2004; TRB, 2012; VTPI, 2010). It is debatable whether the inclusion of TTB in MARS is a credible step forward in addressing the bias toward infrastructure construction that traditional transport model such as the FSM has (as suggested by (McNally, 2000)). A pragmatic approach is taken here to draw a conclusion on the matter; the consequences of adopting two different stances on the constant TTB are compared in Table 8-1 and assessed against the study's objectives.

Table 8-1 Comparison of two different position on constant travel time budget (TTB)

Position on constant TTB	Consequence in the context of MARS model
Acceptance of constant TTB	<ul style="list-style-type: none"> • Reject time-saving benefit derived from transport developments; hence enable transport demand control measures to be evaluated alongside transport capacity improvement measure. • Disutility of travel time can only be influenced by shifting time to different part of trips, which have different subjective values
Rejection of constant TTB	<ul style="list-style-type: none"> • Accept time-saving benefit derived from transport developments; hence it favours transport capacity improvement measure • Disutility of travel time can be influenced primarily by decreasing the main component of vehicular trip: the in-vehicle time

One of the main objectives of this study is to devise a policy package that will improve the sustainability of the city's transport sector. Thus, **the adoption of the constant TTB concept is favoured**; it will enable comparison between progressive transport measures, such as pedestrian facility improvement with the conventional ones, such as road construction project.

In the next part, four elements of TTB principle are examined in the context of the case study specific and the model structure.

a) TTB of Chiang Mai city (Case study specific)

There are only two sources providing information about the average daily travel time for the residents of the city of Chiang Mai: 2002 Punravee, (Kongboontiam, 2010) and the 2012 CM-MTS. Table 8-2 provides a comparison between the two.

Table 8-2 Comparison of average daily travel time and distance (minutes and kilometre)

Average daily	Travel time (min)	Travel distance (km)	No. of trip
2002 Punravee	44.9	17.9	2.34
2012 CM-MTS	49.3	17.8	3.14

Source: (CM-MTS, 2012)

The difference between the two average daily travel distances is minor, thus suggesting the changes of the city land use over this period maybe small. The rise in the average daily travel time may be due to an increase of congestion level. CM-MTS's average number of trip per day is higher, probably because of the exclusion of non-motorised trips by 2002 Punravee. The two sets of data suggest the travel time budget of the city is approximately 45-50 minutes.

b) Captive household location and captive drivers (Case study specific)

MARS assumes that residents will relocate their household to maintain their travel time. Chiang Mai city has two characteristics that may conflict with this assumption. Firstly, the city has a high proportion of homeowners⁶². The proportion of homeowners may decrease if the shadow population is considered but it is still significantly higher than Vienna's city⁶³. It is widely accepted that the cost of relocation for owned-accommodation is generally higher than rented-accommodation. Thus, it is likely that the residents of Chiang Mai city will accept an increase in travel time, instead of relocating their accommodation.

Secondly, residents may be willing to increase their travel time instead of increasing their expense on accommodation. A survey in Bangkok shows that office workers in the CBD area have an average commuting time of 64 minutes each way (Kheawsanun, 2004),

⁶² The NSO and the CM-MTS data show that over 80% of their respondents live in own-accommodations

⁶³ which shows 12.6% is home owner (source: <http://www.statistik.at/blickgem/gwz1/g90001.pdf>)

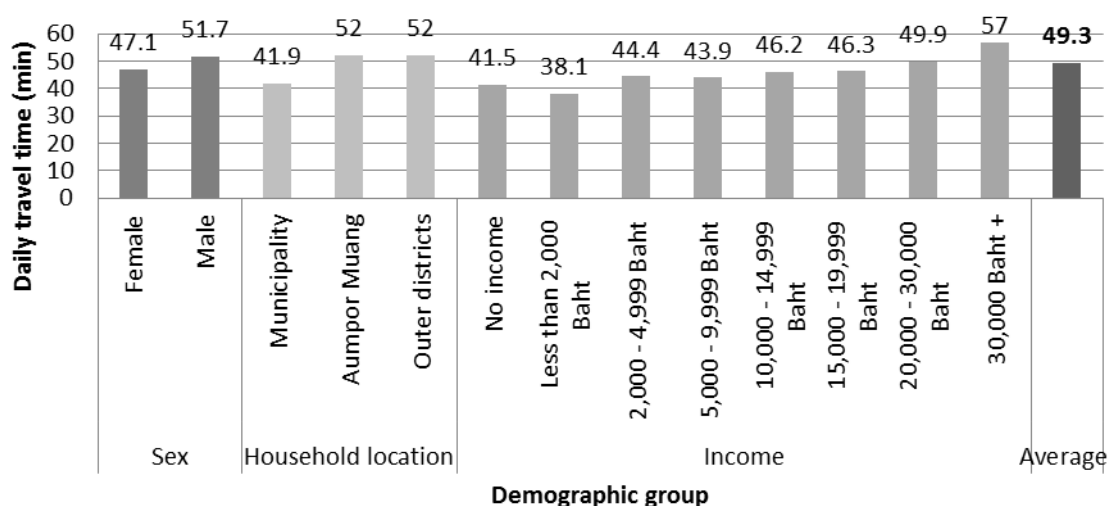
which is significantly higher than Chiang Mai city's average of 16 minutes. Although, land use and travel behaviour of Bangkok residents are different, the higher trip time suggests an increase in travel time may be an acceptable trade-off for other costs, such as accommodation.

The city's lacks of land use and mobility data records makes it difficult to assess and adjust the model to address the two points above. Nevertheless, the analysis made here has taken these points into account.

c) A singular TTB value for the study population (Model specific)

Currently, the MARS model applies a single travel time budget value for the whole study population. Although it is widely accepted that there are some constancies of travel time at the aggregate level, travel time of individuals can be highly influenced by their socio-demographic characters (Mokhtarian & Chen, 2004). The result of the CM-MTS survey also supports this observation. The variations of daily travel time are found across different demographic groups as shown in Graph 8-1.

Graph 8-1 Average daily travel time of the CM-MTS respondents, by different sex, household location, and income groups



Source: Raw data from (CM-MTS, 2012)

The graph above suggests that sex, household location, and income all influence average daily travel time. Thus, alterations to enable input of TTB value for each different demographic group may enhance the model. It is possible to assume that each zone has a homogenous demographic characteristic and assign TTB value for each zone in each year.

This will enable the simulation of how poorer elements within the population may substitute their travel time for other cost. However, this modification will entail quite an effort.

d) The dynamic nature of the TTB (Model specific)

The TTB of a population is thought to change in accordance to the 'background condition' or the environmental conditions of the population. A study by Wee et al. (2006) finds several factors that increase a population's travel time. These are: 1) Increase in the utility of travel⁶⁴, 2) Increase in the proportion of women participating in the labour market, 3) change of travel cost⁶⁵, and 4) Change in the population's demography and its travel behaviour⁶⁶.

The time horizon of MARS model is typically set to 30 years or more, which is long enough for TTB of the study population to change. The implementation of this improvement should be straight forward, but the lack of understanding in TTB change over time, and time series data of the city's TTB, may reduce the benefit of this improvement.

8.1.2. Subjective valuation of friction factor

The subjective friction factor was developed by Walther (1991), based on his observations made in German cities. The study suggests that changes in urban environment affect changes in behaviour and that there are variations on the perceptions of intensities in both positive and negative stimulus. For example, a positive stimulus can be a car-free street with even footpath and nice shade, while a negative stimulus can be hot and polluted air, narrow footpath, and streets congested with cars. Although another similar observation has been made in Vienna by Peperna (1982) (cited by (Pfaffenbichler, 2003, p. 231)), both studies were carried out in European cities.

The transferability issue of the subjective friction factors has been recognised by Pfaffenbichler (2003). He proposed the transformation of Weber-Fechner's Law, which Knoflachner (1981, 1987) (cited by (Pfaffenbichler, 2003, p. 231)) formulated to explain human

⁶⁴resulted from an increase in distance to obtain service (spatial trends), specialisation of skills, and housing market segmentation

⁶⁵ due to an increase in road safety and comfort level of car

⁶⁶ such as a decreased in household size and an increased in trip chaining

behaviour concerning transport systems. The transformed Weber-Fechner's Law reflects the stimulus of destination and mode choice's intensity or the friction factor of a certain mode between a particular O-D pair. It is equivalent to the time component part of the friction factors developed by ((Walther, Oetting, & Vallée, 1997; Walther, 1991) cited by (Pfaffenbichler, 2003)). The original and transformed Weber-Fechner's equations are shown in Equation 8-1 and 8-2

$$P = \alpha \ln(I)$$

Equation 8-1: Weber-Fechner's law

PHuman perception

αConstant factor

IIntensity of the stimulus

$$I = e^{\left(\frac{P}{\alpha}\right)}$$

Equation 8-2: Transformed Weber-Fechner's law

Pfaffenbichler (2003) concludes that the subjective friction factors are derived from the 'basic physiological laws of human behaviour'. In other words, the subjectivity is included to reflect the human internal energy expenditure on different trips components, which should be universal. He also insists that this component is likely to be transferable 'as long as the urban environment is roughly comparable' and that the cost component is likely to vary the most between different urban environments and the sensitivity of the time component, which can be adjusted to fine tune and reflect an adaptation factor for each case study.

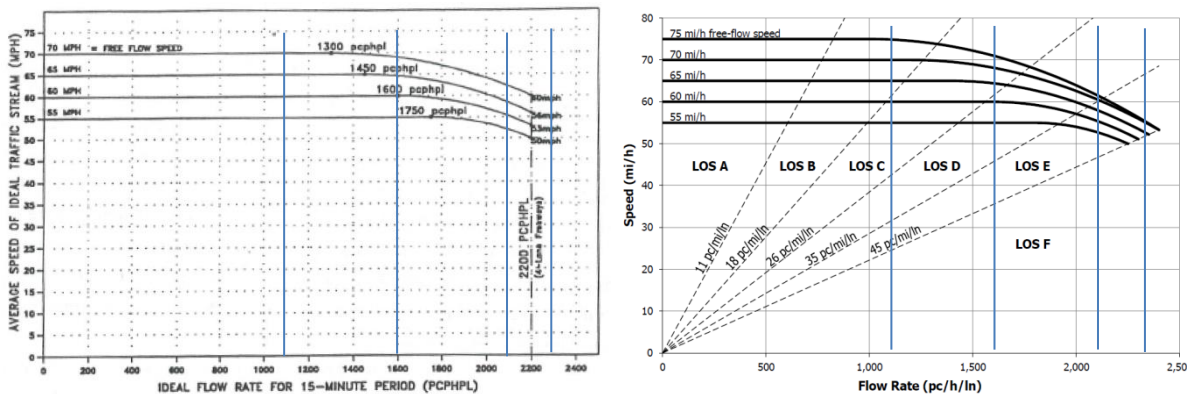
In this study, the subjective values were adjusted in a heuristic manner to reflect the changes in urban environment, such as the quality of infrastructure and meteorological conditions. The adjustment was carried out as part of the calibration process. This pragmatic approach was chosen due to the lack of past study on the topic for the city.

8.1.3. Area speed flow relationship

The adaptability of the area speed flow relationship to the case study was addressed in two steps. First, the HCM's 1994 speed flow curve used in MARS was checked. It was

found that the curve had been updated in 2010 with two additional features: (1) speed flow data for 75-miles/hour on basic freeway segments, and, (2) the reassessment of the method employed to predict free flow speed (Roess, 2011a). The two curves are compared in Graph 8-2 below.

Graph 8-2 Comparison between the freeway speed–flow curves from HCM 1994, uses in MARS (left) and the revised HCM 2010 (right)



Note: (LOS = level of service; pc = passenger car; ln = lane)

Source: edited from (TRB, 1994, pp. 1–2) cited by (Roess, 2011b) and (Ryus, Vandehey, Elefteriadou, Dowling, & Ostrom, 2011)

The comparison shows close similarities between the two sets of curve. The main difference being the addition of 75m/h curves. Therefore, the update of the speed-flow curves made in 2010 did not require an update to the speed-flow equations in MARS.

Second, the omission of speed flow relationship for non-commuting trips (i.e. off-peak trips) was examined. In MARS, off-peak trips are assumed to spread out over the non-peak period; in other words congested conditions are not expected during the off-peak hours.

An analysis to identify the trends between the off-peak and the peak traffic volumes was carried out to assess the transferability of this assumption to the case study⁶⁷. The analysis found that the average ratio between the off-peak and peak traffic volumes increased from 0.72 in 2001 to 0.81 in 2006. This result suggested that the off-peak traffic

⁶⁷ The analysis examines the traffic data of 7 different junctions at two different points in time: 2001 (data from the JICA study) and 2006 (data from the CTS study). However, only one out of the seven junctions has data available for both periods.

volume was increasing in relation to the peak traffic, thus application of the speed-flow curve during the off-peak period should be considered in CNX-MARS.

8.1.4. PT overcrowding

PT overcrowding is the occupancy rate of public transport that can be adjusted to reflect the sensitivity of public transport user to overcrowding. The transferability of PT overcrowding should be a straightforward exercise. However, with limited information available on the city's PT service, the default value was used and adjusted in a heuristic manner.

8.1.5. Accessibility

The accessibility equations in MARS are simple location-based distance ones, defining the relative accessibility based on the travel time between two points. It is an efficient method to assess accessibility at the macro level. However, based on the criteria proposed by Geurs & Wee (2004), two improvements were considered for incorporation into CNX-MARS with regards to accessibility analysis.

Firstly, the inclusions of components that affect accessibility, such as age, income, employment were considered. This improvement would embrace variations in transport needs across different socio-demographic groups. MARS assumes homogeneity of a zone, which effectively ignores the influences of these components. Secondly, MARS assumes that accessibility values remain constant throughout a modelling year, which may be appropriate for its aggregate nature. The inclusion of this temporal component into CNX-MARS would enable variations in accessibility at different times to be analysed.

However, the implementation of these suggestions proved overly complex and outside the scope of the research budget. After much deliberation, a decision was made to use the existing accessibility analysis of MARS within CNX-MARS. The aggregated accessibility values for all zones within the study area, measuring the aggregate number of opportunities for shopping and working, were used.

8.1.6. *Modes of transport*

MARS includes six transport modes: bus, train, car, motorcycle, bicycle and walking. Discussion on two of these elements point to some of the limitations of MARS with regard to the scope of this study *viz* 1) assumptions about the use of motorcycles, 2) the challenge of assessing the shared-taxi service

MARS treats motorcycle traffic as factored car traffic (i.e. a converting factor of 0.2 or 0.3 is used to translate motorcycle to car traffic). Within Mars the motorcycle also adopts the same speed curve as the car. This means that motorcycle vehicles are assumed to travel and queue behind car vehicles in a straight line, while in reality ‘staggered effects⁶⁸’ of motorcycle traffic can be observed at junctions and links. This is particularly acute in Chiang Mai as motorcycles weave their way to the front of the traffic queue at traffic lights, often in flagrant disregard of the Highway Code. However, MARS cannot simulate this effect as it does not have a network assignment module; it was therefore, not possible to modify this element of the model to reflect traffic conditions in Chiang Mai

The city’s shared-taxi service has two types of operation: an on-demand service and a fixed route service. Various studies have suggested that around 80% of the fleets operate as on-demand service (Chansri, 1994). The literature review and personal observation also led to the conclusion that the shared-taxi is an obstruction and a pivotal point for the transformation of the public transport service of the city. It was considered important to include assessment of the shared-taxi in CNX- MARS, despite limited available data on the service operation. A pragmatic approach was taken to model the shared-taxi service using MARS’s bus service components, with some adjustments to the input data, such as OD distance and waiting time. In addition, detour factors were used to simulate the indirect routes taken by the shared-taxi.

8.1.7. *Vehicle availability*

MARS uses the percentage of residents with a driving license as an accurate estimation of the percentage of people who legally have access to car. This is appropriate for a city with strict traffic enforcement, but this is not the case in Chiang Mai. As shown in

⁶⁸ The motorcycle vehicles filter through traffic gaps and form staggered queues at stop lines

Table 8-3, CM-MTS shows that a high proportion of respondents who have access to and drive vehicles do not have an appropriate driving licence.

Table 8-3 Ownership of appropriate driving licence for different vehicle availabilities (in % of each group)

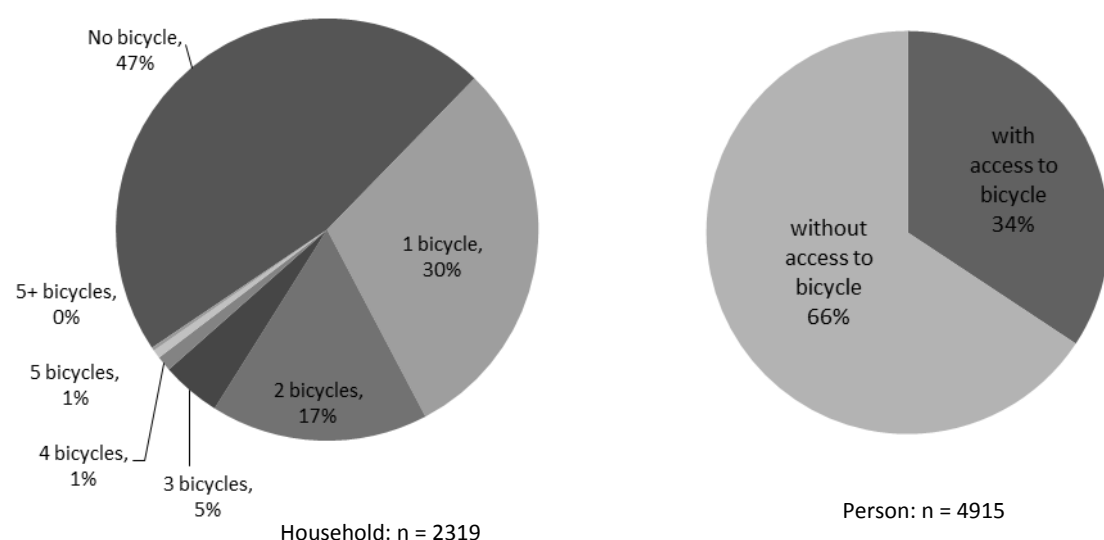
	..has appropriate driving licence	
	Yes	No
..has car availability	88.0	12.0
..has motorcycle availability	73.5	26.5
based on 5474 samples		

Source: CM-MTS 2012

The foregoing led to the conclusion that vehicle availability should be used instead of license ownership in the case study.

Next, MARS assumes that bicycle availability is universal. However, this proved not to be the case in Chiang Mai as shown in Graph 8-3.

Graph 8-3 Bicycle ownership in household and accessibility to bicycle by person



Source: CM-MTS 2012

The survey found only 53% of the respondent households have at least one bicycle and only 35% of the population have personal access to a bicycle. Without an additional function to enable the adjustment of bicycle availability/accessibility within MARS, an overestimation of cycle trips is likely. However, it was found this improvement also entails a complicated restructure of the model, even though it seems simple enough from a mathematical point of view. With the relatively low cost of acquiring a bicycle in

comparison to buying a car or a motorcycle, it was decided to proceed with the existing bicycle assumptions within MARS.

8.1.8. Tour rates

Four elements of the tour rates are addressed here.

a) Constancy of the Home-work-home (HWH) tour rate

The constancy of the HWH tour rate is one of the principle assumptions in the trip distribution and mode choice sub-model. It assumes that all of the population make a constant number of commuting trips on working days. This assumption seems to fit well if the employment structure is dominated by the employee class⁶⁹. However, Chiang Mai city has a higher mix of the self-employed class and those employed in the agriculture sector. A comparison is made between the professional status of Vienna and Chiang Mai to elaborate on this point in Table 8-4.

Table 8-4 Comparison of Vienna and Chiang Mai province professional status

			%
Professional status	Vienna 2011	Chiang Mai 2010	
Total Employment	948,871	965,545	
Standard forms employment	81.9	52.1	
Note: For Chiang Mai city - the standard form of employment combine Civil servants and private employees, who have regular working hours			
Source: Statistics Austria and NSO Thailand			

Additionally, the CM-MTS data found that there are differences between the tour rate for the self-employed class and the agriculture sector as shown in Table 8-5.

The self-employed class and the agriculture sector have higher HWH tour rates than those in the employee class; they make approximately 10% more trips per day than those in the employee class, but their trips have lower averages of travel time and distance. This suggests that these classes make more but shorter trips per day. It was found that the MARS structure could be adjusted to enable input of two mobility data sets for different employment classes. It was decided not to make the changes, however, as these would have proved very time consuming and the difference in tour rates was not considered sufficiently high enough to significantly affect the result of MARS model to justify the changes

⁶⁹ For example, over 80% of Austrian population are in the service and the industrial sectors (White and Blue Collars workers)

Table 8-5 Comparison between of travel behaviour of different professional status

Employment class	NSO (2010) % of pop			
		Average daily travel time (min)	Average daily travel distance (km)	Average number of trips per day
Employee class	52.1			
Civil Servant/state worker/state enterprises	6.5	63.5	25.1	3.2
Permanent employee/sales	29.8	54.4	20.1	3.1
General employee/freelance	10.1	44.8	17.0	3.3
Police force/soldier	n/a	62.8	37.1	2.8
Academic sector – state and private	5.7	n/a	n/a	n/a
Self-employed class	47.9			
Agriculture/fishery/herdsman	26.8	40.6	11.0	3.5
Craftsmanship	1.3	40.3	14.4	3.6
Personal business/proprietor	18.1	46.9	18.2	3.4
Other	1.7	38.6	9.3	3.2

Source: (CM-MTS 2012 and NSO Thailand)

b) Symmetrical tour rate

MARS considers two types of tour: Home-Work-Home (HWH) and Home-Other-Home (HOH), both are home-based symmetrical tours with a single destination. The CM-MTS analysis showed that the proportion of these trips for Chiang Mai accounts for approximately 60.6% of the total daily trip as shown in Table 8-6.

In comparison with Pfaffenbichler's (2003) estimation that his Vienna MARS model considered 58% (1991) and 71% (1995) of the city's daily trips, the percentage of trips considered here is adequate. There is room for improvement; however, as the current MARS model cannot include non-home based trips because of the symmetrical tour structure. An improvement to the transport sub-model to include asymmetrical tours would enable non-home base trip to be included.

Table 8-6 % of trip purpose made by the CM-MTS respondents classified into Non-home based⁷⁰ and home based trips (in % of total trips)

				%
	Non-home based	Home based	Trip considered in Mars	
Trip purpose				
Work trip	4.1	18.5		18.5
School/University trip	0.6	6.5		0.0
School run	1.8	4.1		0.0
Shopping	2.9	9.2		9.2
Going home	0.0	42.0		30.3*
Go to eat	2.5	1.5		1.5
Business matter	0.0	0.2		0.2
Temple / Church	0.7	2.4		0.0
Leisure / exercise / relax	0.3	1.5		0.0
Personal matter	0.2	0.6		0.6
Others	0.1	0.3		0.3
Sum	13.2	86.8		60.6

Note: * The Going home trip % considered by MARS is estimated based on the symmetrical trip assumption
Source: Analysis of raw data from CM-MTS

c) *Inclusion of school and school run trips*

An inclusion of school trips and school run trips could also increase the percentage of trips considered by 13% and 6%, respectively. School trips are defined as trips made by the students themselves to their institutions, whereas the school-run trips are trips made by their parents or guardians to drop off or pick up their children. The inclusion of these two trip types would improve the model as both are peak time trips and, potentially, they can significantly affect the demand factors and the speed flow calculation of the model.

A method to accommodate this limitation was found by including school trips as a number of working places in a zone, because it has a similar trip time pattern to working trips. Some adjustments to the magnitudes of attraction were necessary to account for the differences. CM-MTS revealed that school trips have the highest average travel distance and time among all trips purpose, which suggests a higher willingness to travel a further distance for such trip. Nevertheless, at the aggregate level of MARS, it was thought adequate to treat school places as workplace, with an assumption that those driving to school have similar vehicle availability to the workforce.

The inclusion of the school-run trips proved to be more complex. School-run trips are an additional part of a trip chain i.e. the driver will tend to make school run trip *en-route*

⁷⁰ The definition of a Home-Based trip is a trip that has Home either as its origin or destination.

to their workplace or on the return home trip. An analysis of trip purpose by sequence was made to confirm this supposition. The trip sequence of CM-MTS respondents by trip purpose is shown in Table 8-7.

Table 8-7 % of trip purpose across each trip sequence (in % of total trips in each sequence)

	% of trip in each sequence			
	1st trip	2nd trip	3rd trip	4th trip
Trip purposes				
Work	45.4	6.4	29.4	5.1
School run	9.0	1.3	8.7	3.6
School/University	19.9	1.3	1.6	0.4
Shopping	17.6	6.2	18.6	5.8
Business matter	0.4	0.0	0.4	0.0
Go to eat	0.7	8.5	4.1	1.7
Going home	0.1	73.9	24.0	80.4
Other	6.8	2.4	13.3	3.0
Total	100.0	100.0	100.0	100.0

Note: CM-MTS recorded up to 8 trips, but only the first four trips are shown here as the average no. of trips per day is 3.1

Source: Raw data from CM-MTS 2012

The result indicates a higher proportion of school run in the first and the second last trips (9%, and 8.7% respectively), in comparison with the 2nd and the final trips (1.3% and 3.6% respectively). Thus, drivers tend to make a school run trip as their first trip before work and their second last trip before going home.

The analysis above confirmed that to include school run trips, the model must be able to incorporate asymmetrical tour and additional trip purpose with different attraction equations, which was found to be too highly complicated to execute within available resources and budget.

d) Shopping trips

MARS derives attractions of shopping trips from the number of workplaces in the retail sector of each destination zone. This approach raises two transferability issues for the case study. Firstly, the official number of workplaces in the city is thought to be inaccurate

as it reports only registered workplaces. It is known that there are a high number of unregistered workplaces in the retail sector, especially in the city's marketplaces⁷¹.

Secondly, the number of workplaces in the retail sector may not reflect an attractiveness of modern shopping centres accurately. Over recent years, a number of car-orientated shopping centres have sprung up around the city. They often combine dining and leisure facilities, such as restaurant, food hall, and cinema to attract customers. The combined facilities increase their attractiveness as a destination. An alternative approach should be employed to reflect the attractiveness of these shopping centres⁷². There are currently at least 10 shopping centres within the Aumpor Muang district. Figures 8-1 indicates the locations of the marketplaces and shopping centres mentioned.

Thus, the current assumptions on shopping trips attractiveness may lead to an underestimate of such trips. However, to accurately include such trips would require detailed information on facilities and floor space of each shopping centre, which was not available.

8.1.9. Frequency of household relocation

There is a lack of information in the city's records concerning internal household relocation. Empirical evidence, however, suggests that the city has two main groups of residents with different relocation behaviours. The first group are local residents of the city; they are likely to be permanent homeowners and stay longer in one location. The second group are non-local employees and students, whose origin can be within Thailand, or other countries (such as Burma, Lao and Cambodia). This group is traditionally more mobile and tend to stay in rented accommodation. They also tend to belong to the non-registered population (i.e. the shadow population) of the city.

Despite these differences, the current MARS model uses a single relocation year value for all its residents. An additional household relocation model within MARS will be necessary to enable the analysis of these two different relocation behaviours. Such modification is highly challenging as it involves changing the model at a fundamental level.

⁷¹ There are at least 11 major fresh markets within the municipality area, the number is likely to be more if the Aumpor Muang and the outer districts areas are included.

⁷² Perhaps a pragmatic approach to grade the attractiveness of shopping centre based on floor space and facilities' qualities.

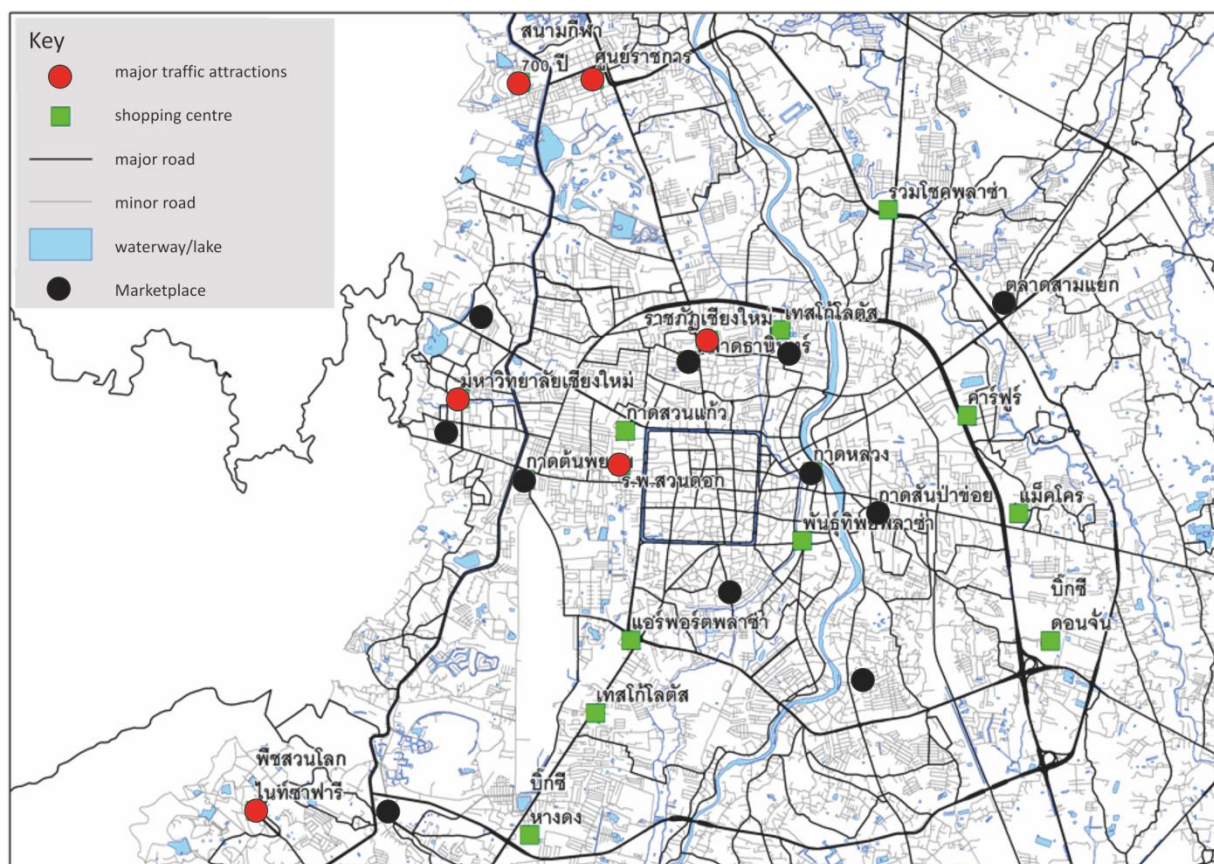


Figure 8-1 Location of marketplaces and shopping centres in the municipality area

Source: modified and translated from (CMU, 2012a)

8.1.10. The quality of life indicator

The quality of life's definition is broad and subjective. MARS uses the quality of life to indicate relative attractiveness for the residents to choose their residential zone. MARS assumes that the share of green space within each zone is an indicator of the quality of life within that area. However, it was questionable whether this approach was appropriate for this case study as other factors, such as accessibility received a higher priority.

Moreover, Chiang Mai's policy on green space is unclear and has weak enforcement. These factors will enable green areas to be converted to residential unit so long as there are demands for additional housing. Thus, a combination of other factors was used to determine relative attractiveness of the zones. This modification was relatively straightforward to undertake.

8.1.11. *Update zonal demographic characteristic*

MARS tracks the movement of its population but does not update the demographic characteristics of the zones to match the inter-zonal movements. In other words, the model assumes that zonal demographic characteristics remain fixed throughout the modelling years. Modifications to enable the model to update its zonal demographic data would provide additional feedback loops and improve the model's general performance. However, this improvement requires a major reconstruction of the model and perhaps deserves a thesis of its own.

8.1.12. *Update emission and fuel consumption module*

MARS can be modified to produce different outputs including emission and fuel consumption. An update to the emission and fuel consumption module with data from Thailand would improve the output of the model. It was found that a suitable emission and fuel consumption data was available from Koan Kean University, Thailand.

8.1.13. *Selecting improvements and conclusion*

The forgoing sections of this chapter have listed a number of possible improvements that could enhance MARS. However, resources were limited to support the implementation of all these enhancements. All possible improvements were assessed, however, to find the most feasible to implement. Table 8-8 lists and ranks the improvements according to their final scores, which is a sum of the three following categories: 1) level of difficulty to implement, 2) the estimated magnitude of its impact, and 3) the availability of relevant data. These scores are based on my personal judgement in consultation with Dr Paul Pfaffenbichler, the author of MARS.

The following three measures were selected for the implementation.

- Quality of life indicator adjustment
- Addition of the Shared-taxi (Song Teaw) mode
- Construction of emission and fuel consumption module

Table 8-8 Ranking table of the proposed improvements to MARS

Improvement proposed	Benefit	Difficulty (1 high - 5 low)	Impact (1 low - 5 high)	Data use (1 high - 5 low)	Score sum
1. Travel time budget					
1.1 Multiple TTB for different income groups	Enhance the transport sub-model	3.0	2.5	2.0	7.5
1.2 Variable TTB for different model years and zones	Enhance the transport sub-model	5.0	2.5	2.0	9.5
2. Speed flow relationship		4.0	1.5	4.0	9.5
2.1 Includes some non-commuting trips into the peak period	Enhance the transport sub-model	4.0	1.5	4.0	9.5
2.2 Applies speed flow curve to off-peak trips	Enhance the transport sub-model	3.0	2.0	4.0	9.0
3. Mode					
3.1 Addition of the Shared-taxi (Song Teaw) mode	include the Shared-taxi in the transport policy assessment	3.0	3.5	4.0	10.5
3.2 Inclusion of freight transport	Integrated freight-passenger transport assessment	1.0	2.0	3.0	6.0
4. Enables the adjustment of bicycle availability	Allow lack of bicycle availability to be modelled	2.0	2.5	5.0	9.5
5. Tour rate					
5.1 Enables variable tour rate for different groups	Enhance the transport sub-model	3.0	3.0	3.0	9.0
5.2 Enables asymmetrical tour rate	Increase % of trips included in MARS	1.0	3.5	3.0	7.5
5.3 Adds additional indicators for Shopping trips	Enable concentrated shopping area such as shopping mall to be modelled	4.0	3.0	3.0	10.0
5.4 Inclusion of School trips	Increase trips included by 13%	4.0	4.0	2.0	10.0
5.5 Inclusion of School run trips	Increase trips included by 6%	2.0	2.0	3.0	7.0
6. Household relocation models based on two income groups	Enhance the household relocation sub-model	1.0	4.5	3.0	8.5
7. Adjusts the quality of life indicator	Enhance the household relocation sub-model	5	3.0	3.0	11.0
8. Update zonal demographic characteristic	Enhance the model in general	1.0	5.0	3.0	9.0
9. Update emission and fuel consumption module	Enable emission and fuel consumption outputs	4.5	3.0	4.5	12.0

8.2. *Development of the model*

Development of Chiang Mai city MARS (CNX-MARS) began after completing a transferability appraisal in early 2011. By mid-2011, the addition of the shared-taxi mode was complete. Two other modifications; adjustments of the quality of life indicator, and construction of fuel consumption and emission were carried out and finished in late-September 2011. Planning for the household mobility survey then commenced. This was tailored to gather data for the model in October 2011.

The model was targeted for completion in May 2013 but the development process was halted in November 2011. The Climate Change and Infrastructure Research Unit (ICM), Faculty of Engineering, Chiang Mai University expressed interest in adopting the model for one of its projects. The project was commissioned by the Chiang Mai municipality to deliver an Integrated Land Use and Sustainable Urban model for the city. The development of the model was stopped to review the initial CNX-MARS model as well as the planning of the survey. These additional resources from the ICM enabled an increase of the sample size from 300 to 2,000 households. Representatives from ICM and IVV-TU Wien also agreed that two modifications should be made: the amendments of the zone structure and revisions of input data.

The survey was carried out between November 2011 and May 2012. It took six months to collect the data and a further six months to process and complete the survey report, which was published in June 2013. However, the project suffered a significant delay due to time taken to collect additional data by ICM and other issues related to their projects. However, development of the model continued based on the initial zone structure (28-zones). Figure 8-2 shows the CNX-MARS zoning system used in this study.

Two types of data sources were used to complete the model: primary data and secondary data sources. The primary data sources come from the Chiang Mai City Mobility and Transport Survey (CM-MTS 2012), undertaken by the author. The CM-MTS is tailored to capture data for MARS. It collects mobility data that is normally excluded, such as trips made by non-motorised mode, walking time to parking spaces, and parking search time. A brief description of the survey is contained in Appendix C.

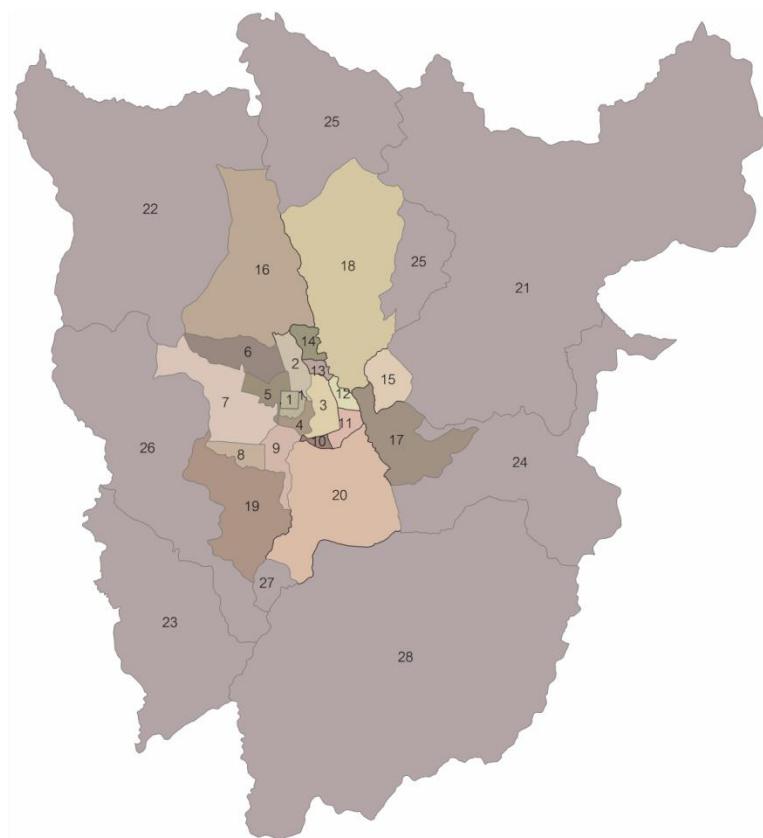


Figure 8-2 CNX-MARS zone system (28 Zone)

The secondary data can be divided further into two types: statistical data and administrative data. The former was collected from the National Statistical Office Chiang Mai (CM-NSO) and the latter from the Chiang Mai municipality and the Ministry of Interior (MOI). The modification of the zone structure required revisions of data collected from secondary sources.

The model was finally completed and calibrated with the unstinting support of Dr Paul Pfaffenbichler in March 2014.

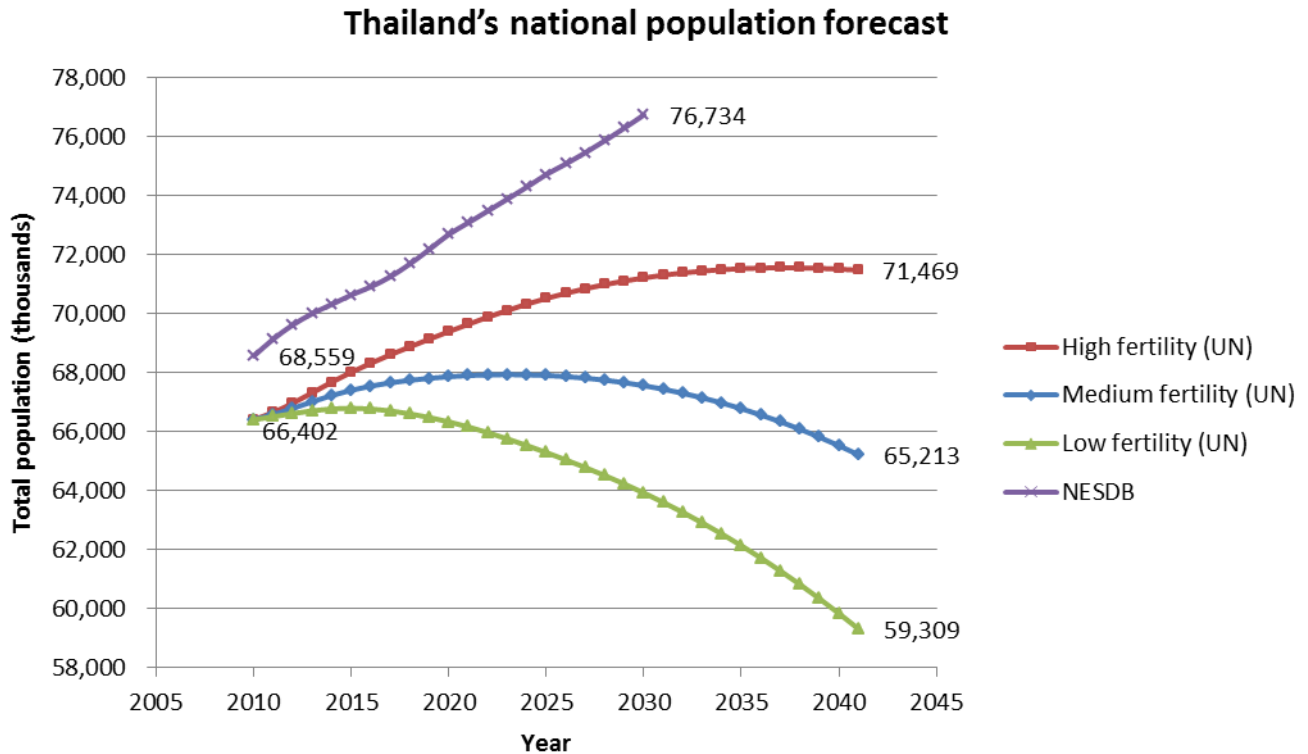
8.2.1. Principle assumptions of the data used

Population projection

The review of available data did not find any official projection of the city's population. Thus, the projections were derived from other sources. Two forecasts are available at national level; the UN's population division and the National Economic and Social Development Board (NESDB). The NESDB's forecast is made for 2010-2030 at the national level and also the provincial level. In addition, the UN's Population Division also

made a 2010-2100 long term population projection for each country. The two sets of data are compared in Graph 8-4.

Graph 8-4 Thailand's national population forecast 2011-2041



Source: UN's population division 2012 and NESDB 2011

The three UN's scenarios with different fertility rates show the population will continue to increase before levelling off and then decreasing. The year the population reaches its plateau depends on the assumed rate of fertility. In contrast, the NESDB's forecast shows continuous increment with an average rate of 0.6% per year. The NESDB's prediction reflects its assumption that the population growth will not be hindered in the foreseeable future. In other words, NESDB does not assume a limit to growth whereas the UN's prediction takes a different approach. The NESDB's assumption may stem from observation that Chiang Mai city is still developing and has much room for growth, which is reasonable. Therefore, the growth rate of the city's population in this study was assumed to be linear with awareness of the limit of growth.

A preliminary check on population data shows that there are inconsistencies in the average household size data. These are compared in Table 8-9.

Table 8-9 Comparison of different average household sizes and adjusted values

Area	DOPA (2010)*	CM-Municipality (2010)*	CM-NSO (2010)	CM-MTS (2012)	Adjusted HH-size (2011)
Municipality	1.9	1.9	n/a	3.1	2.6
Aumpor Muang	1.7	n/a	2.6	3.2	3.0
Outer areas	2.2	n/a	2.9	3.3	3.3

*-calculated value

Source: DOPA, CM-NSO, and CM-municipality

The household size from the DOPA and the CM-municipality are calculated values from their population and number of households with in the area. They are significantly lower than the CM-NSO and the CM-MTS household's survey data, because they are based on registered population. In other words, they do not take into account the shadow population or unregistered population who live in the area. The adjusted values are estimated values; they represent a heuristic approach to take account of the unregistered population. The population in each area is recalculated from these values and yields 45% more residents in the municipality, 79% in the Aumpor Muang, and 52% in the Outer areas. These are within the estimated number of people making up the shadow population outlined in Chapter 4.

Next, the projected population, household unit, and density are shown in Table 8-10.

Table 8-10 Projected population, household units, and density for each area

Area	Population (person)			Household (unit)			Density (person / sq. km.)		
	2011	2041	Annual growth rate	2011	2041	Annual growth rate	2011	2041	Annual growth rate
Municipality	199,722	168,767	-0.6%	76,816	80,365	0.2%	4,968	4,198	-0.6%
Aumpor Muang	175,272	237,484	1.0%	58,424	91,340	1.5%	1,554	2,106	1.0%
Outer areas	486,912	748,393	1.4%	147,549	267,283	2.0%	989	1,520	1.4%
Total	861,906	1,154,644		282,789	438,988				

The density trends are directly related to population; however, the growth rates of household units are based on past trends. It is assumed here that the density of the municipality area will decline linearly by -0.6% per annual to reach 4,200 person per square kilometre over a 30 year period. In contrast, other areas will see annual increases in density; 1.0% in Aumpor Muang area and 1.4% in Outer area.

Employment and establishment

The official number of people employed in the city is only aggregated into district level. Thus, the number of employments in each zone is an estimated value, in proportion to the zone population. This estimate is based on 2011 national and 2004 Chiang Mai province data. It is estimated that 60%⁷³ of the population are active members of the workforce (60% employed, 2% unemployed), and 38% fall outside normal employment age.

An adjustment is made to the proportion above to account for School trip (students who drives themselves to school); 1% of the outside employment group is relocated to employed group. Thus, it is assumed in this study that 61% of the population is employed, 2% unemployed and 37% are students, retirees or unable to work through disability.

In addition, it is assumed that the proportion of the active workforce will remain the same at 63% throughout the modelling years. The increase in employment will only affect the proportion between the employed and unemployed. It is assumed here that in year 30 the unemployment rate will drop by half to 1%. This yields 0.06% growth in the employment rate in relation to the population.

The number of workplaces in each zone is estimated from the number of employments in that zone. The estimation is based on the average sizes of an establishment in each zone from the CM-NSO 2012 employment survey. Thus, it is assumed that in the first model year all workplaces have a full complement of employees.

Household relocation period

There is a lack of data on the average period before a household relocates within the city. The most relevant data is the NSO population indicators that shows 7.9% of Chiang Mai province's population have relocated within the past 5 years. Thus, a generic value of 15 years has been assumed here.

Vehicle ownership and driving licence

The CM-MTS survey reports that in 2012 the car ownership of the city was 304 per 1000 capita and motorcycle ownership was 535 per 1000 capita. It is assumed here that car ownership will increase to 400 per 1000 capita in 30 years (+0.9% annually), while

⁷³ Vienna data in 2011 shows 59% is in active workforce

motorcycle ownership will drop slightly to 500 per 1000 capita (-0.2% annually) (see Chapter 4).

Driving licence rate typically represents the percentage of the population who have the ability to drive. However, it does not include the actual accessibility to vehicle, which was captured by a concept called vehicle availability⁷⁴ in CM-MTS as shown in Table 8-11.

Table 8-11 CM-MTS 2012 respondents with driving licence and vehicle availability (%)

Mode	% of population with driving licence	% of population with vehicle availability	Adjusted driving licence value
Car	42%	36%	42%
Motorcycle	57%	66%	66%

Source: CM-MTS 2012

The data shows that while the proportion of respondents with car driving licence (42%) is higher than car availability (36%), the proportion of those with a motorcycle driving licence (57%) is lower than those that have motorcycle availability (66%). These results indicate that some of those with car driving licences may not have access to a car and a proportion of motorcycle drivers may not have a licence. Previous analysis also shows that 12% of car drivers and 26.5% of motorcyclists in Chiang Mai do not have appropriate licences. Thus for Chiang Mai city, the proportions of residents with driving license (ability to drive) are adjusted to 42% for the car and 66% for the motorcycle.

It is assumed here that the proportion of city residents with the ability to drive a car will increase to 55%, and to 70% for motorcycles over a 30-years period. The annual growth rates are 0.9% and 0.4%, respectively.

Average floor spaces, rent, and land value

The average rent per month and the average floor space per flat are the CM-MTS's results. The number of unoccupied flats in each zone is assumed to be a generic 8% of the total number of residence units in the zone. The average land values are obtained from an online-based survey that collected market prices of lands in different zones within the city's area.

⁷⁴ Vehicle availability indicates accessibility to a vehicle based on priority of use i.e. if a household of two (wife and husband) own a car, but the wife uses it mostly. Then only the wife has availability to that vehicle.

Distance matrix

The distance between each zone is derived from the straight line (“as the crow – flies”) distances. These distances are multiplied by two types of factors. The first type of factor is the road network detoured factors, between the three types of area. The factors are calculated from a set of the city’s distance matrix obtained by a GIS-based network analysis. The second type is the mode specific route factor. This is an attempt to replicate effects from network management measurements that favour a particular mode (i.e. pedestrian zone or motorcycle access only). Table 8-12 shows the combined factors used in this study.

Table 8-12 Combined distance multipliers for different modes of transport (baseline)

Origin – Destination	Combined multiplied factors for crow-flow distance			
	Private vehicle	Bus	Non-Motorised	Shared-taxi
Municipality – Municipality	1.59	1.59	1.37 (0.9)	2.39 (1.5)
Municipality - Aumpor Muang	1.71	1.71	1.47 (0.9)	2.57 (1.5)
Municipality - Outer Districts	1.37	1.37	1.17 (0.9)	1.78 (1.3)
Aumpor Muang - Aumpor Muang	1.85	1.85	1.85	2.4 (1.3)
Aumpor Muang - Outer Districts	1.55	1.55	1.55	1.87 (1.2)
Outer Districts - Outer Districts	1.47	1.47	1.47	1.76 (1.2)

Note: a) No. in parenthesis is ratio of the multiplied factor to the private vehicle; none is shown if the value is the same b) External zones have the same multiplied factors as the Outer districts

The non-motorised modes have the lowest combined factors because it can omit one-way and other traffic regulations to obtain the shortest routes. The shared-taxi mode has the highest factor because of its nature.

Average speed

The average speeds between zones are assumed values based on CM-MTS’s results. They are calculated based on the estimated free flow speed between certain origins and destinations. Table 8-13 shows the average speed between different zones.

Table 8-13 Average speed between different zones for car and motorcycle

Origin – Destination	Free flow (km/h)	Car		Motorcycle	
		Peak	Off-peak	Peak	Off-peak
Municipality - Municipality	30	21 (0.7)	24 (0.8)	23 (0.8)	26 (0.9)
Municipality - Aumpor Muang	50	38 (0.8)	43 (0.9)	38 (0.8)	43 (0.9)
Municipality - Outer Districts	50	38 (0.8)	43 (0.9)	38 (0.8)	40 (0.8)
Aumpor Muang - Aumpor Muang	60	45 (0.8)	51 (0.9)	45 (0.8)	48 (0.8)
Aumpor Muang - Outer Districts	70	56 (0.8)	63 (0.9)	53 (0.8)	58 (0.8)
Outer Districts - Outer Districts	70	56 (0.8)	63 (0.9)	53 (0.8)	58 (0.8)

Note: a) No. in parenthesis is ratio of speed to free flow speed, none is shown if the value is the same b) the external zones have the same speeds as the outer districts

Public bus service characteristics

Data on characteristics of the bus service is limited. Currently, the only bus service is run by the municipality. The service has no dedicated bus stops. The assumed values for this study are listed in Table 8-14.

Table 8-14 Assumed public bus service characteristics

Area	Walking time to stop (min.)	Interchange (min.)	
		Peak	Off-peak
Municipality	5.0	10.0	10.0
Aumpor Muang	5.0	10.0	10.0
Outer districts	n/a	n/a	n/a

Origin-Destination	Fare per trip (Euro)		Headway (min.)	
	Peak	Off-peak	Peak	Off-peak
Municipality – Municipality	0.5	0.5	30.0	60.0
Municipality - Aumpor Muang	0.5	0.5	30.0	60.0
Municipality - Outer Districts	n/a	n/a	n/a	n/a
Aumpor Muang - Aumpor Muang	0.5	0.5	30.0	60.0
Aumpor Muang - Outer Districts	n/a	n/a	n/a	n/a
Outer Districts - Outer Districts	n/a	n/a	n/a	n/a

Note: a) the external zones have the same parameters as the outer districts

Shared-taxi service characteristics

Data on characteristics of the shared-taxi was not available due to its self-organised nature and lack of research studies on the subject. However, some data, such as fares, were obtainable. The assumed values for this study are listed in Table 8-15.

Table 8-15 Assumed shared-taxi service characteristics

Area	Walking time to stop (min.)	Interchange (min.)	
		Peak	Off-peak
Municipality	3.0	3.0	5.0
Aumpor Muang	5.0	3.0	5.0
Outer districts	15.0	3.0	5.0

Origin-Destination	Fare per trip (Euro)		Headway (min.)	
	Peak	Off-peak	Peak	Off-peak
Municipality – Municipality	1.0	1.0	3.0	5.0
Municipality - Aumpor Muang	1.5	1.5	5.0	10.0
Municipality - Outer Districts	2.5	2.5	10.0	15.0
Aumpor Muang - Aumpor Muang	2.5	2.5	5.0	10.0
Aumpor Muang - Outer Districts	3.8	3.8	10.0	15.0
Outer Districts - Outer Districts	5.0	5.0	15.0	20.0

Note: a) the external zones have the same parameters as the outer districts

Fuel price and rates of increase

The base year fuel prices are assumed at 30 Baht (0.75 Euro) for Diesel and 43 Baht (1.08 Euro) for Petrol. The annually increase rate is assumed at 2.9% for Diesel and 1.9% for Petrol. These rates are much lower than the average annual increase in crude oil price during 2000-2014 period at 11.3% per annual⁷⁵. The conservative rates are used here to reflex the government policy to maintain oil price at certain stable levels. The fuel usage ratio (i.e. vehicle fleet) is assumed to be 50:50.

8.2.2. Quality of life indicators

In this study, the quality of life indicator is a composite index based on three attributes: 1) average household income, 2) average rent, and 3) average land price in each zone. The three attributes are sorted into five bins, in accordance with their ranges. The scores are summed for each zone and are used to provide relative quality of life indicators for each zone within the area of interest in the initial model year. Equal weighting of these attributes is assumed.

8.2.3. Homogenous use of land within each zone

One of the assumptions within MARS is that the characteristics of land use within each zone remain homogeneous. This assumption is based on the standards of European/western cities where land development is controlled and strict regulations are applied with regard to zoning. This is not always the case in Chiang Mai and other Asian cities, where, for commercial gain, influential businessmen with political connections often pressure local government to ignore inappropriate use of land. This is referred to several times in the interviews held with those responsible for determining transport policy (Appendix D) who expressed the need for stricter controls over land use. Nonetheless, Chiang Mai has been moving towards stricter zoning enforcement, as evidenced by recent by-laws restricting the height of new buildings and the closure of several pubs and open air karaoke bars that sprang up in residential areas. Also a number of local action groups have

⁷⁵ calculated from spot crude oil price (Dubai) Source: BP Statistical Review of World Energy June 2014

become more active in recent years, determined to prevent further high rise buildings in low rise residential areas and have enjoyed some notable successes*

Adjustments to MARS to reflect the lack of land use homogeneity were considered but proved beyond the current research budget. The zoning system adopted here is based on the city's official administrative zones and the assumption made that local government will continue to improve regulatory control of land-use.

8.2.4. Calibration and testing of the model

The calibration process of the Chiang Mai MARS model was carried out in two steps. Firstly, the mode share values of the model in the peak and the off-peak periods are compared against the survey results (CM-MTS). Various parameters were adjusted to minimise the differences between the two values. Table 8-16 compares the final modelled and the surveyed mode share.

Table 8-16 Surveyed and modelled mode share comparison

Mode	Peak			Off-peak		
	Surveyed	Modelled	Difference	Surveyed	Modelled	Difference
Pedestrian	15.5%	15.5%	0%	14.6%	14.7%	+0.1%
Bicycle	5.6%	6.3%	+0.7%	6.8%	9.4%	+2.6%
Car	28.2%	27.8%	-0.4%	30.7%	25.3%	-5.4%
Motorcycle	49.7%	49.2%	-0.5%	46.1%	48.7%	+2.6%
Bus	0%	0%	0%	0%	0%	0%
Shared-taxi	1.0%	1.0%	0%	1.9%	1.9%	0%

The differences between the survey and the model's mode share are apparently much larger in the off-peak than the peak period; the differences are less than 1% in the peak period, whereas in the off-peak period, the difference is as high as 5.4%. Efforts were made to balance the error between the two peaks but the structure and the complexity of the model made it difficult. Finally, a compromise was made and the lower difference in the peak period was preferred as there is a higher volume of trips in this period.

8.3. Chapter conclusion

In the first part of this chapter, the transferability of MARS to Chiang Mai was assessed. MARS has proved to be an effective tool to simulate various transport and land use policies for Chiang Mai city, although its structures and assumption are based on an

understanding of transport behaviour and land use observed in the west. The model transferability assessment found several issues but none were critical enough to dispute its fitness for purpose. Several improvements that will increase the model's effectiveness were identified and prioritised; three of them have been carried out here: 1) quality of life indicator adjustment, 2) addition of the Shared-taxi (Song Teaw) mode, and 3) updating of emission and fuel consumption module.

The development of the model is detailed with a focus on its principle assumptions in the second part. The model was calibrated using mode share of the CM-MTS survey. Various indicators were adjusted to minimise the differences between the modelled and observed values. The lack of data on the city's land use makes it difficult to include other methods of calibration. The calibrated model is used as a baseline, which other scenarios were compared against. This relative comparison provides a sense of scale of the effect of the policies considered⁷⁶.

In the next chapter, it will be shown how CNX-MARS was used to evaluate different transport and land use scenarios that were expected to improve the sustainability of the city's transport system.

⁷⁶ Further effort to calibrate the model will be necessary to validate the absolute values of the model

9. Scenario assessments

In this section the calibrated CNX-MARS model is used to evaluate the effects of transport policies in different scenarios. In all scenarios, demographic attributes, such as birth and death rates are kept constant. Only Transport and Land Use attributes are adjusted. The output indicators and background indicators are compared between scenarios. A description of each scenario is provided under the heading together with a narrative assessment of the results, except for Scenario A1, A2 and A3. The difference between these three scenarios is vehicle growth rate, which is minor, thus enabling discussion of the results to be combined.

9.1. *Modelling scenarios*

The scenarios tested quantitatively by CNX-MARS are listed here (Table 9-1). The formation of these scenarios was inspired and derived from:

- the baseline scenario (A1),
- the foregoing conclusion in Chapter 4 that the city will see an increased number of cars in the future (Scenario A2),
- the potential of the motorcycle as a measure to reduce the negative impacts of motorised transport (Scenario A3, B2, and B3),
- the possible improvement of the shared-taxi service (Scenario C5),
- the type of mitigations offered by the transport decision makers of the city listed in Chapter 6 (Scenarios B1, C1, C2, C3, C4 and C6),
- the combined effects of the above measures (Scenario C7),
- the speculation of Peak Oil and Cheap Oil (Scenario D1 and D2), and
- a search for necessary measures that will deliver the vision of the city (Scenario D3)

A high proportion of measures suggested by the city's decision makers, as detailed in Chapter 6, are included here. Some measures are excluded because they cannot be assessed by MARS model or they are generic conditions of the system (i.e. increase and decrease of population). The excluded measures are: Measure 4 - the relocation of traffic attractors and expansion of city; Measure 6 - population control; Measure 7 - improved transport organisation.

The scenarios considered here seek to investigate the impact of transport measures beyond the effects of the motorcycle and the shared-taxi. This is undertaken with awareness

that the two modes are part of the overall transport system. Before coming to any conclusions, therefore, it is necessary to gain insights into the effects that other measures may have on the system as well.

The policy instruments needed for these scenarios are shown in Table 9-2 based on Pfaffenbichler (2003). The table shows the type of policy, the type of desegregation, the range of value, and whether it has been tested in previous MARS models. The table shows that the two policy instruments focused on within this thesis (i.e. the motorcycle and shared-taxi) have not previously been tested using the MARS model.

Table 9-1 Scenarios considered

Scenario	Summarised scenarios' description	Additional assumptions
A: Business As Usual (BAU)	A1: A baseline case A2: High car growth A3: High motorcycle growth	A1: The transport supplies and cost are not altered beyond its past trends
B: Motorised transport development	B1: Road capacity expansion (Measure 2a,2b, and 2f) B2: Promotion of the motorcycle B3: Promotion of the motorcycle with mitigations	None
C: Sustainable transport	C1: Full scale public transport network with a separate right-of-way (Measure 1a) C2: Decrease in road capacity; road narrowing and pedestrianisation of the central area (Measure 3i) C3: Enhancements to walking and cycling facilities (Measure 1g), C4: Management of parking spaces within the central area C5: Improvement to shared-taxi service C6: Land development control – effects of building height restriction in municipality area C7: Combined measures	None
D: Other	D1: Post Peak-oil -Significant increase in fuel price D2: Cheap oil D3: Visionary	None

Table 9-2 Policy instruments for Chiang Mai MARS

Policies	Disaggregation				Suggested range	Status
	Spatially	Temporary	Both	None		
Non-motorised transport (Pedestrian and bicycle)						
Pedestrianisation	x				0/1	Tested
Improvement of pedestrian and cyclist facilities	x				0/1	Tested
Public transportation						
Non-dedicated right of way bus system	x				0/1	Tested
Dedicated right of way system (i.e. BRT or Tram)	x				0/1	Tested
Shared-taxi operation – reduction of detoured route and increase in average speed to 24kph	x				-100% to +100%	Not Tested
Fares		X			-50% to +200%	Tested
Frequency		X			-50% to +100%	Tested
Private vehicle (Car and Motorcycle)						
Construction of new road	x				0/1	Tested
Parking charges			x		0 - 50 Baht	Tested
Increase/decrease of road capacity	x				-30% to +30%	Tested
Fuel tax				x	0% to +200%	Tested
Parking enforcement (supply level)			x		0/1	Tested
Promotion of motorcycle	x	X			0/1	Not Tested
Land use						
Development control	x				0/1	Tested

Source: modified from (Pfaffenbichler, 2003, p. 178)

9.2. Scenarios set A1-3: Baseline with different vehicle growth rates

Three scenarios are examined here: A1 - Business as Usual (BAU), A2-High car growth, and A3-High motorcycle growth. The only difference between them is the vehicle growth rate. Scenario A1 is the baseline scenario, against which all others are measured. Its growth rates are conservative and are based on past trends. In scenario A2, the growth rate of the car is increased to simulate increasing car ownership and usage. Another scenario, which depicts increasing motorcycle ownership and usage, is simulated in Scenario A3. Table 9-3 summarises the vehicle ownership rates of the three scenarios.

Table 9-3 Assumed vehicle ownership characteristic for scenario A1-3

Mode	Vehicle ownership per 1,000 capita			
	Year 0	Year 30		
		A1-Baseline	A2-High car growth	A3-High motorcycle growth
Car	322	355	450 (+27%)	255 (-28%)
Motorcycle	556	559	466 (-17%)	661 (+18%)
All	878	915	915	915
No. of motorcycles per 1 car	1.7	1.6	1.04	2.6

Note: numbers in parenthesis show the percentage difference by year 30 in relation to the A1 baseline; changes for percentages are absolute values

9.2.1. Scenario A1: Business as Usual (BAU)

In this scenario, the assumed growth rates of the transport system's supply side and the land use parameters are left unaltered. However, there may be some endogenous road developments resulting from a reduction of average network speed due to increased traffic volume. This scenario is presented as a baseline to which other scenarios are compared.

9.2.2. Scenario A2: High car growth

The rate of car growth is increased in this scenario. In year 30, the proportion of car per 1000 capita is +27% higher than the baseline. By contrast, motorcycle growth is lowered – the final proportion of motorcycle ownership per 1000 capita is -17% lower than the base line.

9.2.3. Scenario A3: High motorcycle growth

In this scenario, the percentage of cars per 1000 capita in the final year is 28% lower than the baseline. In contrast, motorcycle growth is higher, i.e. the final proportion of motorcycles per 1000 capita is 18% higher than the base line.

9.2.4. Discussion of results

The performance indicators of the three scenarios are shown in Table 9-4. Firstly, the results of year 0 and year 30 of the baseline scenario are compared. It is evident that the fuel consumption and CO₂ emission per trip of year 30 is higher than year 0, even though the proportion of non-motorised transport (NMT) trips in year 30 is higher. It seems that the effects of an increased proportion of NMT trips, which should reduce the fuel consumption and emission, is subdued by other factors, such as an increase in the number of trips and the total trip distance. Other indicators are cumulative, thus their comparisons are omitted.

Performance indicators

Next, the results of Year 30 are compared between the three scenarios. In the high car growth case (A2), the cumulative fuel consumption is slightly higher (2% more) than the baseline. Yet in the high motorcycle growth case (A3), the fuel consumption value is lower (4% less) than the baseline. Similar trends can be observed on the greenhouse gas values. These trends suggest an increase in the proportion of the number of cars on the roads will intensify fuel consumption and emission of greenhouse gasses, whereas an increase in

proportion of motorcycle results in the opposite. It is also interesting to note that the correlations between these factors are non-linear. For instance, the cumulative fuel consumption in Scenario A2 is only 2% higher than the baseline case, while the consumption of fuel per trip is 7% higher. This suggests there are factors that dampen the effects of increased fuel consumption per trip on raising cumulative fuel consumption, such as a reduction to the average trip distance of the motorcycle and shared-taxi.

Scenario A2 sees an increase in accessibility (+1%) while the value is reduced in Scenario A3 (-2%), which indicates that the population as a whole has reduced opportunity to access work and shopping. The proportion of NMT trips is slightly higher in A2 (+0.4) and slightly lower in A3 (-0.2), which suggests an increase in the percentage of cars stimulates more NMT trips but quite the reverse when more motorcycles are available. The average trip distance during peak period increases slightly in A2 (+2%) and reduces in A3 (-1%), while the changes are relatively smaller for the off-peak.

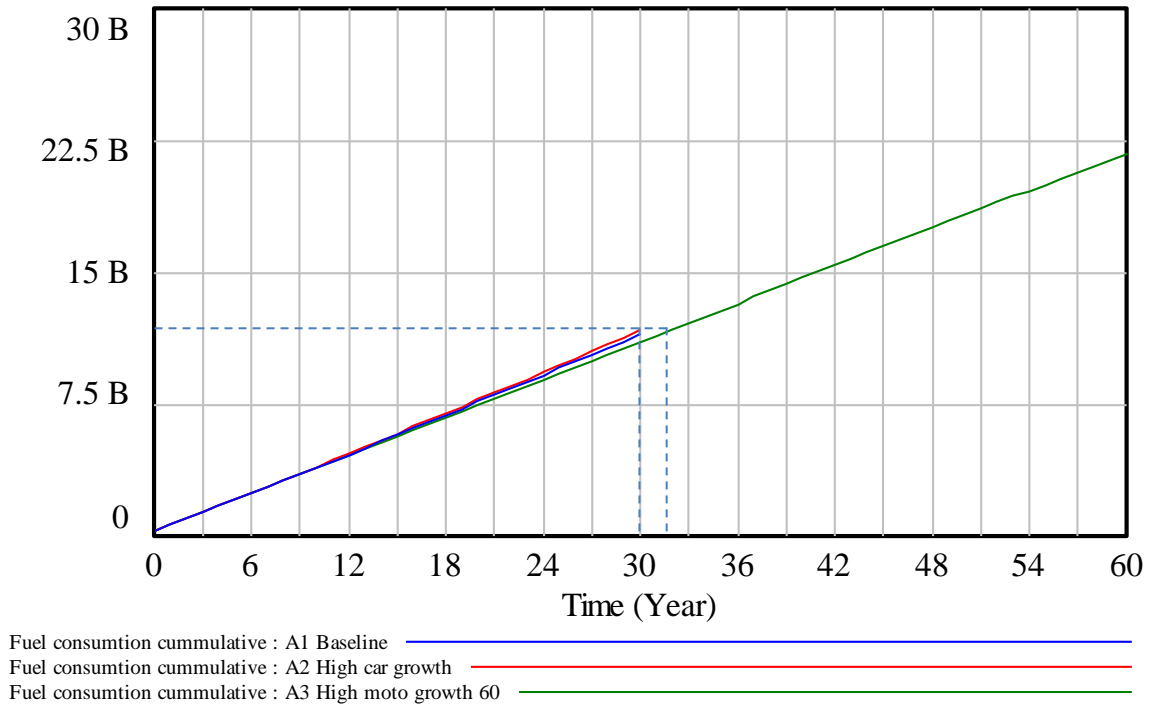
An increase in the proportion of cars (A2) sees the total number of accidents and deaths from transport reduce (-2%), whereas an increase in the proportion of motorcycles results in increased numbers of casualties and deaths (+1%). It should be emphasised that the numbers of casualty and death calculations are based on the average numbers of casualties and deaths per kilometre of vehicle travel of past years. In other words, they are linked directly to the number of kilometres driven and do not take into account any other effects the policies may have on road safety.

Other indicators

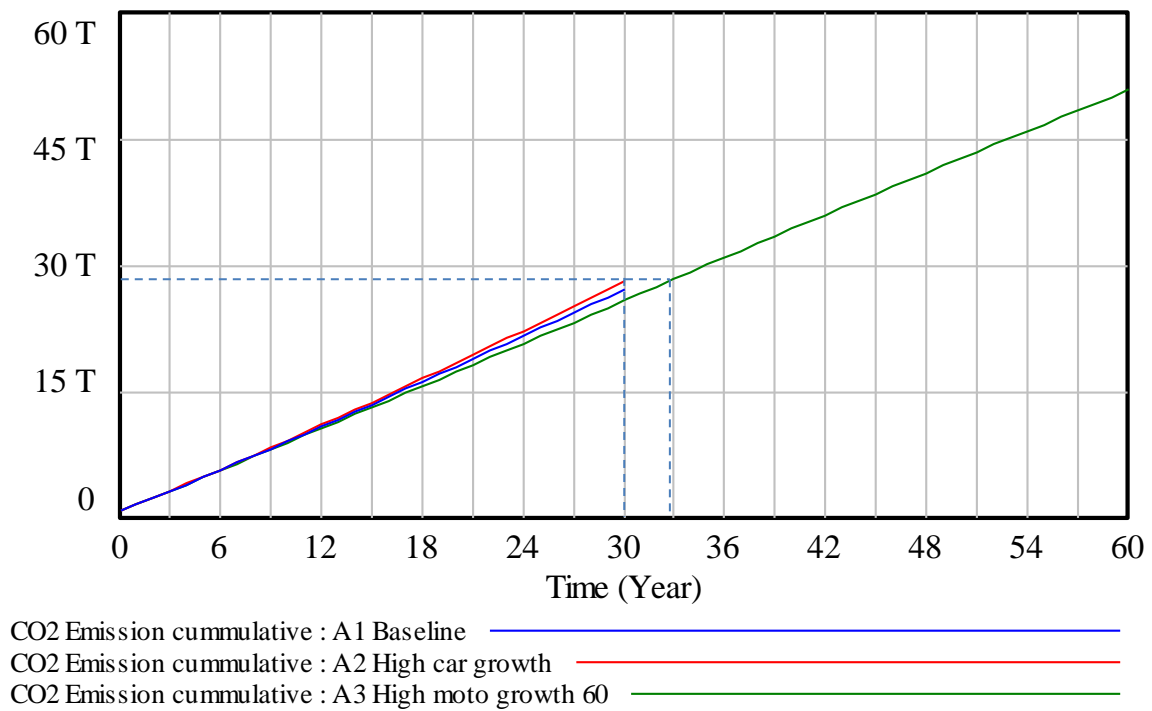
In order to examine an earlier hypothesis, that promotion of motorcycle usage can only delay the effects of motorisation, the time horizon of the model is extended to 60 years. The extended-time horizon model shows that it takes only an additional 2 years (i.e. in year 32) for Scenario A3 to consume the same amount of cumulative fuel and 3 years (i.e. in year 33) to emit the same amount of CO₂ as year 30 of Scenario A2. In other words, the promotion of the motorcycle can only delay the environmental impact of high car ownership by 2-3 years.

Graph 9-1 Role of motorcycle in delaying adverse effects of transportation

Fuel consumption cummulative (Billion litre)



CO₂ consumption cummulative (Trillion kg)



Background variables

The background variables show the A2 increase in the proportion of car trips and A3 increase in the proportion of motorcycle trips. It also confirms that an increase in motorcycle ownership has a negative impact on non-motorised transport, whereas higher car ownership increases NMT trips. The decrease in NMT of the former is likely to be linked to the closer proximity a motorcycle can park in relation to a car, to the start/end of a trip, thus offering a more attractive alternative to walking and cycling. Whereas the increase in NMT in A3 is likely to be a result of a decrease in network speed due to an increase in the number of cars, thus encouraging NMT trips. Interestingly, the percentage of shared-taxi trip increases slightly in A3. This is likely to be linked to a decrease in car trips as the two have similar trip distribution patterns. The change in vehicle ownership seems to have little effect on the average trip distance and trip time of non-motorised transport and public bus. In contrast, the trip time by car, motorcycle, and shared-taxi seem to have been affected and moved in the same direction as vehicle ownership (i.e. high car ownership, higher car trip distance). This trend is logical, as a higher number of cars or motorcycles should lead to an increase in trip time and distance by that particular mode. Again, it is uncertain why the shared-taxi's values move in the same direction and proportion as the motorcycle.

Scenario A2 sees decreases in all motorised vehicles' average trip speeds, whereas A3 results in increases of all motorised vehicles' average trips speeds. The non-motorised modes are unaffected. These trends are perhaps logical; the reduction in the number of cars increases road capacity as motorcycles occupy less road space.

Comparisons of other indicators, such as the values of greenhouse gasses, accessibility, and average trip distance also reveal similar trends as fuel consumption. It is interesting to note that, although a measure to promote motorcycle use can reduce fuel consumption and emission, the overall benefit may be subsumed by an increase in the number of fatalities and injuries. However, this situation is based on the current assumption of the model that the number of fatality and injuries are linked directly with the total vehicles per kilometre of road.

Another interesting finding is the implication that an increase in motorcycle usage has the effect of reducing non-motorised trips more so than when there is an increase in car use. In other words, motorcycle use has a higher detrimental impact on non-motorised

transport than car use. This finding also supports the hypothesis proposed earlier that the motorcycle has higher penetration of usage than the car (see Chapter 5).

It should be noted that the average speed values are door-to-door speed, which includes walking time to and from embarkation/disembarkation points. In other words, the average speed does not reflect only in-vehicle speed but also includes walking speeds as well.

9.2.5. Summary of results

- An increase in car ownership will intensify the effects of negative transport externalities. For instance, it will lead to a higher rate of increase in fuel consumption and greenhouse gas emission.
- An increase in motorcycle ownership will lessen the effect of negative transport externalities. It slows down the rate of increase in fuel consumption and greenhouse gas emission. However, the effects of the delay are limited. High motorcycle growth will delay the level of fuel consumption reached by the high car ownership scenario for only 2 years, and the level of CO₂ emission by only 3 years.
- As expected, an increase in car ownership will lead to increased car usage. A similar trend is also observed with regard to the motorcycle, thus demonstrating there is direct correlation between vehicle ownership and vehicle usage.
- An increase in car trips correlates to an increase in NMT trips, whereas an increase in motorcycle trips correlates to an increase in shared-taxi trips. It is likely the motorcycle affects NMT because of its ability to park closer to origin and destination.

Table 9-4 Results of Scenario A1 Baseline, A2, and A3

Objective	Sub-objective	Indicators	Unit	Year 0	Year 30		
					A1: Baseline	A2: High car growth	A3: High motorcycle growth
1.Environmental protection	1.1 Efficient in the use of resources	1.1a Consumption of fuel per trip	(litre/trip)	0.19	0.29	0.31 (+7%)	0.27 (-7%)
		1.1b Cumulative fuel consumption	Billion litre	0.33	11.44	11.68 (+2%)	11.03 (-4%)
	1.2 Reduce greenhouse to a reasonable level	1.2a Greenhouse gas emission per trip	(CO2 equivalent kg/trip)	429.77	698.55	771.61 (+10%)	627.50 (-10%)
		1.2b Total Greenhouse gas emission	Trillion kg	0.77	27.13	28.03 (+3%)	25.77 (-5%)
2. Accessibility	2.1 Provide reasonable accessibility	2.1 Change in accessibility	(ratio to base year)	1.00	1.35	1.37 (+1%)	1.32 (-2%)
	2.2 Reduce automobile dependency	2.2 % of trips made by NMT	(%)	23.8%	33.0%	33.4% (+0.4)	32.8% (-0.2)
	2.4 Control urban sprawl	2.4a Av. trip distance (peak)	(kilometre /trip)	3.69	4.97	5.05 (+2%)	4.94 (-1%)
		2.4a Av. trip distance (opeak)	(kilometre /trip)	3.64	4.63	4.63 (0%)	4.66 (+1%)
3. Safety	3.1 Reduce transport accidents, including non-vehicular	3.1a Total Number of traffic injuries	(injured)	n/a	23,173	22,806 (-2%)	23,298 (+1%)
		3.1b Total Number of traffic deaths	(death)	n/a	2,988	2,940 (-2%)	3,004 (+1%)
4. Quality of living standard	4.1 Enhance the social, cultural, and recreation activities	4.1 % of trips make by NMT	(%)	23.8%	33.0%	33.4% (+0.4)	32.8% (-0.2)
5. Equity and fairness	5.1 Accessibility for non-vehicular users	5.1 % of trips make by NMT	(%)	23.8%	33.0%	33.4% (+0.4)	32.8% (-0.2)

Note: numbers in parenthesis are ratio in relation to year-30 of the A1 baseline; changes for percentages are absolute values

Table 9-5 Background indicators for Scenario A1, A2, and A3

Mode share %				
Mode	Year 0	Year 30		
		A1: Baseline	A2: High car	A3: High motorcycle
Pedestrian	14.8%	21.3%	21.6% (+0.3)	21.1% (-0.2)
Bicycle	9.0%	11.7%	11.8% (+0.1)	11.7% (0)
Pt bus	0.1%	0.2%	0.2% (0)	0.2% (0)
Car	25.6%	23.5%	26.4% (+2.9)	20.6% (-2.9)
Motorcycle	48.7%	41.4%	38.2% (-3.2)	44.6% (+3.2)
Shared-taxi	1.8%	1.8%	1.8% (0)	1.9% (+0.1)

Average Trip distance (kilometre)				
Mode	Year 0	Year 30		
		A1: Baseline	A2: High car	A3: High motorcycle
Pedestrian	0.53	0.54	0.54 (0%)	0.54 (0%)
Bicycle	1.03	1.02	1.02 (0%)	1.02 (0%)
Pt bus	6.79	8.24	8.23 (0%)	8.23 (0%)
Car	5.56	7.75	8.18 (+6%)	7.13 (-8%)
Motorcycle	3.78	5.98	5.69 (-5%)	6.35 (+6%)
Shared-taxi	11.57	10.90	10.42 (-4%)	11.45 (+5%)

Average Trip time (minute)				
Mode	Year 0	Year 30		
		A1: Baseline	A2: High car	A3: High motorcycle
Pedestrian	15.99	16.13	16.14 (0%)	16.13 (0%)
Bicycle	8.80	8.70	8.71 (0%)	8.69 (0%)
Pt bus	45.26	52.75	53.37 (+1%)	51.86 (-2%)
Car	11.47	19.51	21.74 (+11%)	16.69 (-14%)
Motorcycle	7.81	13.87	13.49 (-3%)	14.23 (+3%)
Shared-taxi	34.55	37.91	37.64 (-1%)	38.10 (+1%)

Travel speed/mode door to door (km/h) – include walking				
Mode	Year 0	Year 30		
		A1: Baseline	A2: High car	A3: High motorcycle
Pedestrian	2.00	2.00	2.00 (0%)	2.00 (0%)
Bicycle	8.57	8.38	8.37 (0%)	8.40 (0%)
Pt bus	9.44	9.44	9.34 (-1%)	9.57 (+1%)
Car	32.89	24.56	23.13 (-6%)	26.71 (+9%)
Motorcycle	36.36	28.22	27.48 (-3%)	29.41 (+4%)
Shared-taxi	14.09	12.18	11.81 (-3%)	12.66 (+4%)

Note: numbers in parenthesis are ratio in relation to year-30 of the A1 baseline; changes for percentages are absolute values *include walking to embarkation point and from disembarkation point during peak period

9.3. **Scenario set B: Motorised transport development**

Table 9-6 plots the results of these scenarios with their background indicators detailed in Table 9-7. Graph 9-1 shows fuel consumption and emissions of CO₂ over the considered period.

9.3.1. *Scenario B1: Increase in road capacity*

Lack of road capacity is thought to be one of the main causes of Chiang Mai's transport problems. There are a number of ways that road capacity can be increased. In this scenario, an increase in road capacity is assumed to be achieved through traffic signal optimisation and traffic management. The city's road capacity is set here to increase between year 5 and 15 by 20% for the whole study period.

Results

An increase in road capacity (B1) has no effect on the average fuel consumption and the average CO₂ emission per trip, but increases the cumulative fuel consumption and CO₂ emission slightly (+3%). Surprisingly, the increase in road capacity (B1) reduces the overall accessibility slightly (-2%). This indicates that an increase in road capacity does not correlate with an increase in the number of opportunities for shopping and work-related trips. The measure slightly decreases the NMT trip (-0.4) and increases the average trip distance in both periods (+2%). The numbers of casualties and deaths also increase by 3%, which indicates road capacity increases the number of vehicles per kilometre of highway.

The background indicators show that an increase in road capacity (B1) only has small effects on mode share and other background indicators. It increases average trip distances and reduces trip time, thus improving the speed of motorised trips by between 2% and 6%.

The assessment result of this measure is in line with the outcome of the qualitative analysis in Chapter 6; it does not deliver an improvement to the system.

9.3.2. *Scenario B2: Promotion of motorcycle*

The effects of measures that promote motorcycle use, such as free parking space for motorcycles, motorcycle only access roads, and closer parking to destinations are tested here. The parking cost for motorcycles is reduced to zero (free parking) in all zones. The distances between destinations in zone 1-14 (area within Aumpor Muang) are reduced by 20% to simulate change in road management that favour the use of the motorcycle in the city

centre area. The distances between parking space and origin/destinations and parking search time for the motorcycle are also reduced by 30% to simulate provision of ample parking space close to origin and destination for the motorcycle.

Results

The promotion of motorcycle usage (B2) significantly decreases the average fuel consumption (-21%) and the average CO₂ emission per trip (-20%) but increases the cumulative fuel consumption and CO₂ emission slightly (+3%). It appears that the measure reduces average fuel consumption and emission per trip but the enhancements are not passed on to the cumulative values. This suggests that the measure must have stimulated the system to react by changing some attributes, such as increasing the number of vehicular trips, which counter the initial improvements.

The measure increases accessibility by 4% but reduces the proportion of NMT trips by 4.9. This indicates that motorcycle use can have a reducing effect on non-motorised trips. It also reduces the average trip distance (-13%). The number of casualties and deaths also increases (+4%), even though average trip distance is lower. This suggests that other indicators, such as an increase in the total number of trips may result in an overall increase of the total vehicular distance travelled; this effect consequently impacts the number of transport casualties.

The background indicators show an increase in motorcycling trips (+8%) at the cost of non-motorised modes (-5%) and car (-3%). The shared-taxi is unaffected. The closer parking distance to origin and destination of motorcycle is a likely reason that the NMT trip is more affected. This is not a desirable result as the original aim of this measure was to promote motorcycle to reduce car use.

9.3.3. Scenario B3: Promotion of motorcycle with mitigation

This scenario tests whether promotion of the motorcycle can reduce the proportion of car trips instead of the non-motorised and public transport modes, with help of additional mitigation measures. Firstly, similar adjustments to the model as in Scenario B2 were made. Parking cost for motorcycles was set at zero to simulate free parking in all zones. The distances between destinations in zone 1-14 (area within Aumpor Muang) are reduced (-20%) to simulate change in road management that favour the use of the motorcycle in the city centre area.

Mitigation measures were factored into the model to demonstrate the impact of parking space organisation. It is proposed here that a form of central parking lot should be provided with the distances between parking space and origin/destinations for motorcycle set at 3 minutes during the peak period. The measure should also implement a parking search time for the motorcycle of 1.75 minutes during the peak period, and 1 minute during the off-peak period.

All values for car usage are set 1.5 times higher than the motorcycle's. These differences take into account that the motorcycle has a significant 'privilege' in terms of required parking space; i.e. motorcycle parking spaces are located closer to origin and destination and are more numerous than for cars.

Results

The deployment of mitigations (B3) reverses the effects of Scenario B2; the average fuel consumption and emission per trip are increased (between 48% and 49%), but there is a 10% improvement on the overall system in terms of cumulative fuel consumption and reduced emissions.

Although the implementation of mitigations (B3) reduces the accessibility (-10%), it has a positive effect on the proportion of NMT trips (+9.4). It also increases the average trip distance by +33% to +21%, which most likely results from increased difficulty in finding parking spaces.

As to the total number of casualties and average trip distance, it is interesting to see a reverse trend to that observed in Scenario B2. The total number of casualties is reduced (-10%) even though the average trip distance is increased. This indicates that the measures employed here work to reduce some indicators, such as the total number of trips.

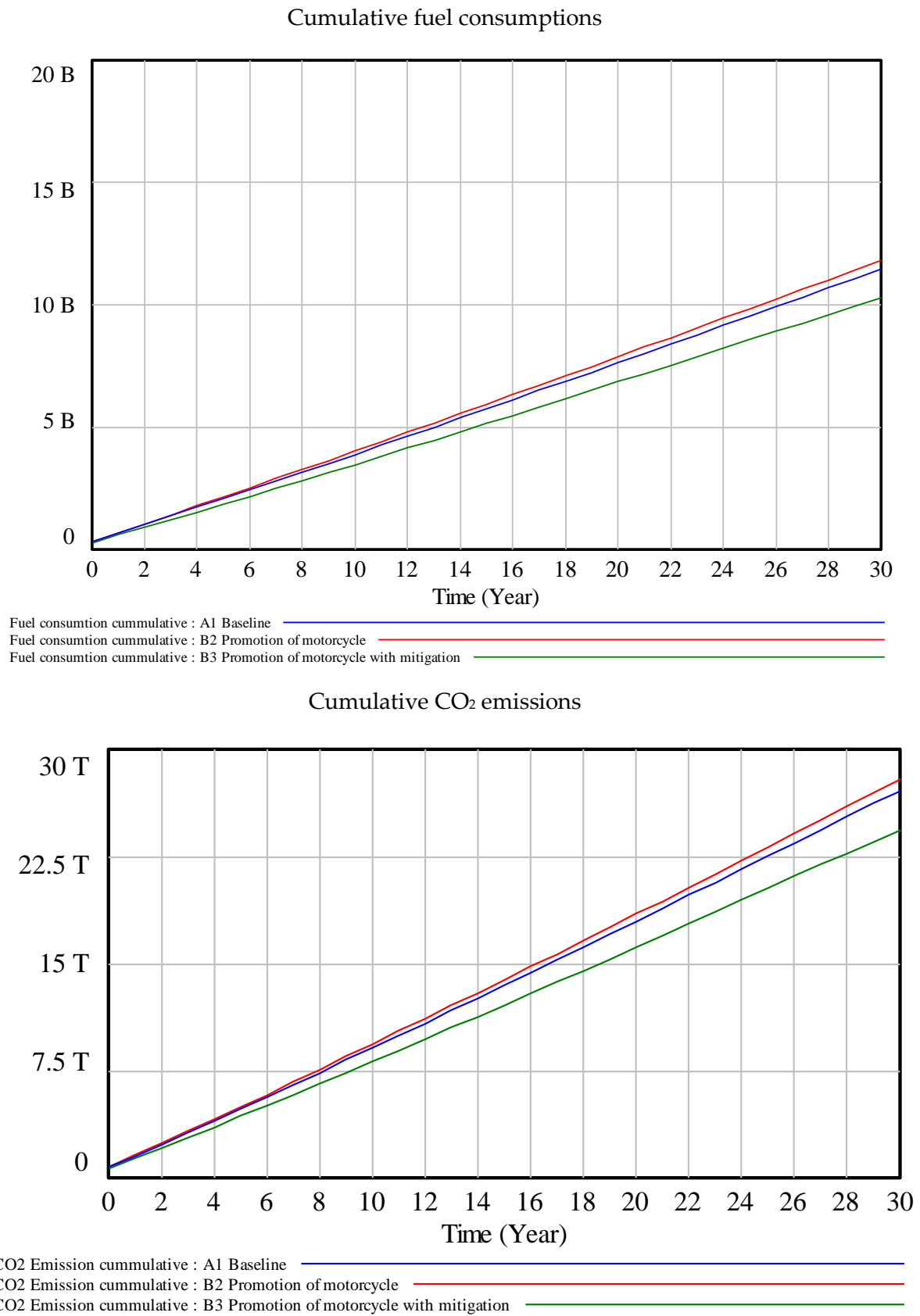
In background indicators, Scenario B3 reduces the average trip distance of the car and shared-taxi trip slightly (-2%) but has a higher impact on motorcycle trips (-27%). The average motorcycle trip time is also reduced by a similar magnitude (-28%). The average trip time of other modes remains largely unaffected. The average speed of all motorised modes decreases, except that of the motorcycle. Moreover, the increase is disproportionate to the decrease in trip distance and trip time, exhibiting a non-linear correlation.

When the mitigation measures are implemented alongside the promotion of the motorcycle as the preferred mode of transport, the overall condition of the system is improved.

9.3.4. Motorcycle promotion effects on impacts delay

The graphs in Graph 9-1 show cumulative fuel consumption and CO₂ emission between the base line and scenarios B2 and B3. They show the benefits gained from motorcycle promotion become insignificant only after year 4. Fuel consumption and emissions in Scenario B2 exceed the baseline thereafter. Thus, promotion of motorcycle use actually results in higher fuel consumption than the base line. In other words, it aggravates the overall condition. However, implementation of proposed mitigations (B3) ensures that the promotion of motorcycle improves the system performance; the cumulative fuel consumption and emission values of B3 remain 10% lower than the baseline at year 30.

Graph 9-2 Cumulative fuel consumption and CO2 emission for Scenario A1, B2, and B3



9.3.5. *Summary of results*

- Increased road capacity worsens the overall system condition; it increases cumulative fuel consumption and emissions, increases accident and deaths, reduces NMT trips and increases average trip distance.
- Promotion of motorcycle usage seems to produce mixed results. It reduces fuel consumption and emissions per trip. It also lowers the average trip distance and increases accessibility rating. However, it also seems to increase indicators associated with high vehicle use; i.e. higher levels of cumulative fuel and emission consumption, higher road casualties, and lower proportionate use of non-motorised transport. This scenario thus illustrates that improvements in some specific areas may lead to an overall undesirable result.
- Implementation of the proposed mitigation factors helps to enhance the benefits gained and suppress the detrimental effects of motorcycle promotion. Although the fuel consumption and emission per trip increase, as well as the average trip distance, the cumulative externalities decrease and the proportion of NMT trip increases. In this sense the converse of the previous point holds true i.e. deterioration in some specific areas can lead to an overall enhancement of the system.

The promotion of the motorcycle alone will provide a limited benefit to the system, in this case only for the first 4 years. After which, it will worsen the overall performance of the system. This demonstrates the limited benefit of oil-fuelled motorcycle promotion, and asserts the necessity of the proposed mitigations in parking organisation.

Table 9-6 Results of Scenario A1 Baseline and B

Objective	Sub-objective	Indicators	Unit	Year 30			
				A1: Baseline	B1: Road capacity	B2: Promotion of motorcycle use	B3: Promo of moto with mitigations
1.Environmental protection	1.1 Efficient in the use of resources	1.1a Consumption of fuel per trip	(litre/trip)	0.29	0.29 (0%)	0.23 (-21%)	0.43 (+48%)
		1.1b Cumulative fuel consumption	Billion litre	11.44	11.75 (+3%)	11.80 (+3%)	10.29 (-10%)
	1.2 Reduce greenhouse to a reasonable level	1.2a Greenhouse gas emission per trip	(CO2 equivalent kg/trip)	698.55	698.03 (0%)	561.99 (-20%)	1,038 (+49%)
		1.2b Total Greenhouse gas emission	Trillion kg	27.13	27.74 (+2%)	27.87 (+3%)	24.39 (-10%)
2. Accessibility	2.1 Provide reasonable accessibility	2.1 Change in accessibility	(ratio to base year)	1.35	1.32 (-2%)	1.40 (+4%)	1.21 (-10%)
	2.2 Reduce automobile dependency	2.2 % of trips made by NMT	(%)	33.1%	32.7% (-0.4)	28.2% (-4.9)	42.5% (+9.4)
	2.4 Control urban sprawl	2.4a Av. trip distance (peak)	(kilometre /trip)	4.97	5.06 (+2%)	4.31 (-13%)	6.61 (+33%)
		2.4a Av. trip distance (opeak)	(kilometre /trip)	4.63	4.72 (+2%)	4.04 (-13%)	5.61 (+21%)
3. Safety	3.1 Reduce transport accidents, including non-vehicular	3.1a Total Number of traffic injuries	(injured)	23,173	23,946 (+3%)	24,100 (+4%)	20,804 (-10%)
		3.1b Total Number of traffic deaths	(death)	2,988	3,087 (+3%)	3,107 (+4%)	2,682 (-10%)
4. Quality of living standard	4.1 Enhance the social, cultural, and recreation activities	4.1 % of trips make by NMT	(%)	33.1%	32.7% (-0.4)	28.2% (-4.9)	42.5% (+9.4)
5. Equity and fairness	5.1 Accessibility for non-vehicular users	5.1 % of trips make by NMT	(%)	33.1%	32.7% (-0.4)	28.2% (-4.9)	42.5% (+9.4)

Note: numbers in parenthesis are percentage in relation to year-30 of the A1 baseline; changes for percentages are absolute values

Table 9-7 Background indicators for Scenario A1 and B

Mode share %				
Mode	Year 30			
	A1: Baseline	B1	B2	B3
Pedestrian	21.3%	21.1% (-0.2)	18.2% (-3.1)	27.8% (+6.5)
Bicycle	11.7%	11.7% (0.0)	10.1% (-1.6)	14.7% (3.0)
Pt bus	0.2%	0.2% (0.0)	0.1% (-0.1)	0.3% (0.1)
Car	23.5%	23.7% (+0.2)	20.9% (-2.6)	19.8% (-3.7)
Motorcycle	41.4%	41.6% (+0.2)	49.1% (+7.7)	35.1% (-6.3)
Shared-taxi	1.8%	1.9% (+0.1)	1.6% (-0.2)	2.3% (+0.5)

Average trip distance (km)				
Mode	Year 30			
	A1: Baseline	B1	B2	B3
Pedestrian	0.54	0.54 (0%)	0.54 (0%)	0.54 (0%)
Bicycle	1.02	1.02 (0%)	1.02 (0%)	1.04 (+2%)
Pt bus	8.24	8.25 (0%)	8.23 (0%)	8.48 (+3%)
Car	7.75	7.90 (+2%)	7.57 (-2%)	11.53 (+49%)
Motorcycle	5.98	6.01 (+1%)	4.39 (-27%)	9.11 (+52%)
Shared-taxi	10.90	11.45 (+5%)	10.69 (-2%)	11.28 (+3%)

Average trip time (minute)				
Mode	Year 30			
	A1: Baseline	B1	B2	B3
Pedestrian	16.13	16.12 (0%)	16.11 (0%)	16.21 (0%)
Bicycle	8.70	8.69 (0%)	8.70 (0%)	8.72 (0%)
Pt bus	52.75	51.77 (-2%)	52.87 (0%)	53.05 (+1%)
Car	19.51	18.92 (-3%)	19.34 (-1%)	31.68 (+62%)
Motorcycle	13.87	13.28 (-4%)	9.98 (-28%)	21.87 (+58%)
Shared-taxi	37.91	37.88 (0%)	37.49 (-1%)	39.28 (+4%)

Travel speed/mode door to door (km/h)*				
Mode	Year 30			
	A1: Baseline	B1	B2	B3
Pedestrian	2.00	2.00 (0%)	2.00 (0%)	2.00 (0%)
Bicycle	8.38	8.38 (0%)	8.36 (0%)	8.36 (0%)
Pt bus	9.44	9.63 (+2%)	9.45 (0%)	9.65 (+2%)
Car	24.56	25.94 (+6%)	24.22 (-1%)	21.50 (-12%)
Motorcycle	28.22	30.00 (+6%)	28.89 (+2%)	26.46 (-6%)
Shared-taxi	12.18	12.75 (+5%)	11.99 (-2%)	12.60 (+3%)

Note: numbers in parenthesis are ratio in relation to year-30 of the A1 baseline; changes for percentages are absolute values - *include walking to embarkation point and from disembarkation point during peak period

9.4. Scenario set C: Sustainable transport Chiang Mai

This set of scenarios explores different sustainable transport measures individually and in combination. The results of these scenarios are depicted in Table 9-10 and background indicators are shown in Table 9-11.

9.4.1. Scenario C1: Full scale public transport system

This scenario models the effects of introducing a full scale public transport system or the replacement of the shared-taxi with a formalised public transport system, which has the following characteristics:

- takes 3 minutes to access bus stop within the municipality and the Aumpor Muang area, 5 minutes for the outer area
- bus headway time: 5 minutes during peak and 10 minutes during off-peak
- bus changing time: 2 minutes during peak and 5 minutes during off-peak
- 30% of the total network is separated from road traffic with an average speed of 30 km/h
- fare is 0.5 Euro at all times

Results

Improvement to the public transport system (C1) delivers significant improvements to the system; it reduces the cumulative fuel consumption and emission by 16% from the baseline. Interestingly, it only slightly improves the consumption and emission rates per trip (0% and -2%, respectively). It also reduces accessibility by 1% but increase the average distance significantly, between 22% and 63%. Improvement to public transport appears to be competing with NMT mode (-3.3) and increases the number of traffic injuries and deaths (+5%). The latter result is questionable, given the common notion that public transport improves road safety⁷⁷. It also points toward the need to improve the model's transport calculation of the number of casualties, which is currently based on the distances travelled by all vehicles.

The promotion of public transport (C1) increases the ratio of the number of trips made by bus significantly (+6.8) with the greatest impact on motorcycle trips which experience the highest reduction (-2.5). It also increases the average trip distance and trip

⁷⁷ <http://www.theguardian.com/global-development/poverty-matters/2013/sep/03/bus-public-transport-road-deaths> (Quote from [Embarq Centre for Sustainable Transport](#)'s document)

time of all modes except walking, and significant change can be seen in Pt bus trip distance (+216%) and trip time (+25%). The average speeds of all vehicles are increased, especially Pt bus, which increases from 9.44 to 23.53 km/h, within a similar range to that of cars and motorcycles.

The assessment result of this measure is in line with the outcome of the qualitative analysis in Chapter 6; it delivers an improvement to the system.

9.4.2. Scenario C2: Decrease in road capacity

This scenario is the reverse of Scenario B1. Road capacity is often decreased due to road closure or road narrowing or pedestrianisation. Although temporary and occasional road closures are already happening in the city, for example, Saturday and Sunday walking markets, a permanent road closure is rare. In this scenario, the road capacity is assumed to be decreased by 20% between year 5 and 15.

Results

Decreasing road capacity (C2) sees minimal change in fuel consumption and emission per trips. Yet the measure slightly improves the overall condition of the system; the cumulative values are reduced (-2%). It also unexpectedly improves: the accessibility (+3%); increases the proportion of NMT trips (+0.4); and reduces the average trip distance (-2%). Additionally, it reduces transport accidents by 5%.

Decrease in road capacity (C2) slightly improves the ratio of NMT trips (+0.6). It has no effect on trip distance and trip time of the NMT modes. However, it reduces the average trip distance and increases average trip time of all vehicular modes. The overall magnitude of this change results in the decrease of vehicular speed by between 3% and 8%.

The assessment result of this measure is in line with the outcome of the qualitative analysis in Chapter 6; it delivers an improvement to the system.

9.4.3. Scenario C3: Enhancements to walking and cycling facilities

In this scenario, significant enhancements to walking and cycling facilities are made across the study area with special focus on the municipality and Aumpor Muang areas. The enhancements are assumed to decrease the distances between destinations for the two modes by 20% within Aumpor Muang area. Additionally, the average speed of bicycle trips increases to 20 kilometres per hour in outer areas.

Results

Improvement to NMT (C3) delivers an overall improvement. It decreases the cumulative values (-1%) without changing fuel consumption and emissions per trip. It also increases NMT trip (+0.3) and reduces the number of road casualties. However, it reduces accessibility (-2%) and increases the average trip distance (+1%). In comparison to C2, the two measures have similar effects on the cumulative values but they have different effects on other indicators.

Improvement to NMT facility (C3) sees slight reduction to walking trips ratio (-0.1) but an increase in bicycle trips (+0.5) at cost of car and motorcycle. It also increases the average bicycle trip distance (+13%) and bus (+1%), as well as the average trip time of the two modes (+3% and +1% respectively). Other modes are unaffected. These changes result in increased bicycle speed (between +6% and +11%) and bus speed (+1%). The speed of the shared-taxi decreases (-1%).

The assessment result of this measure is in line with the outcome of the qualitative analysis in Chapter 6; it delivers an improvement to the system.

9.4.4. Scenario C4: Parking management

This scenario assumes that the city employ parking management measures that affect the cost, parking search time, and distance between parking spaces and origins/destinations. The distances between parking and origins/destinations are increased by 25% and the assumed costs and parking search time are shown in Table 9-8. For ease of presentation, “motorcycle” is shortened to “moto” in Table 9-8 and following

Table 9-8 Assumed parking management characteristics for scenario C3

	Zone	Fee (Euro)		Walking time between origin/destination and parking space		Search time (min.)	
		Short	Long	Peak	Off-peak	Peak	Off-peak
Car	Zone 1-14	1	2	4.5	2.25	2.6	1.5
	Zone15-28	0.5	1	4.5	2.25	2.6	1.5
Moto	Zone 1-14	0.5	1	3.0	1.5	1.75	1
	Zone15-28	0.25	0.5	3.0	1.5	1.75	1

Note: Parking costs for peak and off-peak are the same

Results

The implementation of parking strategy (C4) significantly increases the consumption of fuel and emissions per trip between +57% and +59%, which results in the decrease of the cumulative values (-10%). The measure also decreases the accessibility values (-10%) and encourages more NMT trips (+11.4). The average trip distances are also increases (between +21% and +39%), which likely correlates to the additional distance needed to search for parking spaces. Additionally, the measure also reduces vehicular distance, thus the number of casualties and deaths from transport is reduced.

Implementation of parking strategy (C4) increases the ratio of NMT trips significantly (+11.5) at the expense of the car and the motorcycle (-3.7 and -8.3, respectively). It also increases the average trip distance and trip time of the car and the motorcycle significantly, most likely because of the imposition of parking restrictions. The measure also results in reduction of car speed and motorcycle. It also increases the average bus speed and shared-taxi (between +2% and +3%).

This measure delivers an improvement to the system, in line with the expectation of the CM-LTSS committee.

9.4.5. Scenario C5: Shared-taxi service improvement

This scenario looks to assess the effects of the measures taken to improve shared-taxi service without any changes in the organisational structures. The changes proposed here focus on operational change. The nature of the service remains unchanged, i.e. as an on-demand non-fixed route service.

The detoured factors of the service are reduced by 50% for trips within the Aumpor Muang area to assess the effects (i.e. more direct route to customer destination). The fare levels are capped at 0.50 Euro for zones 1-14 within the city and 1 Euro for outlying districts.

Results

Scenario C5 seems to yield results that are different to the intended purpose of reducing cumulative fuel consumption and emissions of greenhouse gas. The amount of total fuel consumption increases from the baseline by 3% and the total greenhouse gas emission increases by 4%. Interestingly, the measure also increases fuel consumption and emission per trips (+2%) and reduces accessibility values (-3%), as well as the ratio of non-motorised trips, which also decrease (-0.3). Also of interest is that average trip distances are

increased (+2%) but the total number of road casualties falls below 0% of the baseline. This suggests that one or more indicators, such as number of trips, react to keep the casualty numbers roughly the same. The improvement to shared-taxi service (C5) increases the ratio of shared-taxi trips by +0.8, at the expense of NMT trips (-0.2), car (-0.1), and motorcycle (-0.3), with minor roundup error (0.2). The measure is quite effective; it increases the share-taxi trips ratio by nearly 45%. It also increases the average trip distance and time of shared taxi (+15% and +11%) and bus (+2% and +1%) but reduces the values for bicycle (-3% and -1%). The result of these changes increases average bus speed (+1%) and shared taxi (+8%).

Scenario C5 shows that improvement to the shared-taxi service, without changing the nature of its operation can only slightly improve its mode share. However, the overall benefit of the improvement in terms of fuel consumption savings and emission reductions is limited, as it reduces pedestrian, bicycle, and motorcycle trips. These modes already have relatively lower fuel consumption and emission than the car. In order to specifically discourage car use, additional measures, such as parking management that deters car use will be necessary. Moreover, instruments that reduce shared-taxi emission and minimise shared-taxi's fuel consumption will also intensify the overall positive benefits.

9.4.6. Scenario C6: Land development control

After the renewal of the city's principal plan in 2013, the municipality expressed its intention to regulate and control building height within the municipality area. This scenario investigates the effects of such a measure over the whole principal plan. The limitations of the land use in this scenario are described in Table 8-21.

Table 9-9 Assumed land use policy for scenario D2

Zone	Land use restriction
Zone 1-14	100% protected, no development of production sector is allowed and the height of the building is limited to 3 storeys.
Zone 15-28	50% protected, of which 50 % is allocated for residential development and 50% for economic development. The height of the building is limited to 5 storeys.

Results

Scenario C6 yields the results as intended; it reduces the average trips distance (-1% and -2%) and slightly increases the ratio of NMT trips (+0.4). However, it has relatively low effects on other indicators; it reduces the average emission per trip by -1%, the effects to other indicators are minute.

Land use control (C6) increases the ratio of NMT trips by +0.5, while the ratios of car, motorcycle and shared-taxi trips are reduced (between -0.1 and -0.2). This demonstrates that the land use policy encourages NMT trips. The averages for pedestrian trip distance and time remain the same, while the averages for bus increases slightly (by +6% and +3%). The values for other modes decrease (between -1% and -3%). A similar pattern is observed in average travel speeds; the values for pedestrian trips remain unchanged and bus speed increases by 3%, whereas reduced speeds are predicted for the bicycle (-1% to -2%).

The enforcement of land-use regulations (D2) shows some effects on the selected set of indicators in that it increases the ratio of NMT trips slightly. The system was unable to assess the effects of these measures on the city's land use as all indicators considered in the assessment framework are transport indicators. This result points towards the need to include certain land use indicators into the assessment framework.

The assessment result of this measure is in line with the outcome of the qualitative analysis in Chapter 6; it delivers an improvement to the system.

9.4.7. Scenario C7: Combined policies

In this scenario, the effects from combining Scenario C1, C2, C3, C4, and C6 are quantified. Scenario C5, which enhances the shared-taxi service, is omitted because the policy is in conflict with Scenario C1 which sets out to enhance a public transport system. Scenario C7 can be said to represent an actual transport policy, which normally consists of a number of measures addressing different areas of the transport system. The different measures are also combined in such a way as to gain public acceptance in order to justify implementation of the 'package' of policies.

Results

The combined policy (C7) sees significant increases in consumption of fuel and emission per trips (+45% and +44%), as well as a significant reduction in cumulative values (-28%) and accessibility (-12%). The measures increase the ratio of NMT trips by 5.5% and the

average trip distance by 116% and 50%. Additionally, it reduces the transport casualties by -5%. It is interesting to observe that the effects of the combined policy are not equalled to the cumulative effects of each individual policy. In some cases Scenario C7 yields higher values (such as cumulative fuel consumption and emission), and at other times, lower values (such as the average emission per trips, and NMT ratio). This confirms the transport system is complex with non-linear behaviour.

The combined policy (C7) discourages car and motorcycle use. It increases ratio of NMT trips by 5.5 and PT bus trips by 10.7 at the cost of trips by car (-5.1) and motorcycle (-11.2). The ratio of shared-taxi trips also increases by +0.1, even though no modification has been made to its operation. The average trip distance of all modes, except walking trips, increases. This is most noticeable in relation to bus trips (+228%), motorcycle trips (+90%) and car trips (+63%). Similar patterns can be observed in the average travel time. These result in significant increase in bus speed (+153% to 172%). Pedestrian speed remains the same. The speed of other modes increases between 4% and 12%, except the car which decreases by -10% and the motorcycle by -4%.

9.4.8. *Summary of results*

- Implementation of public transport (C1) improves the overall condition of the system. However, it seems to be in conflict with NMT modes and increases the number of transport casualties. The latter is questionable and points towards the need to revise the model's calculation of transport casualties.
- Decreasing road capacity (C2) slightly effects on the system. It encourages NMT trips and improves the overall condition of the system.
- NMT improvement (C3) unexpectedly reduces walking trip slightly but increases bicycle trips. Overall, it makes a higher level of enhancement to bicycle trips than walking trips and contributes positively to the system.
- Parking management (C4) is the most effective measure to reduce fuel consumption and emission per trip and increase the number of NMT trips. However, its impacts on cumulative fuel consumption and emission are of a lesser magnitude.
- Improvement to the shared-taxi operation by decreasing the detour factor (C5) does not reduce cumulative fuel consumption and emissions of the system; in fact it worsens the system as a whole. The only tangible gain is an increase of the shared-taxi ratio.

- Land development policy (C6) was found to have a positive effect on NMT trips. Inclusion of land use indicators will be necessary to assess this measure in more detail.
- The combined policy (C7) yield results which were not equal to the sum of all policies included. It depicts the nonlinearity behaviour of the complex system.

Chapter 9: Scenario assessments

Table 9-10 Results of Scenario A1 Baseline and C

Objective	Sub-objective	Indicators	Unit	Year 30							
				A1: Baseline	C1: Public transport	C2: Dec. road capacity	C3: Improve NMT	C4: Parking strategy	C5: Improve Shared taxi	C6: Land control	C7: Combined (C1/2/3/4/6)
1. Environmental protection	1.1 Efficient in the use of resources	1.1a Consumption of fuel per trip	(litre/trip)	0.29	0.29 (0%)	0.29 (0%)	0.29 (0%)	0.46 (+59%)	0.30 (+3%)	0.29 (0%)	0.42 (+45%)
		1.1b Cumulative fuel consumption	Billion litre	11.44	9.63 (-16%)	11.05 (-3%)	11.37 (-1%)	10.28 (-10%)	11.64 (+2%)	11.39 (0%)	8.29 (-28%)
	1.2 Reduce greenhouse to a reasonable level	1.2a Greenhouse gas emission per trip	(CO2 equivalent kg/trip)	698.55	687.83 (-2%)	698.73 (0%)	698.21 (0%)	1098 (+57%)	723.12 (+4%)	689.72 (-1%)	1,007 (+44%)
		1.2b Total Greenhouse gas emission	Trillion kg	27.13	22.74 (-16%)	26.34 (-3%)	26.96 (-1%)	24.33 (-10%)	27.71 (+2%)	27.02 (0%)	19.51 (-28%)
2. Accessibility	2.1 Provide reasonable accessibility	2.1 Change in accessibility	(ratio to base year)	1.35	1.33 (-1%)	1.39 (+3%)	1.32 (-2%)	1.21 (-10%)	1.31 (-3%)	1.34 (0%)	1.18 (-12%)
	2.2 Reduce automobile dependency	2.2 % of trips made by NMT	(%)	33.1%	29.8% (-3.3)	33.5% (+0.4)	33.4% (+0.3)	44.5% (+11.4)	32.8% (-0.3)	33.5% (+0.4)	38.6% (+5.5)
	2.4 Control urban sprawl	2.4a Av. trip distance (peak)	(kilometre /trip)	4.97	8.12 (+63%)	4.87 (-2%)	5.00 (+1%)	6.92 (+39%)	5.05 (+2%)	4.90 (-1%)	10.74 (+116%)
		2.4a Av. trip distance (opeak)	(kilometre /trip)	4.63	5.65 (+22%)	4.53 (-2%)	4.62 (0%)	5.61 (+21%)	4.71 (+2%)	4.55 (-2%)	6.96 (+50%)
3. Safety	3.1 Reduce transport accidents, including non-vehicular	3.1a Total Number of traffic injuries	(injured)	23,173	24,228 (+5%)	22,233 (-4%)	23,015 (-1%)	20,762 (-10%)	23,196 (0%)	23,102 (0%)	22,049 (-5%)
		3.1b Total Number of traffic deaths	(death)	2,988	3,124 (+5%)	2,866 (-4%)	2,967 (-1%)	2,677 (-10%)	2,990 (0%)	2,978 (0%)	2,843 (-5%)
4. Quality of living standard	4.1 Enhance the social, cultural, and recreation activities	4.1 % of trips make by NMT	(%)	33.1%	29.8% (-3.3)	33.5% (+0.4)	33.4% (+0.3)	44.5% (+11.4)	32.8% (-0.3)	33.5% (+0.4)	38.6% (+5.5)
5. Equity and fairness	5.1 Accessibility for non-vehicular users	5.1 % of trips make by NMT	(%)	33.1%	29.8% (-3.3)	33.5% (+0.4)	33.4% (+0.3)	44.5% (+11.4)	32.8% (-0.3)	33.5% (+0.4)	38.6% (+5.5)

Note: numbers in parenthesis are ratio in relation to year-30 of the A1 baseline; changes for percentages are absolute values

Table 9-11 Background indicators of baseline and C scenarios

Mode share %								
Mode	Year 30							
	A1:	C1	C2	C3	C4	C5	C6	C7
Pedestrian	21.3%	19.4% (-1.9)	21.7% (+0.4)	21.2% (-0.1)	29.1% (+7.8)	21.2% (-0.1)	21.7% (0.4)	25.2% (+3.9)
Bicycle	11.7%	10.4% (-1.3)	11.9% (+0.2)	12.2% (0.5)	15.4% (+3.7)	11.6% (-0.1)	11.8% (0.1)	13.3% (+1.6)
Pt bus	0.2%	7.0% (+6.8)	0.2% (0)	0.2% (0)	0.3% (+0.1)	0.2% (0)	0.2% (0)	10.9% (+10.7)
Car	23.5%	22.6% (-0.9)	23.3% (-0.2)	23.4% (-0.1)	19.8% (-3.7)	23.4% (-0.1)	23.3% (-0.2)	18.4% (-5.1)
Motorcycle	41.4%	38.9% (-2.5)	41.2% (-0.2)	41.2% (-0.2)	33.1% (-8.3)	41.1% (-0.3)	41.3% (-0.1)	30.2% (-11.2)
Shared-taxi	1.8%	1.7% (-0.1)	1.8% (0)	1.8% (0)	2.4% (+0.6)	2.6% (+0.8)	1.7% (-0.1)	1.9% (+0.1)

Average trip distance (km)								
Mode	Year 30							
	A1:	C1	C2	C3	C4	C5	C6	C7
Pedestrian	0.54	0.54 (0%)	0.54 (0%)	0.54 (0%)	0.54 (0%)	0.54 (0%)	0.54 (0%)	0.54 (0%)
Bicycle	1.02	1.05 (+3%)	1.02 (0%)	1.15 (+13%)	1.04 (+2%)	0.99 (-3%)	0.99 (-3%)	1.19 (+17%)
Pt bus	8.24	26.06 (+216%)	8.21 (0%)	8.33 (+1%)	8.44 (+2%)	8.44 (+2%)	8.71 (+6%)	27.02 (+228%)
Car	7.75	8.32 (+7%)	7.56 (-2%)	7.74 (0%)	11.73 (+51%)	7.74 (0%)	7.68 (-1%)	12.62 (+63%)
Motorcycle	5.98	6.68 (+12%)	5.95 (-1%)	5.97 (0%)	9.93 (+66%)	5.98 (0%)	5.92 (-1%)	11.34 (+90%)
Shared-taxi	10.90	11.21 (+3%)	10.12 (-7%)	10.86 (0%)	11.25 (+3%)	12.50 (+15%)	10.78 (-1%)	11.26 (+3%)

Average trip time (minute)								
Mode	Year 30							
	A1:	C1	C2	C3	C4	C5	C6	C7
Pedestrian	16.13	16.18 (0%)	16.14 (0%)	16.13 (0%)	16.20 (0%)	16.13 (0%)	16.13 (0%)	16.29 (+1%)
Bicycle	8.70	8.77 (+1%)	8.70 (0%)	9.00 (+3%)	8.71 (0%)	8.60 (-1%)	8.60 (-1%)	9.00 (+3%)
Pt bus	52.75	65.88 (+25%)	54.08 (+3%)	53.03 (+1%)	52.94 (0%)	53.36 (+1%)	54.11 (+3%)	67.54 (+28%)
Car	19.51	20.04 (+3%)	20.32 (+4%)	19.49 (0%)	32.02 (+64%)	19.45 (0%)	19.37 (-1%)	33.86 (+74%)
Motorcycle	13.87	14.73 (+6%)	14.71 (+6%)	13.86 (0%)	23.36 (+68%)	13.84 (0%)	13.76 (-1%)	25.85 (+86%)
Shared-taxi	37.91	38.61 (+2%)	37.77 (0%)	37.97 (0%)	39.26 (+4%)	41.90 (+11%)	37.99 (0%)	40.44 (+7%)

Travel speed/mode door to door (km/h)*								
Mode	Year 30							
	A1	C1	C2	C3	C4	C5	C6	C7
Pedestrian	2.00	2.00 (0%)	2.00 (0%)	2.00 (0%)	2.00 (0%)	2.00 (0%)	2.00 (0%)	2.00 (0%)
Bicycle	8.38	8.38 (0%)	8.38 (0%)	8.88 (+6%)	8.36 (0%)	8.36 (0%)	8.27 (-1%)	8.71 (+4%)
Pt bus	9.44	23.52 (+149%)	9.17 (-3%)	9.48 (0%)	9.60 (+2%)	9.50 (+1%)	9.73 (+3%)	23.87 (+153%)
Car	24.56	25.52 (+4%)	22.86 (-7%)	24.57 (0%)	21.62 (-12%)	24.65 (0%)	24.67 (0%)	22.10 (-10%)
Motorcycle	28.22	29.37 (+4%)	26.07 (-8%)	28.23 (0%)	26.52 (-6%)	28.34 (0%)	28.32 (0%)	27.08 (-4%)
Shared-taxi	12.18	12.52 (+3%)	11.31 (-7%)	12.18 (0%)	12.59 (+3%)	13.10 (+8%)	12.16 (0%)	12.74 (+5%)

Note: numbers in parenthesis are ratio in relation to year-30 of the A1 baseline; changes for percentages are absolute values

*include walking to embarkation point and from disembarkation point during peak period

9.5. Scenario set D: Other scenarios

9.5.1. Scenario D1: Post Peak-oil

This scenario investigates the effects of a significant increase in fuel price resulting from the scarcity of global fuel supply, or during the “Post Peak Oil” era, as proposed by M. King Hubbert (See Chapter 9.4.4) and others. The effects can also be compared with financial measures, such as fuel tax that will increase the cost of vehicle use over the whole city.

The fuel price is set to be 1 Euro/litre for diesel and 1.5 Euro/litre for petrol in year 5, based on the 2011 fuel price. It then increases by 30% per year to reach 30 Euro/litre for diesel and 45 Euro/litre for petrol in year 18 and remains at that level until year 30. The growth rate of vehicle ownership is kept at the same level as the baseline scenario; the ticket price for bus trips and shared-taxi fares are also kept constant.

Results

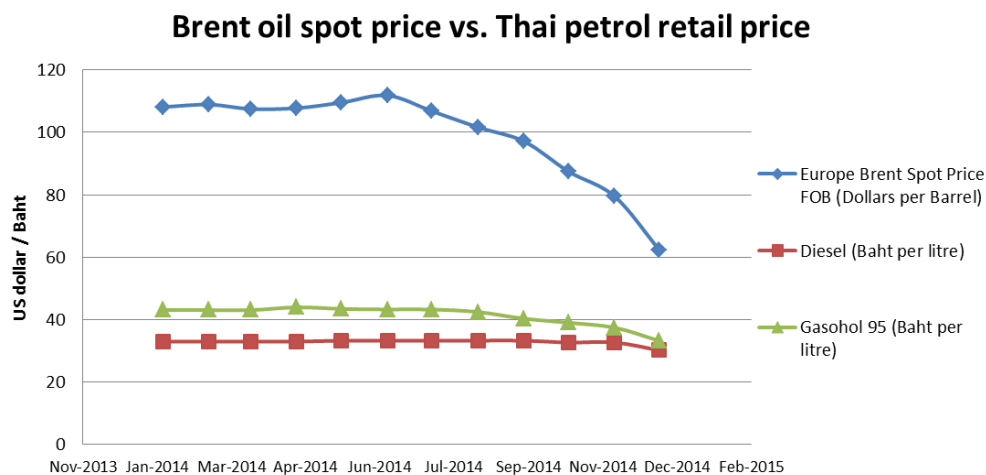
The effects of a significant increase in fuel price (D1) are a decrease in per trip fuel consumption (-17%) and greenhouse emissions (-15%). The measure also decreases the cumulative fuel consumption and emission values (-21% and -20%, respectively). This is the only measure assessed here that sees the ‘per trips’ values and cumulative values change in the same direction. The measure sees the accessibility value decreased by -14% as well as average trip distance (-48% and -46%). The ratio of NMT trips is also significantly increased (+24.2). These trends indicate that residents respond to the financial impact of the Peak Oil scenario by switching to walking and cycling mode for travel to/from local destination, which is likely to reduce the number of shopping and work related trips.

The measure also sees a decrease in transport related accidents (-25%). It increases the ratios of NMT, public transport, and shared-taxi trips at cost of motorcycle and car trips. It reduces car trips (by over -20%) and motorcycle (by over -50%). The average trip distance and trip time for car and motorcycle are also highly reduced. By contrast, it increases the average trip distance of shared-taxi (+11%). The average trip times of bus and shared-taxi decrease slightly as the road capacity increases allowing their speeds to rise. This measure delivers a near absolute overall improvement to the system.

9.5.2. Scenario D2: Cheap oil

Brent crude oil price dropped by more than 50% between June 2014 (\$115 a barrel) and January 2014 (under \$50 a barrel). This significant reduction was caused by an increase in oil supply, mainly driven by an increase in USA's Shale oil production, and the decrease in demand, due to the economic crises (The Economist, 2014). Moreover, the price of Brent crude oil is expected to stay below \$100 barrel for some time. Analysts have projected an average of \$91.50 in 2015, \$90 in 2016, and \$88 in 2017 (Kindergan, 2014). A comparison between Brent crude oil price and Thai's petrol retail price shows a dip in domestic petrol price but not to the same magnitude as the global oil price, suggesting a dampen and delay of the internal oil pricing mechanism. However, the world bank's long term forecast is that oil price will not reach June 2014 level of \$115 until 2025 (The World Bank, 2014). The extended period of low price may eventually filter through and affects Thai's oil price.

Graph 9-3 Brent oil spot price vs. Thai petrol retail price



Source: <http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=p&s=rbrte&f=m> and <http://www.shell.co.th/th/products-services/on-the-road/fuels/fuel-price/fuel-history.html>

This scenario attempts to simulate the effects of cheap oil to the city transport system over an extended period of time. The fuel price is assumed to be reduced by 10% annually from year 1 to year 10, which results in the drop of the diesel price from 30 Baht to 10 Baht per litre and the petrol price from 43 Baht to 15 Baht per litre. The prices remain constant until the end of the simulation period (Year 30). The effects of this scenario should be similar to a measure subsidising the oil price for the whole city.

Results

The result of this scenario is perhaps predictable; the decrease in fuel price yields opposite effects to D1 scenario. The consumption of fuel and emission per trip increase (by +7% and +6%, respectively), as well as the cumulative values (+2%). The measure increases accessibility slightly (+2%) but reduces the ratio of NMT trips (-2.6). The average trip distance of all other modes also increases (+10%), and consequently the number of transport casualties rises (+3%).

D1's background indicators show an increase of trips made by private motorised modes (+2.8), while ratios of other modes are decreased. Similar trends are observed in the average trip distance and trip time; car and motorcycle average values increased. The values for other modes remain constant except the shared taxi (average values increases by +1%). The average speeds of the car and the motorcycle increase by +1%. Additionally, average speed of the shared-taxi decreases (-1%). Overall, the decrease of fuel price depicts a tangible benefit and promotes private motorised transport.

9.5.3. Scenario D3: Visionary

In this scenario, different attributes of the model are adjusted manually to produce outcomes, which meet the following criteria:

1. Mode share for a combined car and motorcycle trips equates to less than 40% of all trips
2. The annual CO₂ emission level in year 30 is 40% lower than the base year (2011)

The results of the previous tests show that the following scenarios affect NMT trips and CO₂ emission, as depicted on Table 9-12.

Table 9-12 Effects of scenario on NMT trips and CO₂ emission

Scenario	Increase NMT trip ratio	Reduce cumulative CO ₂ emission
A1: Baseline case	n/a	No
A2: High car growth	No	No
A3: High m/c growth	Yes	Yes
B1: Increase Road capacity	No	No
B2: m/c promotion	No	No
B3: m/c promotion with mitigations	Yes	Yes
C1: Public transport	No	Yes
C2: Dec. road capacity;	Yes	Yes
C3: Enhancements NMT	Yes	Yes
C4: Parking management	Yes	Yes
C5: shared-taxi improve	No	No
C6: Land use control	No	No
D1: Post Peak-oil	Yes	Yes
D2: Cheap oil	No	No

Note: Only, individual measures are included here

Bold letter indicates scenario that increase NMT trips and decrease CO₂ emission.

It is apparent that six factors affect the NMT trip ratio and CO₂ emission in a desirable manner, while C1 public transport only affects the CO₂ emission. Therefore, these measures need to be combined and balanced carefully to yield the desired goals.

At first, the attributes of the seven scenarios were combined into one new scenario. However, the result of combined attributes did not meet the criteria. Manual adjustments were made to the model's transport attributes until the required results were obtained. Table 9-13 shows the values of the attributes.

Table 9-13 Attributes that yield required criteria

Measure types	Zone	Descriptions	Time
Parking management	All Zones	Car: 3 min. walking to parking place from origin and destination with 2 minute parking search time Long term parking fee 80 Baht/stay, short term parking fee 40 Baht /stay Motorcycle: 2 min. walking to parking place from origin and destination with 1.5 minute parking search time Long term parking fee 40 Baht/stay, short term parking fee 20 Baht/stay	Off Peak
	Zone 15-20	Car: 6 min. walking to parking place from origin and destination with 4 minute parking search time Long term parking fee 80 Baht/stay, short term parking fee 40 Baht/stay Motorcycle: 4 min. walking to parking place from origin and destination with 2 minute parking search time Long term parking fee 40 Baht/stay, short term parking fee 20 Baht/stay	Peaks
Public Transport		Same as Scenario C1: Full scale public transport	
Fuel cost		Increase by 5% annually	

This set of attributes yield the required criteria with an average CO₂ emission (-42% below the base year or 222 million kg in compare the baseline's 384 million kg). The proportion of NMT trips in year 30 also reached the target of 43%. The scenario increases the average fuel consumption and CO₂ emission per trip by 35% and decreases accessibility (-16%). It significantly increases the average trip distance (+125% in the peak period and +43% during the off peak period), which indicate possible changes in land use or forced detour due to parking restrictions. The number of transport accidents also reduced (-11%).

The background indicators show that these set of measures decrease the proportion of private motorised modes (-24.8) and increase NMT and public bus trips (+10.9 and +13.3 respectively). It also significantly increases the average trip distance and trip time of all modes (except pedestrian's average trip distance). However, only the average speeds of bicycle, bus, and shared-taxi increase. The average speeds of car and motorcycle decrease, which is likely caused by an increase in the average walking time to parking space.

It is clear that the delivery of these attributes will be highly challenging in reality. For example: an adjustment to average walking time to parking space from origin and destination will require the elimination of on-street parking and construction of communal

parking facilities; enforcement of parking charges will require stricter parking control, and increasing fuel cost will need to be backed by strong political commitment. Additionally, some of the magnitudes of these attributes can seem highly extreme. For example, an increase of fuel price from 30 to 130 Baht/litre for Diesel and 43 to 185 Baht/litre for petrol represent approximately fourfold increase. Such extremes may raise doubt on the credibility of the analysis, but such changes are not unprecedented; in 2002 the price of petrol was 16 Baht per litre and by 2012 this had risen to 48 Baht per litre. It should be noted that the poor condition of NMT facilities and the relatively limited public transport network of the city are possible causes of these high values; there is high resistance to shift from private motorised transport trips (car/motorcycle) to other modes. Nevertheless, this exercise has shown it is possible to achieve the required targets and increase the sustainability of the current transport system.

9.5.4. Summary of results

- Significant increase of oil price sees an overall improvement of the system; the cumulative fuel consumption and emission values decrease, as well as the proportion of trips by private motorised transport. The average trip distance is also greatly reduced, indicating that residents shift to non-motorised mode and change their travel destinations to those of closer proximity.
- Reduction of oil price (D2) results in an opposite trends; the cumulative fuel consumption and emission values increases as well as the ratio of private motorised transport. Residents increase their average travel distance. It can be expected that the city will see an increase of private vehicle use and CO₂ emission. This will hamper efforts to improve the sustainability of the city's transport system.
- The Visionary scenario demonstrates that an ambitious transport goal can be achieved with the right combination of transport policies. The delivery of these policies will require strong political commitment.

Table 9-14 Results of Scenario A1 Baseline, D1, and D2

Objective	Sub-objective	Indicators	Unit	Year 30			
				A1: Baseline	D1: Post peak oil	D2: Cheap Oil	D3: Visionary
1. Environmental protection	1.1 Efficient in the use of resources	1.1a Consumption of fuel per trip	(litre/trip)	0.29	0.24 (-17%)	0.31 (+7%)	0.43 (+48%)
		1.1b Cumulative fuel consumption	Billion litre	11.44	9.04 (-21%)	11.71 (+2%)	7.43 (-35%)
	1.2 Reduce greenhouse gasses to a reasonable level	1.2a Greenhouse gas emission per trip	(CO2 equivalent kg/trip)	698.55	591.78 (-15%)	741.72 (+6%)	1,025 (+47%)
		1.2b Total Greenhouse gas emission	Trillion kg	27.13	21.71 (-20%)	27.71 (+2%)	17.56 (-35%)
2. Accessibility	2.1 Provide reasonable accessibility	2.1 Change in accessibility	(% to base year)	202.85	174.67 (-14%)	206.56 (+2%)	169.99 (-16%)
	2.2 Reduce automobile dependency	2.2 % of trips made by NMT	(%)	33.1%	57.3% (+24.2)	30.5% (-2.6)	44.0% (+10.9)
	2.4 Control urban sprawl	2.4a Av. trip distance (peak)	(kilometre /trip)	4.97	2.57 (-48%)	5.49 (+10%)	11.16 (+125%)
		2.4a Av. trip distance (opeak)	(kilometre /trip)	4.63	2.49 (-46%)	5.10 (+10%)	6.63 (+43%)
3. Safety	3.1 Reduce transport accidents, including non-vehicular	3.1a Total Number of traffic injuries	(injured)	23,173	17,279 (-25%)	23,812 (+3%)	20,722 (-11%)
		3.1b Total Number of traffic deaths	(death)	2,988	2,228 (-25%)	3,070 (+3%)	2,672 (-11%)
4. Quality of living standard	4.1 Enhance the social, cultural, and recreation activities	4.1 % of trips make by NMT	(%)	33.1%	57.3% (+24.2)	30.5% (-2.6)	44.0% (+10.9)
5. Equity and fairness	5.1 Accessibility for non-vehicular users	5.1 % of trips make by NMT	(%)	33.1%	57.3% (+24.2)	30.5% (-2.6)	44.0% (+10.9)

Note: numbers in parenthesis are percentage in relation to year-30 of the A1 baseline

Table 9-15 Background indicators for Scenario A1, and D

Mode share %				
Mode	Year 30			
	A1: Baseline	D1: Peak Oil	D2: Cheap Oil	D3: Visionary
Pedestrian	21.3%	36.7% (+15.4)	19.73% (-1.6)	29.2% (+7.9)
Bicycle	11.7%	20.6% (+8.9)	10.78% (-0.9)	14.7% (+3.0)
Pt bus	0.2%	0.3% (+0.1)	0.00% (-0.2)	13.5% (+13.3)
Car	23.5%	18.3% (-5.2)	24.26% (+0.8)	14.9% (-8.6)
Motorcycle	41.4%	20.1% (-21.3)	43.39% (+2.0)	25.2% (-16.2)
Shared-taxi	1.8%	3.5% (+1.7)	1.66% (-0.1)	2.5% (+0.7)

Average Trip distance (kilometre)				
Mode	Year 30			
	A1: Baseline	D1 Peak Oil	D2: Cheap Oil	D3: Visionary
Pedestrian	0.54	0.54 (0%)	0.54 (0%)	0.54 (0%)
Bicycle	1.02	1.02 (0%)	1.02 (0%)	1.10 (+8%)
Pt bus	8.24	8.05 (-2%)	8.25 (0%)	26.60 (+223%)
Car	7.75	4.36 (-44%)	8.45 (+9%)	13.50 (+74%)
Motorcycle	5.98	4.19 (-30%)	6.41 (+7%)	12.83 (+115%)
Shared-taxi	10.90	12.06 (+11%)	10.81 (-1%)	11.89 (+9%)

Average Trip time (minute)				
Mode	Year 30			
	A1: Baseline	D1: Peak Oil	D2: Cheap Oil	D3: Visionary
Pedestrian	16.13	16.09 (0%)	16.14 (0%)	16.30 (+1%)
Bicycle	8.70	8.72 (0%)	8.7 (0%)	8.88 (+2%)
Pt bus	52.75	50.18 (-5%)	53 (0%)	64.70 (+23%)
Car	19.51	12.00 (-38%)	20.98 (+8%)	37.57 (+93%)
Motorcycle	13.87	10.30 (-26%)	14.63 (+5%)	29.84 (+115%)
Shared-taxi	37.91	37.68 (-1%)	38.11 (+1%)	40.63 (+7%)

Travel speed/mode door to door (km/h) – include walking				
Mode	Year 30			
	A1: Baseline	D1: Peak Oil	D2 Cheap Oil	D3: Visionary
Pedestrian	2	2.00 (0%)	2.00 (0%)	2.00 (0%)
Bicycle	8.38	8.42 (0%)	8.39 (0%)	8.36 (0%)
Pt bus	9.44	9.67 (+2%)	9.40 (0%)	24.54 (+160%)
Car	24.56	24.13 (-2%)	24.72 (+1%)	21.11 (-14%)
Motorcycle	28.22	27.99 (-1%)	28.28 (0%)	26.60 (-6%)
Shared-taxi	12.18	13.45 (10%)	12.08 (-1%)	13.46 (+11%)

Note: numbers in parenthesis are ratio in relation to year-30 of the A1 baseline; changes for percentages are absolute values

*include walking to embarkation point and from disembarkation point during peak period

9.6. *Chapter findings and conclusion*

Transport and land use policies for Chiang Mai city were evaluated through CNX-MARS with particular focus on investigating the role of the motorcycle and the shared taxi in the system. The effects of increased motorcycle ownership and use, as well as enhancement to the shared taxi service were assessed. The evaluation also looked beyond the focal area and assessed a number of policies suggested by **Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS)**, which is responsible for deciding transport policy for the city. Moreover, the effects of a set of combined measures are quantified, as well as a search for a set of measures that yield the determined vision. A total of 16 different scenarios were assessed.

The assessment of the promotion of motorcycle ownership (Scenario A3) and usage (Scenario B2) shows that this is not a sustainable policy in the long term. It delivers localised improvement, such as decreasing average fuel consumption and emission per trip, which delays the negative effects of motorisation. However, the benefits gained last for a limited period (2-4 years), after which the measures detrimentally affect the system as a whole in the longer term. Yet it is still possible to employ motorcycle promotion as a sustainable transport policy. Inclusion of parking management measures maintains the levels of cumulative fuel consumption and CO₂ emission below the baseline.

The appraisal shows that an improvement to the shared-taxi service without changing the nature of its operation can improve its mode share. However, the overall cumulative benefits are limited. Additional instruments that (a) discourage car use, (b) reduce shared-taxi emission, and (c) minimise shared-taxi's fuel consumption may increase the overall positive benefits slightly. The result, however, will be incomparable to the benefits gained from implementing a regulated public transport system.

The results of the quantitative assessments of the 6 scenarios from Chapter 6 are in agreement with the results of their qualitative assessment. This adds credibility to the qualitative assessment framework.

The results of the appraisals show a number of interesting phenomena, such as non-linearity behaviour, synergy effects, and time-lags. The results also illustrate that measures which improve a particular criterion can worsen the overall performance of the system, and vice versa. These characteristics are fundamentally features of system behaviour, which are

complex to understand, yet it is essential to comprehend them to achieve a successful transport and land use plan. CNX-MAR has proved a useful tool in helping to gain an insight into the complex effects of these different scenarios.

The assessment of these scenarios also reveals several **limitations of the assessment framework**. For instance, a handful of MARS outputs were selected as performance indicators and background indicators. Although, these indicators were carefully picked, they are still a limited representation of the whole system within a model. In each scenario, there may be benefits and losses occurring in other areas within the system, which are not quantified either by the assessment framework or the model. For example, an improvement to NMT facilities (C3) may involve large scale tree planting activities, which decrease the level of city's CO₂, or might include the implementation of pedestrianized zones that contribute towards the cultural aspect of the city and create business opportunities. Moreover, all of the indicators are transport related, which prevent a thorough evaluation of other types of policy, such as land use (C6).

The framework also only makes comparisons between the values and cumulative values of the final year (year 30). The comparison of the whole time period will make the framework more complex but may produce different results altogether. The framework is also simplified by focusing only on transport and land use changes. Inclusion of other effects beyond the scope of the current assessment, such as a decrease in household size, may also change the result of the analysis. Moreover, the framework discards the cost aspects of each scenario and the difficulty of implementation, which are important factors for policy makers. The exclusion of these factors is acceptable here because the scope of this thesis focuses on quantifying the impacts of these scenarios.

10. Conclusions

This study set out to take a fresh look at the persisting transport problems of Chiang Mai city. The main objective is to contribute towards the discussion about how to achieve sustainable transport, in general, by focusing on and finding solutions at the urban level. As reiterated throughout this thesis, urban transport problems are complex. In this study, the system approach and system dynamics in the MARS model were the tools utilised to help find answers to two specific questions:

(1) What are the unique mobility features of trips made by motorcycle and shared-taxi in Chiang Mai city?

(2) What are the implications of these features in planning a sustainable transport system for the city?

Five additional research questions were added to elaborate the two focal research questions and broken down into the following objectives:

- Research Question 1: to understand the development path of the city's transport system and land use,
- Research Question 2: to identify the unique features of the city's transport system and the implications of these characteristics
- Research Question 3: to ascertain the causal relationships between different elements within the city's transport system and its system behaviour and to review them against the mind map of decision makers
- Research Question 4: to ensure the tool used (i.e. MARS model) was tailored to fit the case study appropriately, and
- Research Question 5: to assess the effects of different transport measures on the system using the modified tool.

The first part of this section provides a brief summary of each chapter of my thesis. It also demonstrates how each chapter addresses the research questions posed. The second part highlights the significant results achieved by this research and points out the study's limitations. The third part provides recommendations for subsequent research. The fourth part contains discussion on various topics related to the study and the final part concludes the study.

10.1. Summary of Main findings

10.1.1. Literature review (Chapter 2)

In this chapter, the research parameters are established for this thesis by reviewing literature in three different areas: 1) motorcycle and shared-taxi modes of transport and their respective roles within a sustainable transport system, 2) position of Metropolitan Activity Relocation Simulator (MARS) as a tool for sustainable transport planning, and 3) past works related to planning the transport system of Chiang Mai city.

In the first review, I found most motorcycle studies focused only on aspects of this mode's vulnerability and safety in traffic. Only a handful of them looked into the use and mobility behaviour of motorcycle riders. The review revealed a number of interesting facts that have been incorporated into subsequent chapters. Overall, the limited research on this topic was surprising, given the high number, and importance, of motorcycles in many parts of the world.

There are a number of demand-response paratransit services akin to Chiang Mai city's shared-taxi service, such as those seen in North America during the 1960s, and those still seen in Hong Kong today. However, the most similar forms of operation are the use of the Bemo in Indonesia and the Jeepney in the Philippines. Other examples have more formal arrangements within a more structured organisation.

In the second literature review, I made a comparison between MARS and five other transport models. MARS stood out for its comprehensiveness, low data requirement, and transparency. The comparison also highlighted several improvements for MARS that were implemented in this study.

In the final literature review, past studies that addressed Chiang Mai's transport problems were separated into four categories, and are classified according to their primary focus. I made seven interesting findings, which provided guidelines on possible new lines of study that this thesis could take. The seven points were:

1) The city's transport problems are complex with multiple facets, yet the solutions proposed by past studies employed only a reductionist approach. Most studies failed to acknowledge the interactions between transport and other aspects. They often focused on specific areas that fall within the responsibilities of the agents who funded the studies or the speciality of the person(s) who carried out the study.

2) Past studies made several findings and recommendations but they did not identify any quantitative goals and measures by which the success of their attempts to resolve the city's transport problems could be judged.

3) There has been a lack of choice and availability of evaluation tools for planning sustainable transport measures and policies for the city. Only traditional four-step models have been employed. The four-step model is known to have several limitations, especially its limited transferability and ability to evaluate sustainable transport measures.

4) Previous studies on the city's transport system are primarily focused on four-wheeler transport, although the city has a high proportion of motorcycle vehicles.

5) The operation of the shared-taxi service has been identified correctly as part of the city's transport problems. Many studies emphasis the fleets' inefficiency and unreliability, but have not given any suggestions on how the service can be improved.

6) There is limited research which focuses on the mobility behaviour of the motorcycle users and shared-taxi passengers. This indicated gaps in current knowledge which this thesis could help address.

7) Comparison between MARS and five other transport models revealed a number of possible improvements and confirm MARS as a suitable sustainable transport planning tool.

10.1.2. Development of the city's land use and transport system (Chapter 3)

I presented the chronological development of the city's land use and transport system in this chapter to address **Research Question 1**. The aims are 1) to look into the development path to understand the city's land use and transport system and 2) to identify any path-dependents that set the city on its current development trail. The tracing revealed several thought-provoking findings, such as:

1) Chiang Mai city was originally designed for non-motorised modes and remained a non-motorised city for many centuries. Walking, cycling, and the use of domesticated animals, were the dominant modes of transport for over 600 years. The development of the city's land use during this period was driven by non-motorised transport modes.

2) The city's mobility then evolved directly from non-motorised to private motorised transport with the first cars imported into the city in 1906. Shared taxis were available after that but only on a small-scale organised by private individuals. A larger scale of organised

public transport arrived at a much later date (1972). The services were privately-owned, where the motive was profit rather than providing a comprehensive public transport service for the benefit of all. As such, a public bus service, enjoyed for many years by Bangkokians, has never played a part in Chiang Mai's transport history, despite several failed attempts. Thus, its citizens have developed perhaps an overdependence on the motorcycle and the private car as the only viable alternatives to meet their diverse transport needs. The shared-taxi (Song Teaw) is the only form of semi-public transport that has operated continuously in the city since 1960 yet meets only a fraction of the public's transport needs.

3) The national government has taken an active role in promoting motorised vehicle with the extensive provision of road infrastructure. This infrastructure has been specifically designed for cars – even in Bangkok there are few “bus only” lanes. The government has neglected its role of promoting and providing an infrastructure that supports public transport services, non-motorised modes, and motorcycles. It has also failed to put in place a strong local organisation with responsibility for the city's transport planning and services. Instead, the organisation of the city's transport and land use developments have become centralised and fragmented rather than localised and integrated.

4) Until after the end of the Second World War, the city's land use remained largely unchanged. It has since undergone a rapid expansion. This expansion correlated with the period when the city began to use motorised transport on an increasing scale and developed its infrastructure accordingly.

These findings demonstrate how the city quickly moved from a reliance on non-motorised transport for over 600 years to embracing motorised transport within a comparatively short period of time. Significantly, the enthusiasm of the city's planning authorities for road construction, without regard to the development of an organised public transport system, has strongly locked residents into and encouraged the use of privately owned 4-wheel vehicles. In other words, the provision of road infrastructure and transport policies after the end of Second World War have shifted the city from its non-motorisation path onto a highly motorised one.

Generally, the findings also show that the planning and the organisation of public transport system in growing cities should be done at an early stage.

10.1.3. Trends observation (Chapter 4) and Analysis of mobility behaviour (Chapter 5)

In Chapter 4, I reviewed a number of relevant primary and secondary data that indicate several trends in the city's land use, and point to the mobility behaviour of its residents. In Chapter 5, I carried out various analyses that focused specifically on revealing the mobility behaviour of the city's residents, with emphasis on trip time and distance distributions. The findings outlined in these two chapters combined to reveal unique characteristics of the city's transport system and addressed **Research Question 2** as follows:

- The city has undergone a rapid rate of motorisation in comparison to typical western cities, such as Vienna. Chiang Mai has high use and ownership of motorcycles, but in recent years car ownership has increased at an exponential rate.
- Survey respondents spend a high proportion of their monthly income on transport, similar to residents in American suburbs, which have high auto-dependence. Moreover, when questioned about the cost of private transport, most respondents considered only the fuel cost of using car and motorcycle; they ignored the capital costs and other operating expenses such as routine servicing and insurance costs.
- Population density appears to reduce trip distance and trip time. However, density seems to have no influence on reducing the number of motorised transport trips; indeed, respondents living within the municipality have a higher motorcycle trip ratio when compared with other areas.
- Among the mobility indicators considered, trip mode has the strongest influence on trip distributions.

In summary, detailed analyses of motorcycle and shared taxi trips result in the following observations:

Motorcycle

- Motorcycle trips generally have a lower average trip distance, trip time, and trip speed than car. The mode's trip distributions have distinguished patterns that sit between non-motorised and 4-wheeler trips.
- Six mobility and demographic attributes⁷⁸ have varied effects on motorcycle use.
- Females travel less often by motorcycle (6% less than males) and female motorcycle riders have slightly lower average trip distance, trip time, and trip speed.

⁷⁸ Trip purpose, trip modes, Sex, Registration status, household location and household monthly income

- Residents who were not registered at their domicile have a higher motorcycle trip ratio (11% higher than registered residents). Unregistered motorcycle riders also have slightly higher average trip distance and trip time.
- Household location and income levels have influences on mode selection; respondents with households in the municipality area and households with lower income make a higher number of motorcycle trips.

Shared-taxi

- Shared-taxi trips have slightly lower average trip distance, but higher average trip time, and lower trip speed compared to privately owned cars. In other words, they travel less distance at a slower speed than cars.
- This mode's trip distributions have similar patterns to the car.
- The six demographic attributes, identified above, have varied effects on its use. The shared-taxi is used mostly for school/university trips. Nearly all of respondents who used shared-taxi were female. Registration status has little effect on shared-taxi use. Respondents in outer district and low income households use the shared-taxi more often.

Some of the correlations between motorcycle use and demographic attributes revealed here seems to be along the same lines as the observations made by some of the past studies; correlation between income, gender, and age, for example, as observed by Kepaptsoglou & Milioti (2011) and Yannis & Golias (2007), as well as the average number of trips per day reported by Solere (2010).

Walking time to/from embarking points for different modes of transport was also analysed. This type of data collection and analysis is rare and has never been done before for the city of Chiang Mai. The results show that motorcycles are parked closer to their origins and destinations than either the car or the shared-taxi, the latter being the furthest away. Thus, the motorcycle has a higher penetration (or ease of access) than the car and shared-taxi as the shorter walking distance results in greater convenience and less effort expended by motorcycle riders and passengers. Thus, in accordance to the Equidistance Parking Principle proposed by Knoflacher (2006), the motorcycle has a potentially higher penetration (or addiction) than the car, as the shorter walking distance results in expending less (human) energy. In other words, motorcycles may have a stronger 'lock in' or captive effect than cars as they are more readily accessible. Interestingly, the assessment of the proposed policy in Chapter 9 to promote motorcycle usage poses threats to non-motorised modes.

Moreover, several remarks are included based on my observations during six months of field work. These remarks provide empirical additions to the quantifiable mobility data gathered, and add valuable insights into the city's transport system.

The unique characteristics of Chiang Mai city's transport system revealed in the two chapters have several implications:

- **Transferability of practise.** The significant differences in the rate and magnitude of motorisation between Chiang Mai and Vienna cities indicate the need for a critical assessment in transferring principles, strategies, and tools used to solve transport problems from one country to another. Several factors, such as the historical development path, current status, and projected future trends, should be combined to create a realistic context for each case.
- **High dependency on motorised vehicles entails high cost.** The lack of alternative mode choice makes the city highly dependent on private motorised vehicles, with residents having to set aside a significant sum to meet high monthly transportation costs. A reduction on this dependency with the provision of a cheaper transport mode would permit residents to make financial savings and allocate cash to other areas that may improve their lifestyle and provide a boost to the local economy.
- **Densification creates the conditions for encouraging non-motorised modes.** The observations in this study imply that density alone will not increase the share of non-motorised trips. However, density will improve the conditions suitable for non-motorised modes, such as shorter trip distance. Respondents in the municipality area have a lower average trip distance (3.8 km) than other areas (Aumpor Muang 6.1 km and the outer district's 6.9 km). A high proportion of trips in the municipality can be replaced by cycling trips, through the employment of a push-pull approach similar to Topp (1994). Using pull factors, such as provision of public transport to support irregular/weekend long trips, and implementation of infrastructure and measures to promote cycling, would help to alleviate traffic congestion. Together with push factors, such as enforcement to limit vehicle access, and changes to parking/building legislation to limit parking space, these pull factors would also encourage the use of public transport, cycling and walking.
- **The motorcycle's potential within sustainable transport and the possible threats posed.** The motorcycle is used by residents for short trips as well as long trips and thus meets the need of a wide range of distance coverage. As demonstrated above, the motorcycle has higher penetration than the car and is more easily parked closer to the origin and destination points of a journey. It is potentially a more sustainable replacement for the car as it consumes fewer resources and emits less pollution. However, the motorcycle is still a motorised mode of transport, which utilises external energy for transportation. Moreover, it threatens to replace short non-motorised trips. The quantitative analysis in the next chapter provides further clarification of this matter.

- **Potential of the bicycle.** The analysis also shows that the bicycle has the lowest access time. Based on the principles established by Knoflacher (2003), the lowest access time should give the bicycle an advantage over other modes. The low proportion of ridership in the city is, therefore, due to other factors, such as perception of safety, riding comfort, effort (body energy) required. Efforts must be made to improve the conditions surrounding these and other factors, if the bicycle is to be promoted as a sustainable transport mode.
- **Enhancing Shared-taxi operation.** With improvements to the current organisational and operational management structure, the shared-taxi has the potential to provide a transport service that could replace a significant proportion of private car trips. Analysis shows that a reduction to the detoured trip distance, combined with a corresponding and increased trip speed, will increase the attractiveness of the shared taxi service.
- **Factors that influence urban sprawl.** The factors that influence urban sprawl are multitude. Analyses of household location, income, and mobility indicators demonstrate conclusively that the higher income group makes a significant contribution to the sprawling of the city. People in this group tend to live further away from the city and utilise motorised private modes more than others. A different analysis revealed the relationship between urban sprawl, vehicle ownership, and vehicle use. Positive correlations were found and the time lag between land use and transport change was estimated to be 6 years.
- **Motorcycle and urban sprawl.** The attributes and magnitude of the effects of the motorcycle on urban sprawl were also discussed and is estimated to be 30-50% less than urban sprawl attributed to the car.

10.1.4. Understanding transport system and evaluate the perceptions of the decision makers (Chapter 6)

A generic Causal Loop Diagram (CLD) of transport system to gain an insight into its behaviour was created specifically for Chiang Mai. The CLD was based on findings within my literature review and validated using my research data for Chiang Mai city. The validated CLD was used to assess the impact of various transport policies suggested by the city's decision makers, based on their interviews. The policy makers are very much aware of the existing problems and are highly dedicated and very committed to finding effective, long-term solutions. The result of this exercise, however, questions the comprehensiveness of the decision makers' current assessment on how to achieve the objectives of a sustainable transport system for the city, upon which they were in broad agreement. The assessment shows that **if their suggested policies were implemented they are likely to aggravate the**

problem further. In addition, the analysis also reveals that the decision makers appear to have a high coherency in their vertical thinking, i.e. a strong focus on particular themes or “group think”⁷⁹.

Successive governments over the last 20 years have introduced policies at both national and local level to actively promote vehicle ownership and enthusiastically created a concrete jungle of expressways, inner ring roads and outer ring roads to address the resulting traffic congestion. The reductionist approach is deeply ingrained at all levels not only as a result of government policies but also academic studies that have reinforced this approach by considering transport systems in isolation of social, economic and environmental factors. It is not surprising, therefore, to find that local decision makers tend to view transport problems in isolation, and thus attempt to solve them as unconnected individual problems.

This finding stresses an urgent need to introduce both national and local policy makers to the tools now available to help them identify and tackle the root causes of the city’s transport problems. An opportunity to present my research findings to the city transport planners would be most welcome.

This chapter addressed **Research Question 3**.

10.1.5. *Establish the goal: A sustainable transport vision (Chapter 7)*

In this chapter, the vision of a sustainable transport system for the city was established to provide a clear goal. This vision combines the ideas of the three most influential authorities within city area; namely, Chiang Mai municipality, Chiang Mai Provincial Administrative Organisation, and Chiang Mai Province. It also takes into account the definition of sustainable transport, sufficiency economy, and interview accounts with the city’s decision makers.

This vision was translated into seven objectives that contribute towards the three main aspects of sustainability, namely, environmental, social, and economic considerations.

⁷⁹ Groupthink is a group psychological phenomenon, which occurs when there is a strong desire to seek consensus within a group or, in order to avoid conflict within the group, decisions are compromised to accommodate all viewpoints and not subjected to robust critical evaluation.

These were then broken down further to 25 measurable performance indicators. These indicators are used to assess the contributions each policy and measure will make towards delivering the vision. In addition, a set of transport variables are included as background indicators.

It was found that MARS could deliver 11 out of the 25 performance indicators and all of the background indicators.

10.1.6. *MARS and assessment of transport policy (Chapter 8 and 9)*

These chapters addressed **Research Question 4 and 5**. MARS was reviewed against the case study's context to ascertain the model's transferability, limitations, and required modifications. The checks found the model's transferability was sufficiently sound. A set of model modifications were suggested and prioritised. Three of them were selected and carried out: 1) addition of shared-taxi mode, 2) adjustment to the quality of life indicator, and 3) an update to the emission and fuel consumption module.

A MARS model was constructed for the city, with the data from the tailored household survey (CM-MTS). A handful of secondary data was also used. The model was named CNX-MARS (CNX is the international airport code assigned to Chiang Mai). It has 2011 as its base year with a 30-year time horizon. The model was calibrated and used to evaluate the impacts of 16 transport system scenarios.

The formulations of these scenarios were made with the objectives of this thesis very much in mind. It focuses on the effects of the motorcycle and the shared-taxi but also considered the wider aspects of the transport system. It includes a number of policy measures suggested by **Chiang Mai Province Land Transport System Management Subcommittee (CM-LTSS)**, which is responsible for deciding transport policy for the city and incorporates radical and contemporary scenarios, such as post Peak-oil and cheap oil. In this study, policies to promote use of the motorcycle and to improve the shared-taxi operation were tested for the first time.

The policy assessments revealed several interesting points. Firstly, it demonstrated that the promotion of motorcycle ownership (Scenario A3) and motorcycle usage (Scenario B2 and B3) will give localised improvements, such as lower fuel consumption and emission per trip. However, the benefits gained are short term, (2-4 years), after which the measure worsens the overall conditions of the system. In the long term, promotion of the motorcycle

decreases non-motorised- trips and increases the number of accidents. The assessments also show that benefits gained in the form of delayed adverse impact are minimal. However, when a parking management policy is implemented as a mitigation measure, it will result in increased average fuel consumption and emission per trip, but sees an overall improvement of the system. It increases the ratio of NMT trips and decreases cumulative fuel consumption, harmful emissions, and transport accidents. These findings have important implications for the promotion of motorised two-wheeler vehicles; for example, e-bicycles as used extensively in China.

Secondly, the appraisal shows an improvement to the shared-taxi service in reducing detoured distance (Scenario C5) and shows a small direct benefit of increasing the ratio of shared-taxi trips. However, the overall result of this scenario is that the transport problems are worsened. By contrast, the introduction of a regulated public transport system (Scenario C1) will improve the system overall, it reduces the ratios of trips made by private motorised trips, and reduces the average and cumulative values of fuel consumption and emission.

Thirdly, the results illustrate effects of several transport and land use policies that are relevant to the city.

- The imminent trend of high car growth (Scenario A2) will intensify the negative effects from transport on the city through higher fuel consumption and increased emissions.
- Traditional road widening measures (Scenario B1) will worsen the overall condition of the system by encouraging more private motorised trips.
- Decrease in road capacity (Scenario C2) and enhancement to walking and cycling facilities (Scenario C3) will promote non-motorised transport and result in an overall improvement of the system.
- The assessments show that parking management (Scenario C4) can bring significant improvement to the system at the cost of car and motorcycle trips.
- Land development policy (Scenario C6) restricting new buildings to a height of 3 storeys in the central districts and 5 storeys in the outer districts results in a slight increase in the number of NMT trips. This shows that the policy creates conditions that promote NMT trips, but may yield limited result if implemented in isolation of other measures.

- An attempt to combined sustainable transport policies (Scenario C7) results in an overall improvement of the system. Interestingly, the magnitude of the outcomes is not equal to the sum of individual policies included. This depicts a complex interaction between different entities within the system simulated.
- The Peak Oil (Scenario D1) and Cheap Oil (Scenario D2) scenarios illustrate the effects that a significant change in oil price can have on the transport system. They show that car and motorcycle trips are encouraged by a decrease in oil price.
- The visionary scenario (Scenario D) shows that it is possible to reach ambitious sustainable transport goals with a strong political commitment in implementing measures, such as public transport system, parking organisation, and fuel cost control.

Fourthly, the assessments revealed a number of complex system behaviours. It demonstrated interactive behaviours, where attempts to improve part of the system resulted in negative consequences for other parts or, indeed, the whole system. It also illustrated a number of interesting phenomena, such as non-linearity behaviour, synergy effects, and time-lags. System Dynamics in CNX-MARS has proved to be an effective and useful tool to analyse urban transport system.

Fifthly, the quantitative and qualitative assessments of the 6 scenarios outlined in Chapter 6 are complementary. This shows a certain degree of coherency between the two analyses and endorses their credibility. Moreover, the exercise also reveals a number of limitations and possible improvements to the assessment framework and MARS model that can be incorporated into subsequent studies.

10.2. *Significance and limitation of the study*

The study has contributed to the practical sphere of transportation study and planning by using Systems thinking and SD in solving urban transport problems in Chiang Mai city, with particular reference to the motorcycle and shared taxi. SD is known to be an effective tool to help better understand complex system problems leading to the implementation of most suitable solutions, yet its application is rare in Thailand and Asia. This study attempts to illustrate that SD can make real impacts on the real world as purported by Shepherd (2014).

The findings in this study have also provided evidence that endorse the suitability of Systems thinking, SD, and CLD as transport planning tools. Incremental improvements have also been made to MARS model in this study. These tools enabled Chiang Mai city's transport problems to be analysed in context, acknowledging the city's historical development path, the current status, and outlooks on possible future transport trends. It has helped to provide an in-depth understanding of the interactions between different elements within the transport system and how benefits gained in certain areas, such as average fuel consumption, can lead to the worsening of the overall system. This finding can help stakeholders within the transport system understand the process and gain consensus and support from public. This approach is novel for the city and is in stark contrast to the manner in which problems have been handled at government level and in past studies.

The system approach has also identified the gap between the perception of the impact of conventional solutions on the transport system and the reality of how effective such solutions would be. Morichi & Acharya (2012) had previously created a CLD (Causal Loop Diagram) for a generic transport system. Here, efforts were made to check the causal relationships with quantitative data. The verified qualitative model is then used to evaluate solutions to transport problems suggested by conventional wisdom. **This exercise has provided additional evidence on the usefulness of CLD in understanding complex system and testing transport policy.** It is also the first time such an exercise has been carried out in Thailand involving high ranking decision makers.

The study thus provides an alternative transport decision making tool to existing models. **CNX-MARS is the first non-Four-stage model developed for Chiang Mai city.** Its system dynamic structure enables the relationship between land use and transport to be fed back into the analysis. The model is also flexible, transparent, and can be used to assess sustainable transport measures. The approach of focussing on the motorcycle and the shared-taxi also stands out from past studies, which focused on the car and implementation of a regulated public transport system. The analysis of the empirical mobility data revealed interesting characteristics of the two modes, such as their trip distance and trip time distribution patterns. These findings enhance understanding of the two modes, which is currently limited.

Several detailed analyses unique to this study were also carried out. These included, for example, an analysis of the trip time, distance distribution and the walking time to/from vehicle embarking point, which also contributes evidence supporting Knoflacher's theory (2003). The detailed analysis on the mobility characteristics also led to research findings that are in contrast to generally accepted thinking. For example, it counters the dictum that higher urban density tends to promote non-motorised modes. In addition, it examined the correlations between different demographic and mobility attributes and estimated the magnitude of motorcycle-driven sprawl in relation to the current sprawl of the city.

The household mobility survey carried out as part of this study included an emphasis on walking and bicycle trips, in stark contrast to the bias of other surveys that focused only on motorised transport trips. It is also the first time that a mobility survey is planned especially to collect data for a land use – transport interaction model in MARS. The presence of the non-motorised modes in the survey results ensures they are accounted for in the planning process. Copies of the survey report have been sent to academic institutions and government agencies, such as Chiang Mai University, the ministry of transport and department of city planning. The survey provides these organisations with a comprehensive set of mobility behaviour data that can be used to aid the planning of the city. In addition, this study has revealed many useful data, such as an estimate for the number of people in the shadow population that can be used by the city's administration in its planning.

Another first in this study is its focus on policies relating to motorcycles and shared-taxis, as well as several radical ones, such as the Peak Oil and Cheap Oil scenarios. The evaluation results of these scenarios have useful practical implications on current discourse in transport fields. For example, the assessment of the policy to promote motorcycle use is relevant in relation to the promotion of electric-powered bicycles or e-bikes. The E-bike has recently gained popularity around the world, as a cleaner and more efficient mode of transport. The number in China alone has grown from nearly zero to more than 150 million in over a decade. It has a similar form to the motorcycle, thus can be parked closer to trip origin/destination than car. This means that it also poses the same threat to non-motorised transport modes and can worsen the overall system performance despite efficiencies in fuel consumption and emission of harmful gasses. The proponents of e-bike can benefit from the findings in this study.

There has been an on-going discourse within Chiang Mai city whether the shared-taxi operation can be changed to provide quality public transport service or not. This study has shown, in a quantitative manner that only limited improvement can be achieved with the current form of operation. The effects of the rise and fall of oil price were also evaluated, addressing the actual situations the city facing. The results show that, in the light of the current low oil price, it is likely that the sustainability of the city transport system will decrease.

This thesis also addresses four out of five gaps identified in the literature reviews. It has provided a suggested holistic approach to the city's transport problems; it has provided an alternative transport model by developing a tailored, system dynamic MARS model for the city; it has focused on non-motorised transport and two-wheeler; it has suggested possible improvements and reforms for the shared-taxi service. It has also provided a foundation for dealing with the fifth gap identified, through the quantification of the city's goals by further modifications to the MARS model (see Recommendations section).

Chiang Mai city is a medium size city, which has been designated as the centre of development for the Northern region, yet it does not have an adequate public transport infrastructure. Its residents rely on the informal shared-taxi service and private motorised vehicles to provide required mobility. There are many cities in Thailand and in Asia that are similar in size, many of which are also motorcycle-dominated and facing similar transport challenges, such as Khon Kaen (Thailand), Hải Phòng (Vietnam), Johor Bahru (Malaysia), and Semarang (Indonesia). These cities can benefit from the lessons and notions learned from this case study of Chiang Mai.

However, despite these very positive outcomes it is acknowledged that this study has several limitations. Firstly, the study's emphasis on understanding Chiang Mai's unique transport system means there is room for improvements in other areas, such as the comprehensiveness of policy assessment. The framework presented here is fairly basic. It assumes that all indicators carry equal weighting, which gives room for different combinations of weightings to be explored. Additionally, the intergeneration factor, which is an important element of sustainability assessment, was not part of the assessment framework as well as factors that take into account the limitation of finite global resources. The inclusion of these factors may affect the outcomes of the assessments. Moreover, the

assessments of policies here were done in relation to the baseline case, which was calibrated only with the observed mode share. Thus, other actual outputs, such as CO₂ emission has little relation to what is observed in reality.

Secondly, there are limitations on the dataset used in the analysis, such as the accuracies of trip distance and trip time and the distribution of the samples⁸⁰. In addition, assumptions were made for data that was not available, such as average network speed between zones for the motorised modes. These assumptions affect the quality of the model's output but can be enhanced with actual data. Moreover, because of the lack of data at city level, there are several instances where provincial level data had to be used instead, such as the VKT data. While it is thought the two levels of data should have some correlation, this approach must allow for a margin of error, and the results would undoubtedly be improved if data at the city level could be included.

Thirdly, policy evaluation here is based on my selection and the limited indicators that MARS can produce. The inclusion of other indicators may alter certain aspects of the assessment results.

Fourthly, the structure for the inclusion of the Shared-taxi service in CNX-MARS was limited by the available data on the service, resulting in a basic level of sophistication. Given time and resource, improvements could be made by including a route assignment module to simulate the on-demand service more accurately.

Fifthly, the qualitative and quantitative models in CLD and CNX-MARS are purpose specific with limited scopes. For example, MARS only considered land use and transport interactions as the principal elements. More entities could have added to the CLD and MARS but the level of detail required would have resulted in an excessive drain on the resources available and a pragmatic approach was necessary to determine where added value to the debate on the development of the city's sustainable transport system was best positioned.

Finally, the analysis did not consider the impact of alternative energy vehicles, such as those driven by electric, hydrogen or solar power. They were omitted because information on their fuel consumption and emission was limited at the time. The

⁸⁰ See CM-MTS report for more a detailed account on the limitation of the dataset

introduction and promotion of these vehicles should yield similar effects to the promotion of the motorcycle (B2) and reduced fuel cost (D2). It should also realise a reduction of average fuel consumption and emission per trip, yet it is difficult to verify the actual outcomes of these speculations without complex restructuring of the system.

10.3. Recommendations

As outlined in 9.2 above, there are a number of ways subsequent studies can make to refine the results of this study:

Firstly, the quality of the assessment framework can be improved through the inclusion of an intergeneration index and weighting for different categories. In addition, the assessments made using MARS could be more easily understood by presenting the results graphically. MARS has an external module called ANIMAP that can display selected indicators visually. Application of this module would enable the spatial dimension to be compared between each scenario with ease, in addition to the cumulative values. Moreover, several improvements can be made to the model itself, such as adjustment of the zone system to reflect actual observed land use. The scope considered in this thesis could also be broadened to include other transport measures. CNX-MARS has the capability to make assessments of a range of transport policies and their combined effects. Making use of these capabilities would contribute to planning future improvements to the sustainability of the city's transport system.

Secondly, further work could be done to expand my attempt to isolate and understand the effects of the motorcycle on urban sprawl, by expanding the study to research how the use of different vehicles impact on land use. MARS was primarily constructed to evaluate transport policy, and further modifications to the basic assumptions of the model are needed to enable the effects of different vehicles on land use to be quantified.

Thirdly, additional data, such as CO₂ emission could be used to calibrate and validate MARS model. This would maximise use of the output data of which MARS is capable and provide enhanced results to the relative comparisons used in this study. It will also enable further translation of the city's vision into quantifiable goals and measures. Efforts to estimate and include the impact of tourists, both domestic and international, on

the transport system can help to gauge how the system will cope with a surge of demand and thus help to improve the system's robustness.

Finally, the qualitative (CLD) and quantitative (MARS) models in this thesis should be presented in detail to the decision makers, especially the CLD. Opportunities should be given to discuss the models. The decision makers might then be interviewed at a later date to see if exposure to CLD and MARS changes their perceptions about how to implement a sustainable transport system. Open consultation with relevant stakeholders and members of public on the model will prove to be invaluable additions to the model.

10.4. Discussion

10.4.1. *Can promotion of the Motorcycle be part of the solution for a more sustainable transport system?*

The motorcycle is the main mode of transport for the city. Although typically associated with negative connotations, such as its vulnerability in accidents (Hsu et al., 2003; SafetyNet, 2009), it shows potential as a more sustainable mode of transport than the car in that it utilises less space and fuel and emits fewer harmful emissions (Pfaffenbichler & Circella, 2009).

From this perspective, it is tempting to promote the motorcycle as a substitution for some car trips⁸¹, with an aim to improve the sustainability of the system. Yet, from the system point of view, this measure **will not contribute positively** to the system in the long term. At best it would be a short term measure to slow down the negative impact of the current transport system, as my modelling has shown the same cumulative consumption/emission values would ultimately be reached over a longer time period. It can be likened to replacing one deadly addictive drug with a milder substitute. The only gain is the delay of the negative effects.

Results from CNX-MARS supported this point. A policy to promote motorcycle shows localised benefit (reduced fuel consumption and emission per trip) but produces cumulative losses (increased overall fuel consumption and emission). The benefit gained in delayed fuel consumption and emission is also minute (first 3 years). Worst still, the

⁸¹ Car trips can never be fully substituted by motorcycle. Car has functionality that better suit some certain purpose, such as goods transportation.

motorcycle seems to have a reducing effect on non-motorised transport modes and may have a stronger “lock-in” effect due to its higher potential to save body energy.

One may consider the substitution of energy source for motorcycle from fuel to electricity (i.e. e-motorcycle) to improve the vehicle’s consumption/emission. This, in turn, however, raises the same challenge of how best to use finite resources.

In addition, encouraging motorcycle use may lead to increased car use in the long term. The motorcycle’s lower purchasing and running costs provide a cheaper entry level to a motorised life-style. Establishment of a motorised life-style provides convenience and allows cheaper accommodation further from the work place to be traded for increased travelling time. This promotes further sprawling of the city. The convenience of owning a motorcycle may also lead the driver to become mentally ‘locked in’ as a willing captive of a motorised life-style. Knoflacher (2013) explained this phenomenon succinctly and described it as ‘Virus Auto’. In addition, the driver may also become physically ‘locked-in’ if relocation to the urban fringe takes place and vehicle ownership becomes a necessity for travel to work as opposed to the acquisition of a convenient means of transport. Finally, unless local government provides an efficient and effective public transport system, upgrading to car ownership is almost inevitable when a certain level of wealth is reached, or the perceived level of safety/comfort for family members is increased, or the air quality drops below an acceptable level for riding a motorbike.

Nevertheless, promotion of the motorcycle may still be used as a ‘time buying’ measure that would delay the negative effects of motorisation and allow time to implement measures that directly improve the transport system’s sustainability. In addition, the implementation of parking and access control can limit the negative impacts from increased use of the motorcycle and discourage use of the motorcycle as a substitute for non-motorised modes. The aim here is to ensure that the motorcycle will reduce car growth, instead of reducing non-motorised trips. Other types of measure, such as education for rational use of motorcycle can also be considered.

These findings have implications for policies that promote motorised two-wheeler or alternative fuel vehicle as a more effective and efficient mode of transport; for example China’s promotion of electrical vehicle, which has thus far received positive endorsement.

China e-bike user is also rising rapidly from zero to a projected +150 million by 2015 in little over a decade (Cherry, 2013).

Cherry (2013) argues that, despite the E-bike's high accident rate and lack of safe design standard, it is a more sustainable mode than its four-wheeler counterpart; it occupies less space and consumes less fuel. Cherry stresses that, "they are the most energy efficient motorised commercial vehicle in existence" and encourage more people to get on a bike. He proposed that the inherent problems can be solved through the introduction of a bike-share system and adoption of a design standard that ensures the E-bike remains more of a bicycle than a motorbike.

However, the measures to promote e-bike themselves also have complicated implications. China's experience of promoting electric vehicles shows that increased electric vehicle use can improve the air quality within urban area, but taking into account that electricity used is produced by burning fossil fuel and coal then the benefits are limited. Worse still, the electric engine further isolates the users from the externalities of their activity, giving them a false impression that they contribute positively to the environment. In addition, an electric bike and car occupies a similar amount of space - also a limited resource (especially within urban areas) - as a fossil fuel motorcycle and car. Moreover, the behaviour of individual residents in response to the fuel or emission savings may limit the system gains as shown in this study.

The promotion of these alternative modes can also benefit from the notions purported here that motorised-two wheeler can contribute positively to the sustainability of the city, as long as mitigation measures that limited its usage, such as parking organisation, is also implemented.

10.4.2. Shared-taxi, a marginal public transport service with potential?

As stated, the shared-taxi is the only form of public transport that has consistently served the residents of Chiang Mai over time. However, it currently constitutes only 1% of trips made by CM-MTS respondents. One of the main contributory factors for this is its long journey time. The shared-taxi's average journey time is 16% longer than the car and 82% longer than the motorcycle.

The results from CNX-MARS have shown that provision of priority lanes, decreased journey time and detoured distance have a positive effect on trips made using the shared-taxi. It increased the mode share of the shared-taxi from 2% to 4%. However, while the percentage increase is relatively high, it is small in absolute numerical terms. With high ownership of motorcycles and private cars, the improvements which otherwise might be achieved does not bring about any significant overall benefit to the system.

Additional measures may help to increase the benefits gained, such as conversion of engine to reduce emission/fuel consumption or enlarging the fleet capacity to increase efficiency of the service. However, it is considered that these enhancements will also bring limited benefit as they are “end-of-pipe” measures (i.e. controlled reduction of emissions, rather than elimination). This points toward the need to reform the structure of the shared-taxi as the potential benefit of the existing on-demand structure of the service seems limited.

Attempts have been made to reorganise the shared-taxi in the past most recently in 2012 and again in 2014. Both instances yielded unsatisfactory results and stirred much dissatisfaction from the fixed-route service operators and also city’s residents. In light of the city’s worsening transport problems, this status quo is unacceptable. Something needs to change urgently to transform the deteriorating trends of the system.

It is clear that the city desperately needs a quality public transport service, which has a regulated fare, timetable, and route system. The most challenging task of establishing such a regulated service is the negotiation with the shared-taxi organisations. They are, perhaps, one of the key stakeholders that need to be considered. Although, their membership is merely 2,500, the organisations exercise high leverage of the transport system with their strong connections to politicians (Watthanakul, 2008). The organisations themselves are also highly complex with a closely knit organisational structure that has enabled them to remain independent of local government control and sustain its *status quo* operation for decades. Past events have shown that the organisations will strongly resist any changes that appear to threaten the livelihood of its members.

Yet despite their considerable political clout, the shared-taxi is still an entity within the transport system. From an objective point of view, tackling the chaotic manner in which transport is offered to the public through the shared taxi must be part of the solution. The failed attempts to organise the public transport system around the share-taxi by the local

government in 2012 and 2014 have demonstrated the inherent difficulties. It shows that by starting from the premise that the demand-response service provided by shared taxi is the root of the city transport's problem will not lead to an effective solution.

From a system's point of view and within the context of the city's transport system development, the shared-taxi is not a problem. The operation grew and its organisational structure evolved as a response to the need for mobility of the public in an earlier period when car and motorcycle ownership were beyond the means of the majority. The shared taxi, operated by independent private individuals, fulfilled an obvious need. What changed things was the intervention in 1975 by the CM-DLT who forced drivers to become part of the shared-taxi co-operatives. This event, aimed at establishing regular routes and fare structures, was to prove pivotal in creating the stranglehold the shared-taxi has had over attempts to introduce a regulated public transport system. The insistence on a formal organisation evidently lacked an understanding of the potential of the cooperatives to create a collectively powerful union that would dictate how transport would evolve in the city. It also lacked an understanding of the service requirements inherent in public transportation; it failed to provide an organisational structure that would enable strict service regulations and the ability to ensure quality service coverage. With hindsight it is easy to point to the failures of the city fathers of the time. The main strength of the cooperatives was their ability to protect their members' benefits, and in this the shared-taxi cooperatives of Chiang Mai have evidently excelled.

After the formalisation, the authority kept its distance in managing the city's transport system. Eventually, the lack of profit resulted in members of the cooperatives breaking their agreements to serve assigned routes and they operated an on-demand service which proliferated. Again, the authority did not act to enforce the regulation or interfere with the operation.

In the meantime, the number of private vehicles increased rapidly, driven by a multitude of causes, such as increasing affordability of vehicles and government subsidised fuel to keep goods transport costs down and protect citizens from price spikes in oil costs. In Chiang Mai in particular, the lack of quality public transport resulted in phenomenal increases to the number of vehicles on the road. In the eyes of the public, these factors further decreased the competitiveness and the need for the shared-taxi.

In addition, its drivers are untrained and its operations are not strictly regulated. These aspects contribute to reduce the significance of the shared-taxi to a marginal transport service predominantly for tourists, people who do not have access to other vehicles, and people who are unable to drive.

This assessment may reflect only part of the reality, but it attempts to provide an insight to help balance the typically negative opinion of the service. Moreover, the service's high leverage is also a high-potential factor to improve the transport system and provide a viable alternative to the car.

10.4.3. *A suitable form of public transport for the city?*

It is widely accepted that the provision of quality public transport promotes sustainable transport. A number of past studies have been done to identify a suitable form of public transport for the city. Implementation of BRT and an underground rail system have been proposed as a suitable form of public transport for Chiang Mai. Yet despite numerous plans, public consultations and approval of budgets, these systems have never been implemented due to various factors including vehement opposition from the shared-taxi cooperatives (Watthanakul, 2008).

It is apparent from the forgoing discussions in this thesis that the task of establishing a regulated public transport service for Chiang Mai city is not only a technical one. Political commitment and endorsement from stakeholders are key factors to ensure successful implementation. Discussions should begin from a common point all parties can agree - perhaps an acknowledgement of the city's worsening transport problems and the need for urgent solutions. The undertaking must be carried out in an honest and sensitive manner.

Subsequent to having all parties agree on the need for reform, the discussion then needs to move on to decide a suitable form and organisation of public transport for the city.

Transformation of organisational structure

One obvious solution is to establish a new organisation to run a regulated public transport service. This organisation can be either public company or government agency but it must operate under strict scrutiny by a public body, perhaps the CM-DLT. The public body's task is to regulate the corporation's operating standards and ensure that the corporate's goal is to provide an affordable and quality transport service for the public in a

sustainable manner. In short, the main objective of the new organisation must be kept on making positive contributions toward the sustainability of the city's transport system. Measures to ensure accountability for failing to meet this goal, and a reward system for meeting it, should also be instituted at the initial stage of the organisation's creation.

The government could aid the establishment of the new organisation by proposing to 'buy-out' shared-taxi driver's licence at a certain price; for example, at 1 million Baht⁸² per vehicle. Alternatively, the 'buy-out' cost can be adjusted according to driver's age until his retirement. This would enable the local authority the opportunity to make a fresh start and strictly regulate both its fixed routes and the paratransit fleet (see Funding source for the 'buy-out' scheme. below).

An alternative choice to the 'buy-out' scheme might be given to the driver: either to transfer their licence to become employees of the new corporation or to continue to operate an on-demand service which would also be subject to additional regulations and scrutiny.

Deadlines should be given in advance to allow the shared-taxi drivers to make their selection from three choices: 1) to give up their licences in return for a one-off cash payment, 2) to convert their licences to the regulated service or, 3) to continue to operate as an on-demand service. Two deadlines should be set; early bird (with additional incentives, such as additional financial bonus) and a final deadline.

New service operation

The new organisation would provide strict control of the services' operating standards. These would include clearly defined routes with a published timetable, stop points, speed limits, and a standardised fare system. The design of routes should aim to provide a door-to-door service and linkages between different trip attractions, such as residential areas, markets, schools, and shopping malls. The stop locations should be easily accessible by walking and cycling and integrate with the existing fixed route services. "Park and ride" facilities for motorcycles and cars might be provided at some stops and terminus points, where possible, to allow mode switching. The eventual goal of the new system

⁸² This 'buy-out' price has been estimated by a representative of Chiang Mai University in a meeting with the director of the Office of Transport and Traffic Policy and Planning on 17 October 2014 (Source: <http://www.thainews70.com/%E0%B8%9A%E0%B8%97%E0%B8%84%E0%B8%A7%E0%B8%B2%E0%B8%A1%E0%B9%80%E0%B8%84%E0%B8%B2%E0%B8%B0%E0%B8%AA%E0%B8%99%E0%B8%B4%E0%B8%A1%E0%B8%82%E0%B8%99%E0%B8%AA%E0%B9%88%E0%B8%87%E0%B8%A1%E0%B8%A7%E0%B8%A5%E0%B8%8A%E0%B8%99-%E0%B8%8A%E0%B8%A1-%E0%B8%95%E0%B9%88%E0%B8%AD/>)

would be to replace the shared-taxi vehicles with air conditioned vehicles with increased passenger capacity and installed with modern day safety features such as seat belts. Changing the form of the transport fleet over time would ensure maximise efficiency, effectiveness and passenger safety. It is recommended the vehicles should run off liquid petroleum gas or electricity rather than diesel.

Ideally a cash collection system, similar to Octopus in the UK, for example, should also be introduced to enable prepayment and perhaps a more sophisticated fare structure, such as day pass, a discounted monthly pass, and an annual pass offering significant savings. The financial savings made from buying the monthly and annual passes would help lock passengers into using the public transport service rather than privately owned vehicles. The cash collection system should be secure and integrated into the existing fixed route services that provide access to the city's surrounding area. This would enable passengers to travel on all routes using the same payment method. A fare zoning system similar to Vienna city should be established⁸³.

Gradual improvements of the service

Planning the introduction and growth should take a cautious approach over a long time horizon. The current low public transport culture and the high ownership rate of private vehicles are likely to result in a slow pick up rate. Moreover, the current budget limitation of the city poses a strong financial constraint. Recognising these, it could be argued that the development of the service should be done gradually. For example, the number of routes might begin with essential core services of perhaps 5 routes to enable easy recognition and comprehension of the system from a users' point of view, with additional routes introduced over time. Measures such as bus only lane or priority at junctions should be considered to provide right of way and ensure the punctuality of the service. Conversion to a rail base service, such as tram, can also be implemented at a later stage when ridership and patronage are sufficiently high. The implementation of a tram service within the inner

⁸³ All public transport in and around Vienna area are part of the fare union Verkehrsverbund Ost-Region (VOR). This means that passenger with a VOR ticket can use every means of public transport in the area. Transits are allowed as often as required without buying a new ticket. Tickets are available for different fare zones; e.g. Vienna central area is zone 100. If passenger crosses a zone boundary, additional fare has to be paid. See <https://www.wien.gv.at/english/transportation-urbanplanning/public-transport/> for more info.

city area will also provide opportunity to redesign the city's streetscape and space allocation, which is currently biased towards the car.

The gradual change will aid the life-style changes needed for wide adoption of the service, ease the city's financial burden of funding the capital costs, and allow the benefits of the service to be experienced by the operators and the public. Nevertheless, should appropriate political and financial supports become available, public transport with higher investments and impacts, such as underground system should be considered.

The employment benefit package for drivers of the new regulated service must be attractive and fair. It should offer tangible benefits, such as regular income, job security, and the same medical and pension rights as other local government employees. A financial package should be offered to transfer vehicle ownership to the corporation.

Stronger enforcement on on-demand service

The CM-DLT must also strictly enforce regulations governing those drivers who wish to continue offering an on-demand service. The CM-DLT should consider prohibiting drivers from plying their trade on the streets as happens under the current system. Instead, it should be limited to providing an on-demand feeder service into the regulated system. This would be akin to paratransit services in USA and Austria that provide mobility in remote regions with low level of demand or for those without access to car and motorcycle. It is a form of taxi service similar to Uber⁸⁴, but with the additional ability to share rides.

Each on-demand service driver should be registered with a dedicated central system, which stores their detailed profile and service history. The system will enable residents in each community to register their travel demand directly or through a central information point, such as the representatives or at temples within their local community. They would also be able to view the driver's profile, provide feedback on the service, and view drivers' reviews online.

Given the huge popularity and market penetration of smartphones and tablets in Chiang Mai, and the wide-scale access to free Wi-Fi service throughout the city, registering demand into the central system and taking prepayment from the passenger could be done

⁸⁴ see www.uber.com

over the internet. However, it is acknowledged that by and large Thailand is a cash oriented society and therefore the system would need to be flexible enough to embrace cash collection. Once a request for service has been registered at a central service centre, the driver nearest to the passenger's embarkation point would be alerted and given the opportunity to accept or decline the demand.

Moreover, the CM-DLT must strictly control vehicle safety, and make it a condition of annual licence renewal that vehicles are regularly serviced and checked for levels of gas emissions.

The advantage of maintaining this on-demand service are 1) it can provide feeder service to the regulated system and 2) it enables some drivers to retain their supplementary income stream and way of life as discussed in the foregoing chapter.

Funding source for the 'buy-out' scheme

The cost of the buy-out scheme could be funded through new vehicle taxes and/or the introduction of a controlled parking zone (CPZ) within the municipality and the Aumpor Muang areas. Local residents would be required to buy a parking permit if they wish to park their car on the street. The permit would be valid for one year and at minimal level for the residents (e.g. 20 Baht per day for car and 10 Baht per day for motorcycle). Visitors from outside of the zone, who wish to park their car in the controlled area, would need to buy a permit covering the duration of their stay. The visitor permit would be substantially higher (e.g. 100 Baht per day for car and 50 Baht per day for motorcycle) and might be purchased at various vendor points, such as convenient stores (7-Eleven), corner stores, newspaper stores, etc. The controlled time could be between 0700-1800hr during the weekday and Saturday. Areas where parking is not allowed will be clearly defined. Special loading bays for good transportation and disabled parking spaces will be provided adequately. Park and Ride locations should be designated around the city. The cost of parking here would be at a reduced rate for visitors (e.g. 20 Baht per day for car and 10 Baht per day for motorcycle), or free of charge if a day pass for the city's public transport system is purchased. The management of these parking systems could be assigned to the newly founded organization. The scheme will provide the organization with an additional source of income to operate the public transport service and take additional workloads off the traffic police. Certain legislations will need to be modified to enable the organization to

operate, such as parking fee legislation and also the transfer of responsibility to control parking from the traffic police. The organization would be given the power to clamp any vehicle found within this zone if found without the permit being displayed. Owners would need to pay a substantial fine before releasing the clamped vehicle. Strong involvement by residents and public consultation from the initial stage of this project will be the key for its successful implementation.

Deploy additional measures to promote sustainable transport

Alongside the establishment of the new public transport service and the stricter control of the on-demand service, the government should look to deploy other measures to promote non-motorised transport modes. For example, with the introduction of well-planned changes to the infrastructure such as adoption of streetscape⁸⁵, improved road design⁸⁶, and provision of facilities⁸⁷ within the city to better accommodate these modes. Cycling should also be integrated into the new public transport services and the on-demand transport system by providing cycling parking space at pick-up points and perhaps the installation of bicycle carriers on the service vehicles.

Measures to discourage use of private motorised vehicles, such as parking management, should also be implemented. The aim here is to increase ridership of public transport service. Policy makers should consider their transport measures as factors that ‘push’ people out of their private vehicles and ‘pull’ them on to public transport or non-motorised modes, as illustrated vividly by Topp (1994)⁸⁸ in Figure 9-1

⁸⁵ Trees, shared space, cycle path, foot path

⁸⁶ For instance; cycle route, several one-way restrictions for four-wheeler should be in place, to provide space and distant advantage for cyclist. Motorcycle should be allowed to use cycle lane but its speed should be controlled

⁸⁷ bicycle parking, and safe crossing points

⁸⁸ cited by (Topp, 1994)

Measures with push-effects

Area-wide parking management, parking space restrictions in zoning ordinances, car limited zones, permanent or time-of-day car bans, congestion management, speed reductions, road pricing...

Measures with pull-effects

Priority for buses and trams, high service frequency, passenger friendly stops and surroundings, more comfort, park-and-ride, bike-and-ride..., area-wide cycle-networks, attractive pedestrian connections...



Measures with push- and pull-effects

Redistribution of carriageway space to provide cycle lanes, broader sidewalks, planting strips, bus lanes..., redistribution of time-cycles at traffic lights in favour of public transport and non-motorized modes, public-awareness-concepts, citizens' participation and marketing, enforcement and penalizing...

Figure 10-1 the push-and-pull approach towards less car traffic in urban areas measures

Source: (Topp, 1994)

Most of the procedures proposed above are neither new nor radical, yet the transport problems of the city continue to persist and can generally be seen to be getting worse.

My ideas for tackling the situation described above can be summarised into the following points:

- 1) Establish a common point of agreement and trust among all stakeholders.
- 2) Transform organisational structure – the current co-operative structure must be replaced by an organisation structure that provides a guaranteed income and other benefits for drivers, perhaps a government-owned corporate. The organisation must be able to strictly control the service quality. Its standards must be checked and controlled by an independent public authority.
- 3) Introduce Standard Operating Procedures – the new service should have a timetable, formal embarking point, speed limit, fixed routes and a fixed fare. It should be predictable, reliable, and safe. It should also integrate with the other services (shared-taxi to outer district) in fare payment and timetable.
- 4) Introduce visual changes – the form of vehicle (colour and shape) must be completely different from shared-taxi, to allow clear distinguish of the formal fleet from the on-demand service. Perhaps a new name for the service should also be established.

- 5) Stronger enforcement of the regulatory controls for the on-demand service
- 6) Deployment of measures to promote non-motorised modes and discourage use of private vehicles

10.4.4. *From a System's perspective...*

On increasing vehicular use and ownership

The rigorous procedures adhered to in this study ensure a holistic understanding of the problems, in this case, transportation, and the system in which they are embedded, in this case, Chiang Mai city. In other words, an in-depth situation analysis was rigorously carried out and researched before any mitigation was suggested. The review of mobility data shows a high level of private motorised vehicle ownership⁸⁹, which will continue to rise. Worryingly, there has been an increase in the ratio of the number of cars to the number of registered motorcycles, thus indicating that higher negative effects from motorisation can be expected⁹⁰.

From the system approach perspective, the growing trends of the city's motorisation suggest the existence of several factors that will either; 1) continue to strengthen the need for motorised vehicles ownership and usage and/or 2) continue to weaken the forces that limit motorised vehicle ownership and use. Table 9-1 suggests a handful of these factors.

Table 10-1 Factors that influence the city's motorisation

Factors that strengthen/drive need for motorization	Factors that weaken/hamper efforts to limit motorization
<ul style="list-style-type: none"> • long trip distance • lack of alternative mode • perceived safety and convenience in motorised vehicle • perception that the cost to use car and motorcycle is restricted to fuel cost only 	<ul style="list-style-type: none"> • low cost of ownership / usage • ease of ownership / usage • lack of negative feedbacks

Comparisons made in Chapter 4.3.1 demonstrate how car ownership continues to increase for Chiang Mai, whereas it has levelled off in Vienna city. This suggests several measures have been implemented in Vienna to weaken the forces that drive motorisation (e.g. reduction in the need for privately owned vehicles by improving the public transport

⁸⁹ 97% of household own at least one motorised vehicle and 54% of households have at least 1 motorised vehicle for each of its member.

⁹⁰ Car consumes more space, fuel, and emits more externalities than motorcycle.

system and making cycle and walking paths more attractive to use). At the same time, the forces that limit/control the use of motorised vehicles (such as parking restrictions) were also strengthened. Those responsible for transport management of Chiang Mai city should follow similar approaches, using a number of measures to strengthen control over private vehicle use and ownership and weaken the need for motorisation.

On the limit of resources

Awareness that there may be finite limits to the resources that can support human activities, for example, oil, gas and coal, is relatively recent and two very distinct schools of thought have evolved.

Proponents of the view which advocate that over-exploitation of the world's finite resources could bring about the collapse of civilisation as we know it, can trace their roots to early modern thinkers in this field, such as M. King Hubbert. Hubbert was a geologist who worked for several years at Shell Oil. In a 1956 paper, he predicted U.S. oil production would peak, probably in the early 1970s, and then decline. This was the basis of the modern day concept of Peak Oil – the point at which world-wide oil production would reach its highest level and then begin to decline until the end of its product life cycle. According to Peak Oil proponents, the decline in oil production will inevitably raise the price of oil significantly, as demand outstrips supply (Campbell & Laherrère, 1998).

In 1972, The Club of Rome commissioned a study, which resulted in the publication of the *'The Limits to Growth'*. The book's central point is that "the earth is finite" and the quest for unlimited growth in population, material goods, and a seemingly insatiable demand for fossil fuels, would eventually lead to a global crash affecting all aspects of our daily lives. The publication of the book is arguably a milestone in using computer modelling to predict the impact of population growth on finite resources. Some of the predictions made in the book appear to have been correct, particularly with regard to carbon emissions and climate change (The Guardian, 2014a). However, the book was met with much criticism at the time and dismissed by many in the scientific community as a "doomsday fantasy". Strong opponents and critics of the predictions contained in the book can still be found far and wide, but, equally, there are strong proponents of its main conclusions (Dennis Meadows, 2012)

Dennis Meadows, subsequently demonstrated through his own research that, in his opinion, the period of 'Easy Oil' has already ended. He pointed to three critical points: the discovery of easily accessible oil reserves peaked in the 1960s; there has been an excessive rate of increase in global oil consumption since 1984, which, if the trend continues, would outpace the discovery of new and accessible oil deposits; global oil production has reached a plateau since the latter years of the twentieth century and the early years of this century (Dennis Meadows, 2012).

The other school argues that such an apocalyptic scenario is unlikely in the first half of the 21st century for a number of reasons. Firstly, there is an economic argument put forward by the late Morris Adelman, Professor Emeritus of Economics at Massachusetts Institute of Technology. He, and others since, have argued oil will never run out so long as technology continues to advance and selling prices remain high enough, but not so high as to be unaffordable, to justify its extraction from below the surface of the earth and the bottom of the sea (Blackmon, 2014). While not without his critics who dismiss his arguments with the suggestion that "economists appear to think themselves far better at finding oil than geologists", Adelman's theory appears to be born out by the ingenuity of the oil and gas industry in finding new methods to extract oil. For example, since the introduction of widespread use of fracturing to extract oil from shale, the United States has increased home-based production of oil to 8.3 million barrels a day in the first half of 2014 from a low of 5 million barrels per day in 2008. Other countries, such as the United Kingdom, are gearing up to follow suit. Moreover, the oil and gas industry continues to spend billions of dollars each year on oil and gas exploration, which suggests that the industry is convinced oil has a profitable future and they will see a return on their investment.

Secondly, other scientists argue that the assessment of the quantity of oil available has been vastly under-rated. In 2006, Cambridge Energy Research Associates (CERA) stated that, "the remaining global oil resource base is actually 3.74 trillion barrels -- three times as large as the 1.2 trillion barrels estimated by the [Peak Oil] theory's proponents". The organisation went further and suggested that, rather than peak and decline, "the world's oil supply will eventually resemble an "undulating plateau," with small peaks and valleys that

will continue to meet the needs of global oil consumption for several decades to come (Sallery, 2014).

Thirdly, spurred on by the possibility that the Peak Oil proponents are right, and also by the desire to deplete the amount of carbon emissions created by burning fossil fuels, we are seeing a race to discover efficient alternatives to provide the power we need to sustain and improve our way of life. Perhaps the most convincing project to date is the Japanese experiment in the towns of Fukuoka and Kitakyushu, where a number of homes have been equipped with hydrogen fuel cells and some public transport vehicles and other vehicles run on the same technology (Altenergymag.com, 2012)

Whether hydrogen fuel cell technology, or another alternative fuel source, can provide a global solution to avert the disaster which proponents of Peak Oil have predicted remains to be seen.

Certainly, the debate between the proponents and opponents of Peak Oil continues to be lively and is pursued with almost religious conviction and evangelical fervour on both sides. It is perhaps appropriate to take a step back and consider the positive outcomes of adopting either way of thinking. Will the proponents of Peak Oil eventually drive global leaders into a position where they are prepared to enter amicable discussion and negotiation about how best to share finite resources? Will the end of relatively cheap and accessible oil, which both sides admit will happen, but disagree on the timing, drive us to be more conscious about our use of resources and to create infrastructure that reduces our dependency on finite resources? Both schools of thought ultimately lead to the same conclusion. There is an undeniable limit to our resources, and we have to find a more effective way to utilise them, as well as reduce our dependency on them. Taking sides on who is “right” and who is “wrong” is not very helpful in finding common ground. It is perhaps more creative and more challenging to find a way forward that embraces both sides of the argument. In my opinion, it is more valuable to take a balanced view and have high hopes for an unknown future, while, at the same time implementing necessary precautions firmly grounded in reality.

One of the criticisms which may be levelled at the transport modelling adopted in this study is that it assumes a constant level of oil supply over the model's thirty year horizon and omits any discussion of the potential impact of diminishing oil reserves. The

assumed rate of increase in fuel costs in CNX-MARS has incorporated this concern to a certain degree. Nevertheless, there are rooms for improvement, which potentially opens up an interesting field for future research.

Incorporating the more conservative Peak Oil approach and assuming limited resources by 2030, could enhance the analyses in this study, if further amendments were made to the CNX-MARS model. This would probably result in the analysis showing an increase in the bias toward non-motorised modes and public transport. However, it is thought that there would be little difference to the conclusions I have arrived at in my thesis as the adoption of the constraints on resources will be universal for all scenarios considered here.

On re-thinking transport planning

Traditionally, transport planning focused on “predict and provide” (S. Batty et al., 2001; Schiller et al., 2012) i.e. predict the growth in private and public transport needs and provide the infrastructure to meet the demand. However, increased awareness in the need for a sustainable transport system has seen a progressive shift away from this conventional approach.

It is apparent that the transport system of Chiang Mai city is highly unsustainable; it is highly dependent on external energy (fossil fuels), which produce harmful emissions, creating a health hazard especially for children and the elderly, not to mention the adverse effects of traffic congestion, and injuries and death from transport accidents.

While Thailand is an oil and natural gas producer, the country relies on imports to sustain its rising fuel demand. Domestic oil reserves and supply are limited in Thailand, and it has to import around 60-75% of its annual fuel consumption. Any reduction on this dependency will have a positive impact on the country's trade balance. Chiang Mai city can take a lead in helping the nation to reduce its reliance on imported oil.

To achieve this, the city urgently needs to shift away from its ‘predict-and-provide’ approach, which will only continue and strengthen the unsustainable path of the transport system. Efforts must be made to shift away from the existing path and creating a new one that is more sustainable.

Recognising the hold which the shared-taxi co-operatives have over the development of a public transport system in Chiang Mai, I have suggested an interim step whereby local

government works with the co-operatives to provide a transport service to serve the public and encourage fewer trips in private vehicles. I have also demonstrated that another interim step, i.e. encouraging greater use of the motorcycle, which uses less fuel and produces less harmful emissions, is not as attractive as it may first appear but would serve as a short stop-gap measure.

However, these steps alone will not be enough to shift the city away from its current unsustainable path. What lies beyond this series of small, but necessary, interim measures designed to move the city towards a sustainable transport system?

The city needs to include in its vision the aim of having a completely sustainable transport system, with zero emissions, zero accidents, and, as far as possible, independent from energy that the city cannot produce itself. This vision would need to be broken down into a series of measurable objectives that moved towards this overall goal over a period of time. A similar concept was proposed by Droege (2010) and his peers.

The goal to have a totally sustainable transport system is indeed a challenging one. The first step might be to set a reachable goal, such as 'to create 20% of energy requirements used within its transport system from alternative energy sources by 2030'. Given the abundance of sunshine and bio-waste in Chiang Mai, the city's transport planners might give some thought as to how these technologies might be incorporated into the city's sustainable transport plan. Lessons can be learnt from around the world; for example, the solar powered bus the 'Tindo' of Adelaide, Australia, or the first bus in Bristol, United Kingdom, powered by the by-products of human-faeces.

Adelaide launched its first solar powered bus, the Tindo, (aboriginal for "sun") in December 2007 which continues to operate within the city and provide free transport along its route. Its batteries have a range of 200km before needing to be re-charged overnight. Electricity is generated from solar panels installed on the roof top of the Adelaide Central Bus Station. Excess electricity produced during the summer is fed into the national grid and during periods when there are fewer sunlight hours, the system draws from the national grid. Overall, the city claims the system produces more electricity than that required to power the Tindo. The solar panels and installation cost was approximately \$500,000 (Adelaide City Council, n.d.).

In November 2014, Bristol City saw Britain's first 'poo-bus', as it is known locally, begin its operation. The bus is powered solely on human and food waste. The range of the 40-seater bus is 186 miles or around 300 kilometres. It runs on bio-methane gas, each tankful of methane gas takes the annual waste produced by *circa* five people. The service currently runs between Bath and Bristol Airport, and is provided by the Bath Bus Company (The Guardian, 2014b).

Mighty oaks from little acorns grow. The implementation of similar projects in Chiang Mai would create a basis for the future scaling up in operation. Once in use, there is likely to be public pressure for more of the same. Non-motorised transport modes should also be actively promoted alongside these measures.

Over recent years there have been several proposals for the implementation of various public transport systems in Chiang Mai, ranging from purchasing a fleet of air conditioned buses, a tram service in and around the city following major arterial routes, to a rather more fantastical sky train running around its historic moat complete with cable cars to the top of Doi Suthep (mountain). There is no lack of understanding that the city needs to find a solution to its congested roads and poor air quality. What seems to be lacking is the political will to actively change the current transport system and pave the way toward a more sustainable future.

Emphasis must be made that a decision to break away from the current unsustainable path is not and cannot be an economical one. The current infrastructure was created with a bias toward private motorised transport; ample provision of accessibility by road and cheap or even free parking space. As a result, even greater effort must be made to bring the transport system onto a more sustainable path.

Allow me to illustrate this with what I hope is an easily understood example. Most people have probably had the experience of buttoning a shirt or a blouse and find they started by placing the wrong button in the wrong button-hole. To correct this mistake means undoing all the buttons and starting again from the beginning. In the same way, proponents of sustainable transport system should always keep in mind the unavoidable demanding effort required to go 'against the grain' to correct the development path and improve the sustainability of a transport system.

10.4.5. Urban sprawl, likely but inconclusive.

The demographic and mobility data analysis suggests the city is decentralised and sprawling. However, it is difficult to draw a definitive conclusion on the matter as only registered population data was available. I estimated the proportion of the 'shadow population' or unregistered population in each area from the CM-MTS data and publicly available data showing the usage of electricity in residential areas. My estimates demonstrate that the number of unregistered residents can be anywhere between 46-79% of the registered population and suggest that this alarmingly high number should be further assessed and taken into account by city planners. Until there is an accurate count of Chiang Mai's permanent population, any proposals to manage urban sprawl will continue to work from the wrong base. There is an implied need to reform the registration process to make it simpler and easier than it is currently.

10.4.6. The need for training on Systems thinking and open discussions

The decision makers responsible for transport planning are very aware of the problems and are fiercely committed to bring about improvements to the sustainability of the city's transport system. However, analysis of the decision makers' perceptions in Chapter 6 demonstrates that policy makers are likely to deploy measures which may effectively improve one aspect of transportation but detrimentally affect the system as a whole. The analysis also found that decision makers appear to have a strong focus on particular topics and a demonstrably prominent vertical thinking process in relation to these issues. These characteristics potentially inhibit finding best fit solutions for complex issues, such as transport, that require awareness on the interactions between different entities. These characteristics and the preponderance to adopt a reductionist approach to transport problems needs to be challenged and the city's policy makers given the opportunity to analysis transport measures using a systematic situation analysis and decision making process.

Currently, the CM-LTSS⁹¹ consists of 23 members drawn from across different organisations, where nearly all of them are representatives from government sectors. This finding perhaps indicates a need to increase the diversity of CM-LTSS, or to establish a platform where feedback on the city's transportation management can be provided from diverse sources into the CM-LTSS. This would provide a system of checks and balances ensuring that all stakeholders were adequately represented in the decision making process

10.4.7. *Use of transport models as tools for decision makers*

A robust model assessment, transferability check, and the evaluation of scenarios in this thesis have highlighted several crucial points about using a model to aid decision making. This study has demonstrated through example that the validity and transferability of the model should always be critically checked and assessed for its suitability. Any model is purpose-specific and is based on a set of assumptions and observations made in a certain environment at a point in the past, which may have limited application in other locations and for another time. Sterman (2002) made a bold statement that all models are wrong. In other words, there is always a mismatch between the model and reality, i.e. a model can only ever be a representation of selected parts of reality.

This has several implications. Firstly, implementation issues can arise when policies or measures that have been tested by the model are implemented. For instance, the interactions between the two main components of land use and transport are assumed to be perfectly balanced within the algorithms used by MARS. But in Chiang Mai city, the organisations responsible for transport and land use are fragmented. A further example is that MARS assumes designated zones are strictly controlled and homogenous while such enforcement in Chiang Mai city is known to be weak. In other words, the structure of MARS may not accurately reflect the actual condition within the organisational operation and structure of the city. Thus, there is likely to be a mismatch between the results from the model and actual results in real life. Sensible application of the findings and further checks before implementation, especially where there are unusual or unexpected results, would help to narrow this gap. Secondly, there is always a risk that the model is rejected. Decision

⁹¹ Chiang Mai Province Land Transport System Management Subcommittee

makers and other stakeholders may potentially dismiss the result from the model, if these do not fit preconceived ideas about their preferred solutions. Frank and open discussion and consultation between modeller, decision makers, and stakeholders is crucial to avoid such conflict.

Finally, users of a model should be always be aware that any model is purpose specific and may not, in some circumstances, be suited to the task at hand. A model is, in effect, a set of assumptions that is put together to represent reality from a point of view of a group of people. These basic assumptions should always be checked to ensure the suitability and transferability of a model. Any required modification should be identified and carried out to ensure the model's fitness for purpose. The performance and background indicators are also purpose specific and need to be checked.

It is also important to be aware of the limitation of these indicators, which are often selected by a person or group of people. Performance and background indicators can be akin to selected jigsaw pieces of a picture. They do not make up the whole picture but are the essential pieces that combine to give hints of what the completed jigsaw might be. Yet, other jigsaw pieces that are not included in the selection may alter the picture altogether. Thus, efforts should be made to refrain from drawing conclusions only from the selected jigsaw pieces.

Nevertheless, the transport model in MARS has shown in this study its usefulness and effectiveness in providing support to decision maker. They can summarise the complex interactions and relationships between different entities within the system. They also enable the evaluation of different measures in a quantitative manner.

These issues affirm the need to use a model as **a tool that aids decision making**, and not as a tool that make decisions to solve transport problems. Moreover, the user should be fully aware of the model's limitations and bear in mind its partial representation of reality.

10.5. Conclusion

Humankind has made great advances in the field of transportation. We have invented machines and means that help us to travel faster and further, whether by using animals, bicycles, automobiles, vessels, trains, planes and telecommunication. We have expanded the range of our connectivity beyond our personal physical limits through these means. Yet, while each stage of this progress has resulted in many desirable features that

have made our lives easier and travel more convenient, we have failed to understand, assess and mitigate the negative effects of each mode of motorised transportation. On the contrary, the so called 'transport problems', such as chronic congestion, increased road accidents, and, ever growing dependency on the automobile seems to be intensifying around world. The negative effects from transport, such as deteriorating air quality, continue to increase and worsen the quality of the environments in which we live, especially in urban areas.

These adverse effects from urban transport point to the need to improve our understanding of our transport systems, which have become more and more complex. They are a wakeup call to challenge the traditional view that simplifies the complexities inherent in the system by severing the connection between interdependencies. This thesis has shown that a reductionist approach, at best, can provide only a short term improvement (i.e. reduction in congestion) before the system responds by producing even more undesirable effects (i.e. creation of additional traffic using improved roadways and encouragement of more trips), which can worsen the overall condition of the system. It is also a call to adopt a holistic approach that takes account of the interconnectedness between different entities in the system.

Over recent years, awareness of the need for a system approach has been increasing but more must be done to raise greater recognition of the benefits. The adoption of such approach will improve our ability to understand the realities of the system and find effective solutions to facing problems.

Nichiren Daishonin, a 13th century Japanese Buddhist monk emphasised the importance of an accurate perception of reality. In a letter to one of his disciples, he wrote, "When the skies are clear, the ground is illuminated." (Daishonin, 1999, p. 376) The aim of this thesis is in essence, to contribute toward efforts to rid fallacies that cloud the true perception of transport system. It seeks to increase the chances of successfully solving urban transport 'problems' and to improve the sustainability of the system through the case study of Chiang Mai city.

Appendices

Appendix A: Past studies on Chiang Mai city's transport problems

A total of 38 studies related to transport management and planning of the city have been included here. The review divides this literature into four groups according to their primary focus. For most of the literature, I made reviews from the primary sources but in some cases, secondary accounts have been included as the originals were not accessible. Their sources are cited here explicitly.

Transport system planning related

Official studies

The Master Plan for *the Management of Traffic in the City of Chiang Mai* or *the Traffic Survey Chiang Mai Area study, Thailand* or (OCMRT, 1994) was the first official document that addressed the transport problems of the city. The study was commissioned by the Office of the Commission for the Management of Road Traffic (OCMRT).

The OCMRT report contains recommendations both at the city and provincial level concerning management of transport infrastructure, safety and environment, and building the capacity of traffic police officers to enforce traffic regulations (JICA, 2002). The study prioritises road infrastructure development, even though it recognises the need to improve the city public transport system (D. Charoenmuang, 2009a). The study collected mobility data through a combination of household interviews and roadside interviews. The data was used to construct a four-step model to forecast the city's traffic demand (JICA, 2002). In addition, the publication of the OCMRT report indicates that the transport problems in the city had become apparent at the time of its publication, although the increase in vehicle numbers was observed as early as 1980 by Nimnual, Srisakda, & Satayopas (1980).

The Japan International Cooperation Agency (JICA) commissioned the *Study on Improvement of Road Traffic Environment in Chiang Mai city* in 2002. The study is intended to be a follow up of the OCMRT study although the JICA study focuses solely on the Chiang Mai municipality area. The study observed heavy traffic congestion, increased traffic accidents, and reduced traffic speed in the city. It concluded these adverse traffic conditions resulted from rapid increases in the number of vehicles, the lack of a comprehensive public transport system, and the poor condition of road infrastructure (JICA, 2002). Consequently, the study made several project-level recommendations to improve the physical conditions of the city's transport infrastructures and its management. JICA's proposal prioritised six infrastructure improvement projects, worth a total of 126 million Baht (3.15 million Euros); 45% of which

was allocated to pedestrian related projects. Several soft measures, such as the restructure of the shared-taxi cooperative groups, were also included.

The study constructed a four-step traffic demand forecast model. The demand matrix used was an update of the 1995 OCMRT traffic demand matrix, which used the 2001 socio-economic and traffic count survey data. The updated matrix was applied to the city's road network to calculate the traffic demand for the year 2010. The model indicated that the existing network could cope with an increase of road traffic until 2010, when, even with addition road network, the level of congestion would become severe.

JICA (2002) was comprehensive and rooted in expansive data gathering and traffic surveys; it undertook eight transport surveys, which included two face-to-face interview surveys focused on school trips made by personal and public transport. The study also included a junction improvement pilot project, which was implemented and increased the junction's safety significantly. The strength of the study was in its pragmatic approach, with its recommendations focused on improving safety and capacity of road infrastructure. However, the study did not take account of possible unwanted side-effects, such as encouraging more vehicles onto the improved road infrastructure ultimately leading to congestion.

The OCMRT changed its name to the Office of the Commission for the Management of Land Traffic (OCMLT) after 2002. It commissioned an update to its previous report, entitled *the Traffic and Transport master plan for Chiang Mai city*. The study reported that Chiang Mai city had become a car dependent city due to a lack of quality public transport and public transport-supported policy. It concluded transport safety, availability of public transport, congestion around academic institutes, and environmental impacts from the growing number of cars and to other means of transport, as issues which should be a high priority for the city to address.

In addition, it proposed a set of transport policies to solve the problems such as a reduction in the numbers of personally owned vehicles allowed with the inner city, the enhancement of network safety, and the improvement of NMT (Non-Motorised Transport) facilities. The proposed policies were in accordance with the ninth National Economic and Social Development Plan (NESDP), which emphasised road developments should be based on sustainability and efficient economy¹. The strong points of this study were (a) its acknowledgement of the connection between land use and transport and (b) its aim to

¹ See Appendix E

reduce and control the demand for vehicle trips. The study recommended implementation of 23 short term, 12 medium term, and 6 long term projects, over a ten-year period, several of which, were adopted from JICA (2002). The projects' total value was 383 million Baht (9.6 million Euros), of which 116.5 million Baht (3 million Euros) or 30% was allocated to non-motorised transport projects. However, the construction of the middle ring road underpasses project, worth 1,000 million Baht (25 million Euros), was the only project implemented.

The Department of Public work and Town and country Planning (DPT) proposed the *city's principle plan third revision* in 2008. The Chiang Mai Principle City area (CMPC) plan aimed to provide a framework to designate land use by zoning and in accordance with transport system planning. The aim was to ensure harmonisation of developments and maintain the historical charm of the city and the surrounding area. However, the plan, lacking in legislative support and strong enforcement of its principles, resulted in a set of guidelines, rather than a directive (D. Charoenmuang, 2009b).

The Principle plan or the CMPC plan was created in 1975 and was revised, for the first time, in 1983. The second revision of the plan (1999) contained a proposal to aid city expansion by establishing satellite towns around Chiang Mai city, resulting in the beginning of the decentralisation of the city (Charoenmuang, 1998). The third revision of the plan was initially issued in 2008. It included the land use enforcement regulations and 35 road widening projects. The proposal drew many criticisms from the residents of the city and was subsequently withdrawn. It is understood that the road projects were proposed with the aim of accommodate the increasing road traffic demands of the city. The third revision of the plan was finally issued in 2012 without the road widening projects.

Academic studies

Intapun (1994)'s Impact of Vehicle Increase on Chiang Mai city's traffic study 5 in Chiang Mai city. The researcher interviewed 181 respondents, of which half were road users, the other half were police officers and government agents, working within the transport sector. The qualitative results were analysed using SPSS (Statistical Package for the Social Sciences). The results indicated increased traffic volume arose from a number of factors, including

- A significant rise in the number of people living further away from their place of work or study. The lack of an efficient public transport system therefore drove the rise of private vehicle ownership, as a necessary means of getting to and from work/school. This was compounded by other changes in lifestyle making car ownership increasingly popular

Appendix A: Past studies on Chiang Mai city's transport problems

- The designation of the city as the development centre of the northern region further increased the volumes of traffic as a result of the establishment and growth of a high number of government agencies, and a rapid growth of the general population.

Traffic in Chiang Mai Municipality: Problems and Guidelines for Solution study aimed to identify the cause of transport problems within the municipality area by focusing data collection along the two main streets of the city: Thapae Road and Charormuang Road. Chansri (1994) collected relevant information through on-site observations and interviews with residents and police officers (133 respondents). In addition, the study included comprehensive reviews of policies, regulations, and organisations related to the city's transportation system.

Chansri concluded there were three causes of the transport problems: (a) insufficient attention given to aspects of transport engineering (Traffic Engineering); (b) lack of public understanding of transport regulations (Traffic Education); (c) ineffectiveness of law enforcement (Traffic Enforcement). The study also revealed additional factors that worsened the problems such as public transport inefficiency, and the lack of land use and infrastructure planning. It also pointed out the complexities of the problems and the need for a high level of cooperation between relevant agencies, both in the public and the private sectors, in order to find appropriate solutions.

Chansri's work (1994) was very extensive: it contains in-depth reviews of the nation's transport policies and regulations and the management of the city's transport system. It is apparent from the study that national transport policies and regulations had focused on accommodating private motorised transport. However, the small sample size used in the research and the lack of quantitative analysis weakens the base of the study's conclusions. Moreover, the three main causes of transport problems, identified by the study are factors that have contributed towards the worsening of the problems, and not, as the study concluded, the root causes *per se*

Upayokin's (2001) Travel choice model for bus and other modes in Chiang Mai urban area by using stated preferences data aimed to identify factors that influence residents' travel mode selection decision, and to construct a model that can be used to predict these decisions. Two trip purposes were considered in this study; trip to work and trip to school/university. The study gathered its primary data using a three-part questionnaire.

The survey data of 355 respondents was used to calculate correlations between different demographic characteristics and mode choices. The study finds correlations between different factors and used them to construct a binary logit model. The model was used to simulate mode choice decision of the respondents. The study was well-structured and was theoretically sound. It discussed in detail the

justification of its methodology and presented the outcomes concisely. Nevertheless, it failed to recognise the marginal benefit/gain from increased or decreased travel time/cost. In other words, the model assumed a linear relationship between travel cost/time and mode choice. In addition, the value of time concept, used in the assessment, is the subject of on-going discussion in the field of transport modelling (Mokhtarian & Chen, 2004; Wee et al., 2006).

Pongthanasawan (2003)'s Travel demand model of urban, suburban, and rural residents in Chiang Mai town planning area constructed a three-stage (trip generation, trip distribution and mode share) transport model of the city, using the 1994 household survey. The trip generation model employed the conventional multiple linear regression method. The production-constrained gravity model was used to simulate trip distribution. Finally, the mode share stage utilised polynomial, exponential and linear equations. The study considered four modes of transport: (i) walking, (ii) private vehicle, (iii) motorcycle, (iv) Song Teaw (shared-taxi) and other modes.

The study consisted of comprehensive theoretical background and secondary data preparation. However, a comparison between the study's finding with another similar study, such as (EXAT, 1997), can be valuable. In addition, it is questionable whether the static nature of the three-stage model is appropriate as the structure of the model omits feedback between different stages.

A study on land use and transport interaction (LUTI) model for the city is carried out by *Prathumthip (2002)*. The study aims to develop a model for land use within the municipality area. The study divides the area of interest into 61 zones. The calculated average land price for each zone was based on the local government's Land Office estimated price. Other relevant data such as employment, population density and value of time were retrieved from governmental sources including the 1995 O-D matrix. The employment and population accessibilities were calculated from employment and population densities, respectively.

In the study, the relationships between land use and transport variables are analysed using regression analysis. It reveals that land price, population density, employment density, travel distance, travel time, and travel cost affect the area's land use. A LUTI model was then constructed based on the correlations revealed. The structure of the model is the binary logit based on discrete choice utility theory, which categorised land use into two types: commercial and residential. The ratio between the two land types is calculated as a function of land use and transportation using random utility theory. They also have different utility functions; the residential area's utility function is determined by land price and population density, while the utility function of the commercial area is affected by land price,

employment density, and travel time to the CBD. The study carried out a sensitivity analysis and concluded land price to be the most influential factor affecting change of land use.

The strengths of the study are its comprehensive data analysis and the detail of its model testing. The study consists of detailed descriptions on land use, land price, population and employment densities for each zone. In addition, the application process of the model is well-documented. The main weakness of this model is its static structure and lack of temporal delay. The model lacks feedback between land use and transport and it assumes that land use change occurs in the subsequent time step, when in fact land use changes occur more gradually over a period of time.

Arunotong (1991)'s study, *the Application of spatial interaction model in Chiang Mai*, focused on the migration of the rural population into the urban area. It used a Lowry type LUTI model and consists of two sub-models; residential location sub-model and service location sub-model. The functions of the travel time in the two sub-models are in exponential forms. The model assumed that an increase in tourist arrivals would increase the proportion of work in the service sector, hence affecting the distribution of population and employment. In addition, the study argued that an improvement in road network would decrease travel time and affect the distribution of population relative to employment. The study also revealed that the distribution of population had a stronger effect than the distribution of employment, in influencing travel time. The drawbacks of the model are its omission of non-motorised transport and its bias toward road infrastructure transport improvement. The bias stems from the assumptions of the model on travel time improvement.

Kongboontiam (2010) created a land use and transport system dynamic model to assess energy consumption policy of the transport sector. The area of study is the northern region of Thailand, which includes Chiang Mai and seven other provinces. His study, *An Integrated System Dynamic Model for Transportation Energy Planning and Management in Regional Area of Thailand*, created the integrated model called ENTASIM (ENergy TrAnsportation System dynamic and Integrated Model). The simplified structure of the model is shown in Figure 2-2.

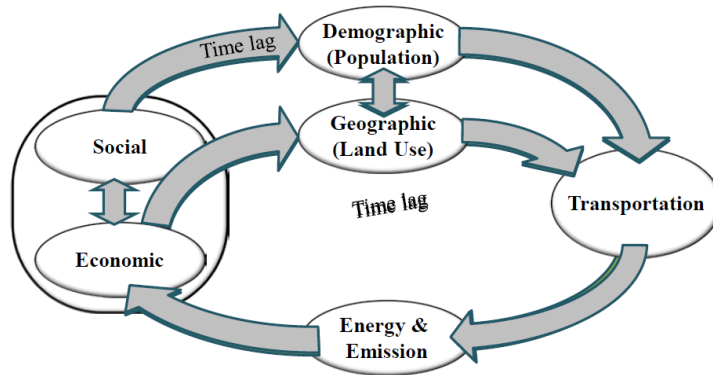


Figure A-1 ENTASIM model structure

Source: (Kongboontiam, 2010, p. 180)

The model consists of five sub-models: socio-economic system, demographic system, geographic system, transportation system, and energy and emission system. The main novelty of this model is the feedback loops between the sub-models over simulation periods. These features enable the study of land use development over time and the complex relationship between different entities of the system to be modelled. The time horizon of the model is between 2003 and 2030 and only motorised vehicles are considered: passenger car, pickup truck, van and sport utility, and motorcycle.

The transport sub-model consists of four modules:

1. Trip generation module – this considers four trip purposes: work trips, school trips, other trips, and back-home trips. The correlation equations are in linear regression form.
2. Trip distribution module - this employs gravity modelling techniques to calculate trip origin-destination matrix for each zone.
3. Mode share module, the probability or proportion of each mode being select are calculated using correlation equations in multinomial logit regression form.
4. Trip assignment module, allocates trip volume onto the transport network using all-or-nothing assignment technique. The correlation equations for this module comprise of two parts. The first part calculates the inter- and intra-zone distances for each mode. The second part predicts the traffic condition of the current time step using a speed-density curve. This curve is derived from the traffic assignment module's result of the previous time step.

The primary and secondary data used in the model was collected between 2003 and 2009 by literature reviews and various survey methodologies, including face-to-face interviews, vehicle fuel diary

recording, and roadside surveys. Part of this data was used to calibrate and validate the model. The test revealed that the population volume in each zone was the analysis's most sensitive variable.

The model was used to evaluate five different scenarios against the "do-minimum" scenario. A decision making framework was developed based on 8 indicators to support the evaluation. These indicators are: (1) vehicle kilometre (km), (2) average speed (km/hr.), (3) volume-to-capacity ratio or V/C (-), (4) fuel consumption (kTOE), (5) CO₂ emission (million MTCOE), (6) average population density all area (person/sq. km), (7) average population density urban area (person/sq. km), and (8) fuel cost (million Baht). The framework enables each indicator to be weighted differently, according to the rankings obtained from key stakeholder interviews. The same modelling structure was successfully applied for Chiang Mai city and presented in (Kongboontiam & Udomsri, 2009; Udomsri & Kongboontiam, 2003).

Public transport system provision

Official studies

The lack of quality public transport system of Chiang Mai city has elicited many studies which have specifically addressed this subject. The first official study on the city's public transport system is *the feasibility study for the master plan of the mass transit system in Chiang Mai* in 1997, commissioned by the Expressway Authority of Thailand (EXAT). The study proposed a construction of four light rail transit lines, totalled of 27 kilometres. The proposed system is an at-grade LRT tram type with its own separated lane or private right of way. The study suggested the service fare should not exceed 20 Baht (0.50 Euro) in the proposed first year (2001). It also recommended several transport and land use policies and operational level measures to compliment the proposed system, such as land use policy around the LRT station, parking policy, shared-taxi and bus feeder services, construction of park and ride sites, and a suitable organisational structure. The study estimated that the construction of the four proposed transit lines on the study year (1997) would induce trips made by light rail mode by 12% of the total daily trip (286,000 passengers per day) in 2004 and would increase to 575,000 passengers per day by 2016.

EXAT created a four-stage model, which employed an aggregated approach due to insufficient detail within the socio-economic data available. In the trip generation module, the correlation equations between transport behaviour and socio-economic data were formulated using Multiple Linear Regression without intercept method. The forecast trips were distributed using the Fratar method. The mode share was calculated using a disaggregate approach in the form of the nested logit model. Traffic was assigned

Appendix A: Past studies on Chiang Mai city's transport problems

on the network by converting traffic into vehicle trips per car, motorcycle, bus, shared-taxi, and LRT and using speed-flow and trip time-flow relationships to determine the effect of congestion on route choice

In 1998, the OCMLT commissioned *a study on the national transport and planning policies*. The study focused on providing transport policy for 16 major cities of Thailand which were expected to have more than 800,000 inhabitants in 2005. The study's result revealed a rapid increase in vehicle ownership in Chiang Mai city (Watthanakul, 2008).

The Chiang Mai municipality undertook *the electric public bus pilot project* in 2000. It attracted much interest from residents due to its novelty and appealing service. However, the pilot project lasted only 20 day; the operation was opposed by the shared-taxi operative group and the Land transport department (D. Charoenmuang, 2009a).

The National Research Council of Thailand (NRCT) commissioned a study to identify *a suitable public transport network for Chiang Mai city* in 2004. The study proposed a step-by-step approach for the development of the city public transport system. It recommended that during year 0-5 of the operation, the fleet should be a combined Song Teaw and bus-based system and the system should change to tram or/and BRT-based system in year 5-10. The study also recommended a radial transit network and that the shared-taxi service should be incorporated into any proposed system (D. Charoenmuang, 2009a).

In addition, the NRCT study pointed out the negative consequence of implementing a road building program as a mitigation measure for transport problems, demonstrating an increase in congestion if transport demand cannot be met in a timely manner. Instead, it recommended the organisation of a public transport system with support from the government. The study forecast an annual decrease of network speed by 5% until the network average fell below 20 kilometres per hour in year 2007 in a do-nothing scenario. The cost of the proposed public transport system was estimated to be below 15,000 million Baht (375 million Euros). The system was expected to increase the share of PT trip to at least 20% of all trips (D. Charoenmuang, 2009a; Watthanakul, 2008). The study provided a tangible evaluation of its proposal. It was suspected that the study employed a four-stage model in its analysis. However, its drawback was its omission of the non-motorised transport modes in its analysis.

In response to the government's plan to transform Chiang Mai city to a domestic and international aviation hub for the northern region, the Office of Transport Planning (OTP) commissioned a study in 2005. The study aimed to create *the transport master plan to support Chiang Mai city to become a regional transport hub* for freight and passenger transport. It proposed 84 projects over a 20-year period, worth an estimated expenditure total of 179,371 million Baht (4,484 million Euros). The

Appendix A: Past studies on Chiang Mai city's transport problems

projects included the implementation of public and private transport projects, such as bus, light rail, BRT, and commuter rail system, road building, and the reconstruction of Chiang Mai International Airport.

The study collected a wide range of primary data such as traffic count, network speed, and face-to-face interviews at transport hubs around the city. It constructed two four-step models, the Chiang Mai city and the northern region models, to forecast road travel demands within the city and the region. The information on the models was not available in the final report. However, the results of the model indicated that 90% of the road network would be at capacity in 2010, and in 2014 the whole network will be at or over capacity, see Figure 2-3. Similar conditions are predicted for the intra-city road network.

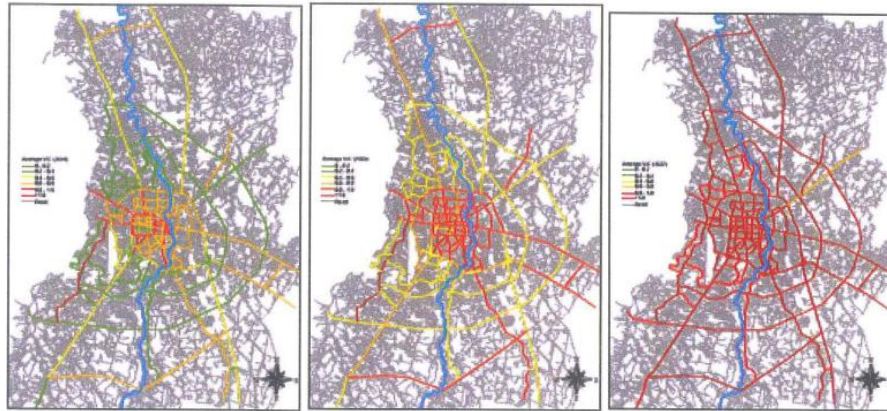


Figure A-2 Chiang Mai road condition forecast (2005, 2010, and 2014)

Source: (OTP, 2005, p. 23)

Some data used to construct these models was from the NRCT study. The OTP study in 2005 was the first official study of Chiang Mai city to consider freight and intercity transport (OTP, 2005). The main drawback of this study is its omission of the non-motorised transport modes in its analysis and planning. In addition, the forecast of the city's road conditions seems extreme. However, the limited information available on the NRCT study prevented any further specific conclusions to be drawn.

The *master plan for Chiang Mai mass transit system project* was commissioned in 2006. It was a follow up project from the OTP's master plan project of the previous year. The methodology of the study is similar to the EXAT study; however, the OTP study proposes a bus rapid transit system (BRT). The service was planned to operate mostly on dedicated bus ways with an initial fare of 10 Baht (0.25 Euro). The fare would increase by 1 baht (0.025 Euro) for every 1 kilometre travelled. The system has a two-phase implementation plan. In the first phase (during year 0-10) the construction of the first four lines totalled 55 kilometres. During this phase, the study proposed to introduce a light public transport system during year 0-3 to initiate behaviour change. In the second phase (year 10-20), the proposal to construct three additional lines and extend the previous lines, would increase coverage by a further 50 kilometres.

In addition, 27 feeder service routes (435 kilometres in total) were planned to ensure high accessibility to the system. It was proposed that the service should be run by 300 of the existing shared-taxi fleets. The estimated cost for the project was 14,000 million Baht (350 million Euros) during the first phase and 17,000 million Baht (425 million Euros) for the second phase.

The study employs a four-step model to forecast the city's transport demand. The model is based on extensive primary and secondary data. The primary data was gathered from 570 household interviews, road side surveys, and various other transport surveys. The model indicates that the proposed system will increase the public transport trip from 9.3% on the base year (2006) to 27.5% of total trips in 2014 (OTP, 2006). The strong point of this study is its comprehensiveness; it provides extensive details of the project from the feasibility study phase until its tender/implementation phase. The main shortcoming of the study, however, lies in its omission of the non-motorised transport modes in the analysis. In addition, the model's prediction of a significant shift toward PT mode seems ambitious; it omits soft factors that may reduce its effectiveness such as captive car and motorcycle drivers.

The most recent attempt to address public transport inefficiency is the *Song Teaw fixed route project* (tentative translation), which ran between November 2012 – February 2013. The project's objective was to provide public transport during the festive seasons and the sport events taking places within this period (Prachatham.com, 2012). - See Chapter 3 for more details.

VoiceTV published a news article in December 2012 related to the project. It stated that although the project provide a cheaper travel alternative, it was dependent on the government subsidy which at the time was equivalent to 6,000 Baht (150 Euro) per month per driver (VoiceTV, 2012).

Academic studies

Srisakda (1989) assessed the city's bus transport operation and identified several areas with limited accessibility to public transport. The study included a bus accessibility map of the city (Watthanakul, 2008).

Although the city has never had a good public transport system for an extended period, residents have consistently shown a positive perception towards various plans to introduce such a service and a high willingness to use public transport. *Chuanchuen (1996)* undertook a qualitative questionnaire survey with 540 respondents who lived in the city and with a number of Song Teaw operators. The interviews focus on their demands and level of satisfaction with the city's public transport system. The study, *Attitudes of Chiang Mai People toward Public Transportation System* revealed several interesting points, such as:

Appendix A: Past studies on Chiang Mai city's transport problems

- Song Teaw operators faced financial loss and lacked funding to improve the quality of the fleets.
- The general public respondents demonstrated a need for an improvement in public transport facilities and better dissemination of information about the existing service
- A large proportion of respondents had positive perceptions of the system, especially those in the lower income and lower education groups.
- There was a high demand for public transport; respondents who owned private vehicle indicated they would use public transport, if time and money could be saved. Eleven years later, a more recent study along the same lines (Patiphantharkarn, 2007,), showed similar responses.

Satayopas, Khamjina, & Arunotayanun (2001) study on the *Characteristics and Organisation of Public Transportation in Chiang Mai City* highlights that the city's public transport organisation problem arises from social and management spheres as well as transport engineering and economic spheres. It points out that the conflict between the Song Teaw cooperative and the local government authorities over the provision of public transport lies in their contrasting goals. The authority seeks to provide a suitable public transport service for the city, while the cooperative's goal is to protect the interests of its members and optimise their operational freedom of not having to stick to fixed routes. Satayopas et al. (2001) contributed significant findings about the number of vehicles and their routes, their daily income and expenditure, and the number of daily passengers. This work was enhanced by the publication of the opinions of users/operators/authority on providing suitable public transport services (Watthanakul, 2008).

Pantamit (2000) studied *the Demand for A Mass Transit System in Chiang Mai Municipality*. The study employed the Multiple Regression Analysis method (MRS) to reveal factors that influence demand for public transport of the respondents. The study found that household location has a direct negative effect toward public transport use, i.e. those living outside the municipality area are less likely to use public transport. It also found that high waiting time deterred respondents from using public transport, especially among students.

The study also concluded that urban sprawl, existing road networks, lack of quality and sustained bus service, and undisciplined drivers added to the problems of providing the city with an adequate public transport system (Watthanakul, 2008).

Panyasan's (2003) Development Potential of Public Transportation System in Chiang Mai Municipality aimed to identify the feasibility of implementing a public transport system and its possible characteristics, using interview methodology as its primary research tool. The study employed the accidental sampling method to gather its 200 respondents. The interview results were analysed using descriptive statistics, chi-square test, and logit model methods. The analysis found that income level, occupation, fare, and safety, affected the respondents' likelihood of using public transport. The study also demonstrated similar factors that obstruct the development of a public transport system as shown by Pantamit (2000).

Borisutthiyangkun (2006) evaluated the effectiveness of the municipality bus system that began its operation in 2005 in his *Feasibility of solving traffic problems in Chiang Mai Municipality by bus system*. It is a qualitative study using descriptive statistical analysis to represent the respondents (420 respondents). The questionnaire used consists of three parts: demographic information, bus system usage, and personal opinion about the bus system. The interview results revealed that public transport was not a favoured choice; because of (a) the lack of routes, (b) the inconvenience of poor accessibility, (c) long waiting times, (d) long trip times, (e) lack of route information, and (f) inconsistent stopping points. Nevertheless, the results showed support and willingness to use the system if improvements were made. In addition, the study showed that 52.1% of public transport users used Song Taews (Shared-taxi), but only 14% used public buses.

Patiphantarkarn's (2007) study, the Mass Transit Preference for Chiang Mai city, aimed to determine the residents' travel behaviours and their preferences on what kind of public transport system they would use. The study undertook two types of interviews with the following groups:

- Local residents (393 respondents), to identify their the weekly travel behaviour
- Transport experts, to reveal their opinions on an appropriate form of public transport system for the city.

The results of the first survey demonstrated correlations between the respondents' travel behaviours and their demographic characteristics. The interviews with transport experts revealed a mass transit system to be most favoured option; moreover they collectively considered passenger safety the most weighted value in designing a public transport system. The study recommended that a tram system would be most suitable for the historical centre of the city, with buses and underground light rail for the municipality and Aumpor Muang areas, and bus for the outer districts area. In addition, it undertook a secondary data research on related documents to establish the city's existing transport problems. The

research concluded that the transport problems of the city stemmed from the conditions of the city's infrastructures (incomplete road network, urban sprawl, and lack of parking spaces) and the public transport service (low quality, lack of enforcement, and lack of information on the service).

Patiphantharkarn (2007)'s study is soundly principled; its recommendations are based on a belief that public transport policy should be drawn in accordance with transport need, travel behaviour, and current traffic conditions. However, the accuracy of its analysis is highly questionable. The results of the resident survey are more than slightly suspect with an average weekly travel of the respondents of 1,806 round trips per person per week, which seems out of proportion with the normal routines of most ordinary citizens. In addition, the accuracy of the study's survey is questionable; the respondents were asked to indicate their weekly travel in a single question, rather than the conventional method of asking respondents to complete a weekly travel diary.

Wattanakul(2008) provides an unusual approach to the subject. Her *Politics of Chiang Mai Mass Transportation System study* analyses the city's public transport system from a political science point of view. This study was conducted using the qualitative interview method. The study describes the history of the city's public transport from 1979 and focused on the Song Teaw, a non-fixed route paratransit that continues to dominate the city's public transport service. The research showed that the service faced many problems such as overlap routing, excess supply, and unreasonable high fare. However, the Song Teaw co-operative group remains influential due to its unity, its association with political groups, and weak enforcement of existing regulations governing Song Teaw routes.

Wattanakul(2008) points out that it is only since 2001 that the government has become active in providing a public transport service. However, faced with strong resistance from the Song Teaw group in 2003, the government has had to take into account the opinions of the group in planning their public transport system. In addition, the study concluded that a conflict of political interest was the key factor in prohibiting the city from running a successful public transport system. Local politicians have received strong support from the shared-taxi group, which is opposed to any public transport service that will compete against it. In addition, the study outlines the causes of public transport's failure: lack of clear vision and fragmented centralism of the organisation, conflict of interest among different stakeholders, and a lack of strong support from the city's residents.

Environment and air qualities

The worsening of Chiang Mai city's environmental quality and the degradation of its historical heritages in the recent years has drawn the attention of many international research institutes. Many of

these studies are included in this review as they make recommendations related to the city transportation.

Official studies

The United Nations Development Programme (UNDP) commissioned *a feasibility study on major cities development* (tentative translation) in partnership with the Ministry Of Internal affair (MOI) in 1983. The study proposed several road improvements (9.1kilometres), road construction (1.9 kilometres), and junction improvement projects around and within the city centre area. In addition, the study proposed several footpath improvement projects in the high density area of the city (D. Charoenmuang, 2009a).

The *Historical and environmental conservation action plan project* (tentative translation) was commissioned by the United States Agency for International Development (USAID) in 1991. It proposed mitigation measures to preserve the historic heritage of the city by designating an area for modern development or the "New Town in Town". The plan took a holistic approach; it acknowledged the transport-land use connectivity and the importance of considering the city's carrying capacity in its planning. It proposed the implementation of many progressive transport measures, such as a pedestrian walking network; effective control of land use along major roads; the implementation of community parking lots. The plan thus proposed an integrated approach to meet the requirements of private vehicle owners and the provision of public transport within the old city area (D. Charoenmuang, 2009a).

USAID's proposal was revised and resubmitted to the government of Thailand in 1992 in the form of *the Preservation and management plans for the old city of Chiang Mai*. The plan proposed the promotion of walking in the city. This recognised that Chiang Mai was planned as a walking city; when the city was first built, the roads in and around the old city area were not suitable for vehicular transport. It also proposed several road construction projects to complete the road network, improvements to and widening of footpaths, and the relocation of the city airport (D. Charoenmuang, 2009a).

The Environmental, community and green area management plan (tentative translation) is the summary report of the participants' planning projects conducted by the Resources and Environmental Policy and Planning (ONEP) in 1996. The plan endorsed EXAT's light rail proposal and contains many radical traffic management goals. For example, to force a reduction of traffic volume by 40%, by restricting vehicle access to certain areas and the reduction of traffic from the outer districts area. In addition, it focused on how to provide a sustainable public transport system that would be in harmony

with the city's environment and emphasised measures to increase the capacity of the existing roads (D. Charoenmuang, 2009a).

The Health System Research Institute (HSRI) funded *A study for health impact assessment: a case study of city and transport development of Chiang Mai* in 2003. The study has two objectives; (a) to review the development path of the city and its transport system in relation to the environment, social, and health of the residents and (b) to set the scope and establish guidelines to assess the impact on social health from city development and transportation. The study's methodology included literature reviews, organisation of stakeholder meetings, focus group meeting, and an opinion survey of 500 residents.

The review of the city's development path indicated that national policies played an influential role in the accelerated growth of the city. This rapid growth has contributed to increased transport problems with an explosion in private vehicle ownership and usage, congestion, and decreased network speed. The study suggested that this increase has significantly affected the air quality of the city, hence the reduction in overall levels of public health.

The study evaluates a set of transport policies; however, the evaluation process was not clear. It concluded by recommending a set of policies to promote public transport and non-motorised trips and reduce transport pollution.

The study contains comprehensive literature reviews on these subjects; it includes the infrastructure development of the city from an historical perspective, as well as the policies that affected the development. Moreover, the study included a diagram depicting the causal relationship between city plan/transport policies and environment/social health issues. It is the first official report that demonstrates the causal connectivity between different entities within the transport system.

However, the weakness of the study is its proposed policies to promote social health within the city and the evaluation of its success. Firstly, some of the policies proposed are vague and appear to be in conflict with the stated goals. For example, it proposed a decrease in travel time, or an increase in travel speed, through the implementation of traffic system management techniques. The decrease in travel time can be linked to the decreased level of stress but an increase in travel speed may increase the severity or death in transport related accidents. Secondly, the study provided ample descriptions of the policies' goals and benefits but it did not provide any quantitative values to support the proposal. Finally, some of the proposals show a lack understanding of the causal relationship between transport and land use. For example, the policy of re-locating famous schools to suburbs and outlying districts may result in unwanted effects that degenerate the initial locations, due to the reduction of amenities/attractions such as shops and facilities associated with the schools.

Sustainable Cities in Chiang Mai: A Case of a City in a Valley is the fourth in a series of five research studies on how to develop sustainable or eco-cities. This study, undertaken by Charoenmuang (2007), is focused on the following objectives:

- To investigate how the traditions and culture of previous generations influenced planning practise and consider how such practice contributed to the sustainability of the city
- To study trends in the development of the city, identify internal and external factors that affected how the city had become what it is
- To survey public understanding about the concept of a sustainable or eco-city

Part of the research addressed contemporary issues faced by the city covers social problems, degradation in the quality of the environment transport congestion and waste management. It provides a comparison between international, national, and local sustainable city indicators. The study's survey, which interviewed 27,941 respondents, revealed that traffic congestion is the highest ranked physical problem. However, the study concluded that congestion is merely a symptom of imbalanced development and suggested seven underlying causes:

- Frequency and volume of inter-district travel (long trip distance), from outer districts into the city centre
- High usage and dependence on private vehicles
- Unplanned urban sprawl into agriculture areas and along roads (ribbon development)
- The city's status as the central development centre of the northern region attracts an excessive number and variety of new developments
- Its attractiveness as a tourist destination both domestically and internationally, creates additional pressure on the transport system
- Personal use of public space, such as using roads as shop parking space, and hawkers setting up food stalls and points of sale on public footpaths.
- Lack of road discipline among the residents

In addition, the study interviewed 2,618 respondents on their opinion regarding the city's public transport system, 94% of them believed a public bus system to be essential for the city. This suggests local residents would be willing to switch from private vehicle use if there was a cost benefit, and it also demonstrates a high demand for public transport service.

Appendix A: Past studies on Chiang Mai city's transport problems

Charoenmuang (2007) provides a broad but comprehensive approach to the concept of a sustainable city using Chiang Mai as a case study; however, its focus on policy resulted in a lack of quantitative goals. In addition, although the proposed measures were very reasonable, it is not clear how these implementations could be evaluated quantitatively. The study concluded by emphasising the importance of encouraging a strong civil society, supported by pro-active involvement of local residents in order to attain a sustainable city.

Charoenmuang published a subsequent book that addresses the relationship between air pollution and transport sectors in 2009; the *Climate Change and Transportation Sector*. The study provides comprehensive accounts on the development of the city's transport system, past transport policies and studies, and the past activities related to the subjects. It points out that the fragmented centralisation of the city's transport sector is an obstacle to its development. In other words, there is a lack of coordination between organisations responsible for setting policy at national level and those responsible for implementation at local level. The study proposed policies that would lead to the sustainability of the city by addressing climate change issues at local, national, and international levels. As with her previous work, Charoenmuang provided a highly comprehensive account on the subject matter of her research.

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) commissioned a study in 2009 to improve air quality of the city as part of the *Clean Air for Smaller Cities in the ASEAN Region* project. The study identifies transport as a major contributor to the city's air pollution; 85% NO_x, 94% Co and 66% PM of total emission come from the city's transportation sector. The report proposed four measures related to transportation: control and reduction of road vehicle emission, improve Song Teaw (shared-taxi) operation, modernise the city public transport system, and support sustainable urban mobility (D. Charoenmuang, 2009a; GIZ, 2009).

Non-motorised transport

Official Studies

The first *bicycle route master plan for the city of Chiang Mai* was completed in 2002. The plan was commissioned by the municipality of Chiang Mai and consists of three development stages. It proposed many novel measures such as contraflow bicycle routes to ensure the shortest path for the riders. Part of the plan was implemented in 2006, within the historical part of the city. However, it was criticised by many residents of the city for its lack of safety considerations; neither bicycle riders nor

vehicle drivers were familiar with the concept of contraflow bicycle lanes and considered them dangerous (D. Charoenmuang, 2009a).

In 2008, the OTP commissioned a project called *the non-motorized and public transport development plan in the urban area*. It is the first official report to focus specifically on the non-motorised transport system of the city. Its study area is the historic area of the city. It recommended three measures to improve the walkability of the area: impose limits on vehicle access; improve facilities for pedestrians and bicycle riders; and improve the public transport system (Jindawattananon & Pradipasen, 2009).

Another study that focused on non-motorised transport was the *Measuring Walkability in Smaller Asian Developing Cities: A Case Study Approach* by Sayeg (2010). Her study quantifies the walkability index within the city's historical area. It shows that the city's pedestrian infrastructure ranked 3 out of 5 but street cleanliness and road crossing remained problems for many respondents.

Another study by the OTP in 2012 evaluated the walkability of the same area using the ADB Walkability index methodology. The study yields WI values between 2.00 to 3.78 and reveals that all roads within the area lack facilities to support disabled persons. The study reports a high number of obstructions on the footpaths within the study area, such as signage, phone box, and roadside stalls. It also noted the absence of sufficient pedestrian crossings. It concluded by proposing measures to address these problems in the short, medium and longer term, and suggested policy and project level implementation plans. The full report of this study was not available at the time of writing – the description here being a summary of information available on the OTP website.(OTP, 2012) A similar comment on the scarcity of pedestrian crossing facilities in the city was also reported by JICA (2002).

Other relevant studies

In the year 1996, the Office of the National Economics and Social Development Board (NESDB) proposed *the Twin City development plan: Chiang Mai and Lamphun*² (tentative translation). The plan proposed several transportation projects, such as: the relocation of the city's airport; the improvement of the public transport system in the city; the construction of the new Chiang Mai – Lamphun road; road expansion projects, and the construction of a suburban train line between the two cities. However, only the road construction, which runs parallel to the existing rail track between the two cities, was implemented (D. Charoenmuang, 2009a).

² Lamphun is a city located approximately, 30kilometres south of Chiang Mai.

Appendix B: A suitable transport model for sustainable transport planning

The literature review in this thesis indicates that the Four-stage model (FSM) is the state of the art of transport modelling of Chiang Mai city. In this appendix, a concise account is provided on the FSM and Land use and transport interaction (LUTI) model, which is a potential substitution. The final part of this appendix compares six sustainable transport planning models. The aim of the comparison was to reveal potential development for the Metropolitan Activity Relocation Simulator (MARS), the transport model used in this study.

Chiang Mai city's state of the Practise: the Four-stage model (FSM)

The FSM is a demand forecasting model for personal travel. Its development began in the U.S.A. around the post Second World War period, together with the practice of transportation analysis. Its first comprehensive application was the evaluation of a road construction project against traffic engineering improvements of existing structures in the Chicago Area Transportation Study (Bates, Hensher, & Button, 2000; McNally, 2000). The FSM has since become a conventional tool used to appraise and predict future demands of a transportation system. The FSM is a trip-based demand analysis; trip being its basic unit of analysis. Figure 2-4 shows the process diagram of the Four-stage model

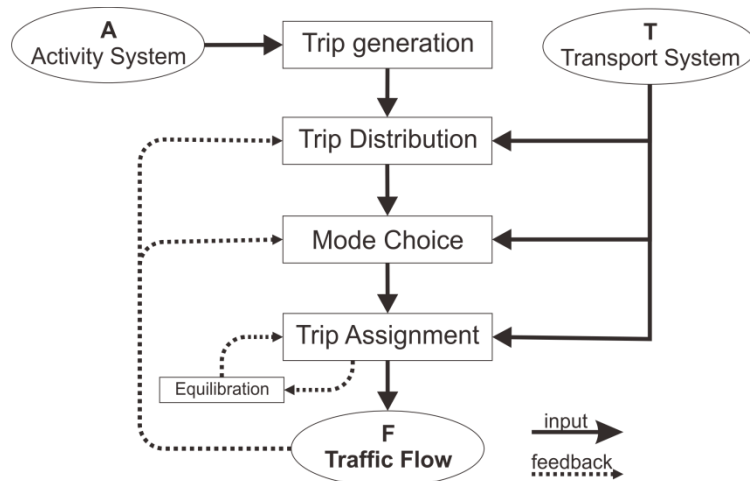


Figure B-3 Four-stage model (FSM)

Source: reproduction from (McNally, 2000)

Criticisms of FSH

In recent years, the FSM has received increasing criticism on its suitability to evaluate transportation systems, which have increased in detail and complexity over recent years (Bates et al., 2000; McNally, 2000; Stopher & Greaves, 2007; TRB, 2007). These criticisms can be summarised as follows:

- Its trip-based approach ignores the fundamental tenet that a trip is a derived demand of activity.
- Its focus on trip disregards the relationship between travel and time/space/activity patterns and personal factors. In other words, it reduces the richness of trip to merely an activity.
- The model inherently lacks ability to evaluate emerging policies (such as road pricing, time specific policy, and non-motorised travel) and its bias toward road capacity improvement projects.
- In most cases, the models are not run to achieve equilibrium due to the heavy computation demand.
- Although it is possible to feedback the equilibrated travel time to the trip distribution / mode choice stages, it is not the case for most applications. That is to say, there is a lack of feedback between the traffic flow, and the transport/activity systems

In addition to the last point above, McNally (2000) indicates that while the FSM is an application of the Transportation Systems Analysis (TSA), the connections between Network Flows (F) and Location/Supply Procedure (L and S) are removed in the FSM. This, in effect, assumed that the demand for travel is fixed; i.e. it severed the relationship between the transport demand and the transport system. The forecast of the activity system is carried out in isolation. Figure 2-5 shows the TSA with typical absent connections.

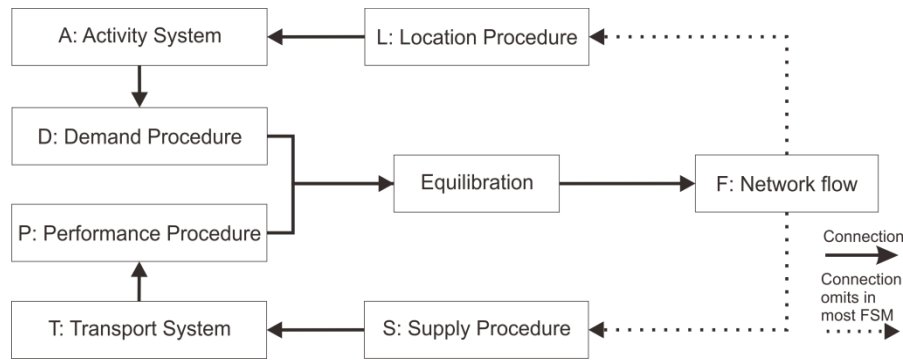


Figure B-4 Manheim/Florian Transport Systems Analysis framework

Source: (McNally, 2000)

Moreover, the goal of a transportation system has changed from providing mobility and capacity to meet forecast demand, to improving accessibility and managing demand (ADB, 2009). This shift affects the attitude within the transport sector; from the traffic-centred approach ‘predict and provide’, which the FSM was crafted for, towards a human-centred approach.

Although the failings of FSM have been discussed within academic circles for some time, it still remains a widely-used model to evaluate transport related projects in many countries including Thailand. McNally, (2000, p. 16) summarised this practise as, “The choice of this approach is not that it is the best available but because it is the only approach available, given current institutional requirements and financial limitations.”

The foregoing suggests that the FSM is not a suitable tool to solve Chiang Mai city’s transport problems. The strength of FSM lies in its capability to forecast travel demands. However, Chiang Mai city is still developing at a fast rate; its economic prosperity continues to attract migrants from within Thailand and neighbouring countries. This growth is likely to increase further when the ASEAN Economic Community (AEC), which promises free movement of goods, services, investment, and skilled labour, commences in 2015. The forecasting of transport demand therefore, has a limited usefulness for the city because of its lack of accuracy under these dynamic circumstances. In order to alleviate its transport problem, the city will need a tool to aid the planning of the city transportation system which incorporates the following features:

- can model the complex interconnections between the city’s transport system and relevant entities, such as land use and environment, enabling an integrated approach
- can evaluate different transport policies, including sustainable transport measures, such as road demand management or improvement to walkway facilities
- aids exploration of the city’s possible development path over a longer period of time

- includes non-motorised modes, such as walking and cycling in its analysis
- provides relevant and quantitative indicators

Figure 2-6, shows the position of the city's transport model within the context of urban transport-land use model development proposed by Wegener (2004).

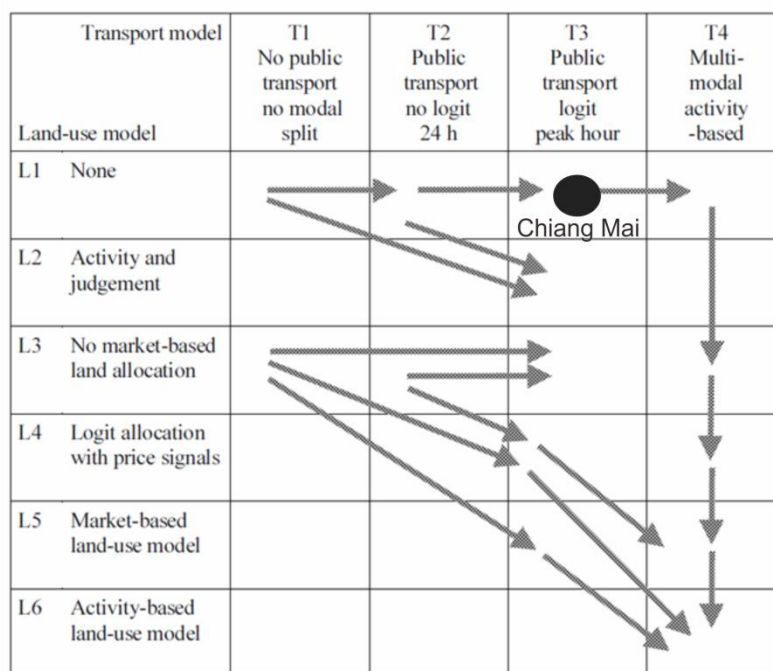


Figure B-5 State of the practice of the Chiang Mai city model

Source: Modified from ((Wegener, 2004) which adapted from(Miller, Kriger, & Hunt, 1998))

The review above illustrates the need for the city to develop its practises to incorporate land use into its transport model. The land use and transport interactions such as (Choovuthayakorn, 2005; Kongboontiam, 2010; Prathumthip, 2002; Wannavichit, 2004) have been employed but use of their findings has been confined within the academic sphere.

Land use and transport interaction (LUTI) model

The development of the Land use and transport interaction (LUTI) model can be said to have begun in parallel to the FSM. The interconnection between land use and transport was acknowledged in the 1950s; Hansen (1959) revealed that sites with higher accessibility had higher potential of being developed. This recognition became a primary basis (perhaps even a pre-requisite) among American city planners. The relationship between land use and transport is commonly illustrated by the 'land use transport feedback cycle' in Figure 2-7 (Wegener, 2004).

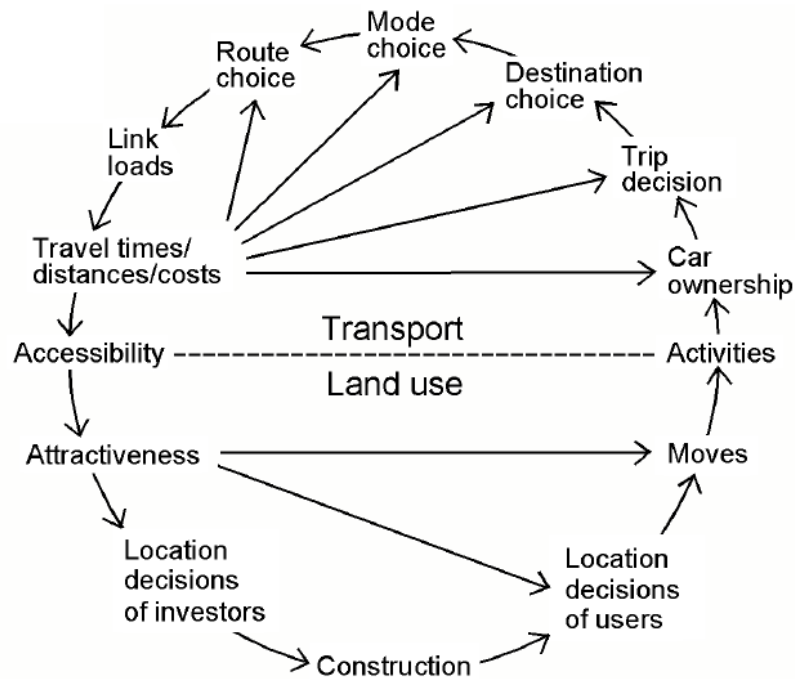


Figure B-6 Land use and transport feedback cycle

Source: (Wegener, 2004)

The diagram can be explained as follow:

- The location of activity is determined by the distribution of land uses, while transportation is needed to spatially link these activity locations
- Accessibility can be used as a measurement of the spatial interaction derived by transport and activity locations
- Locations with higher accessibility are attractive to users and developers who change the land use system

The complexities of land use and transport interaction, and the rise of transport modelling technique during the 1960s, instigated the development of the integrated land use-transport interaction model (LUTI). It should be emphasised here that the ‘integrated’ feature of LUTI denotes that the interactions between land use and transport are endogenously simulated. This is in contrast to other transport models that considered land use exogenously (i.e. as input parameters).

Lowry's (1964) Model of Metropolis is believed to be the first operational LUTI model. Its pioneering efforts paved the way for many modelling approaches. For example, it provided a framework for many subsequent LUTI models such as those reviewed by Wegener (2004). The increase in computing power, better data availability, and improved theoretical understanding, have all contributed

to the development of urban land use transport modelling (Wegener, 2012). For detailed classification of LUTI see Department for Transport (2005).

There are an increasing number of LUTI models being used today. However, Wegener (2004) suggested that most of them (LUTI models) are still based on the FSM framework rather than the activity based model, which is state of the art; it enables complex spatial behaviour of individuals to be modelled.

Sustainable transport system planning models

Metropolitan Activity Relocation Simulator (MARS)

MARS is a dynamic land-use/transport interaction model developed at the Research Centre of Transport Planning and Traffic Engineering, Institute of Transportation, Vienna University of Technology (TUW-IVV). The model consists of several sub models that simulate passenger transport and land use development. A detailed account of MARS structure is presented in Appendix F and omitted here to avoid repetition.

MARS is a spatial aggregation level, closed-loop, system dynamic model. The simulated results about its transport and land use are calculated with inputs from one another (i.e. their interactions are replicated). The model is constructed with the aim of providing a supporting tool for sustainable city planning and decision-making on transport and land use policy with its transparent simulation process and its short run-time. Most of the other existing land-use/transport models focus only on motorized modes. However, with MARS, all relevant means of transport can be modelled including non-motorized modes such as bicycles, and emerging transport modes, such as the electric car.

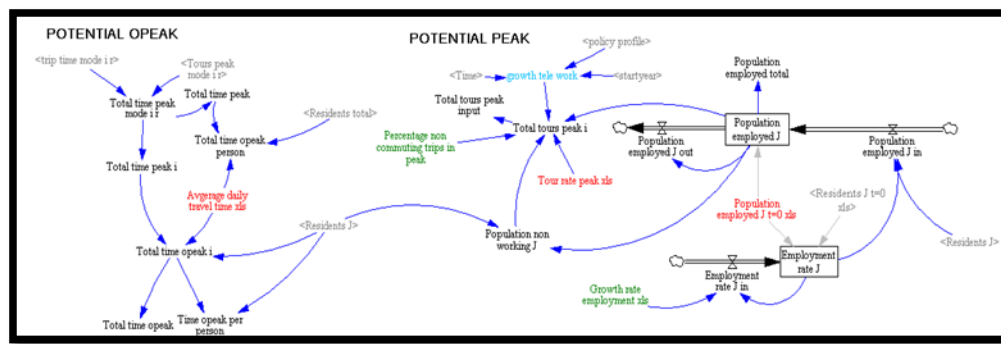


Figure B-7 Extract from MARS model

MARS presents its output visually; indicators such as mode share can be animatedly shown on a map, to simulate the changes of different parameters over a given time period (Figure 2-9). This enables a comparison of results under different scenarios as well. This feature of MARS provides a powerful and

easy-to-understand presentation of the model output. Another key feature of MARS is its ability to use VENSIM's optimisation feature, which provides a different outlook to the conventional formation of policy package.

MARS has been developed at IVV since 2003. To date the MARS model has been applied to ten European cities (Bari, Edinburgh, Gateshead, Helsinki, Leeds, Madrid, Oslo, Stockholm Trondheim, and Vienna), two Asian cities (Hanoi in Vietnam and Ubon Ratchathani in Thailand), one South American city (Porto Alegre) and one country (Austria). On-going projects cover setting up the MARS model for Ho Chi Minh City in Vietnam and Washington D.C. in the United States.

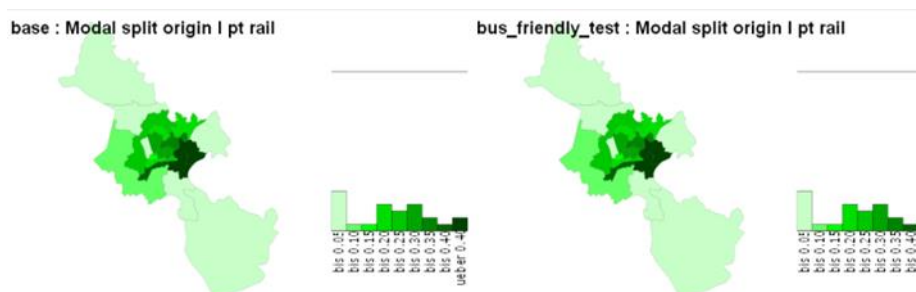


Figure B-8 MARS graphical and animated output for easy comparison between different scenarios

Note: Graphics' results are indicative

ASsessment of TRAnsport Strategies (ASTRA)

The purpose of the ASTRA model is to provide a strategic evaluation of the EU's common transport policy (CTP). The model has a spatial coverage area of EU29 (EU27 plus Norway and Switzerland). It is based on the principle of System Dynamics and is implemented on the Vensim platform. The evaluation process is based on the forecast and the appraisal of policy impacts, with an emphasis on capturing the feedback effects generated between relevant sectors (Rothengatter & Schade, 2000). Over the years, the model's scope has been expanded to provide an integrated assessment of a wide range of policies beyond EU transport policies, and includes renewable energy policy, climate policy, and technology and scenario analysis. The development of the model is still on-going. The model is mostly applied to Germany case studies, within the EU and the global contexts. The basic structure of the model is shown in Figure 2-10.

The model's structure consists of nine sub-modules, which are interconnected through the feedback data sent between them. ASTRA operates at a high level of aggregation. It considers five passenger modes (slow, car, bus, rail, air) and three freight modes (truck, rail, ship) (Schade, 2008).

Appendix B: A suitable transport model for sustainable transport planning

The strengths of ASTRA are its ability to provide integrated analysis of different policies and review their direct and indirect effects on different sectors over a long time horizon (up to 2050). Additionally, it has flexibility to model complex policy packages, which combine many policy instruments and are implemented over different points in time and at different intensities. Hence, the model can illustrate the development trends within the coverage area under different policies and scenarios over a period of time. However, the apparent weaknesses of the model are (a) its high aggregation, which prevents analysis below country level and, (b) its adoption of unconventional economic theory (non-equilibrium model).

The nature of ASTRA is similar to MARS; the differences between the two models are the resolution of their analysis, the structure of the sub-modules, and the inclusion of freight transport. MARS has been applied to provide policy analysis at city, regional, and country level, while ASTRA focuses solely on country level analysis. However, ASTRA consists of a more detailed sub-modular structure with an emphasis on economic factors. Additionally, ASTRA also includes freight modes in its analysis while MARS does not.

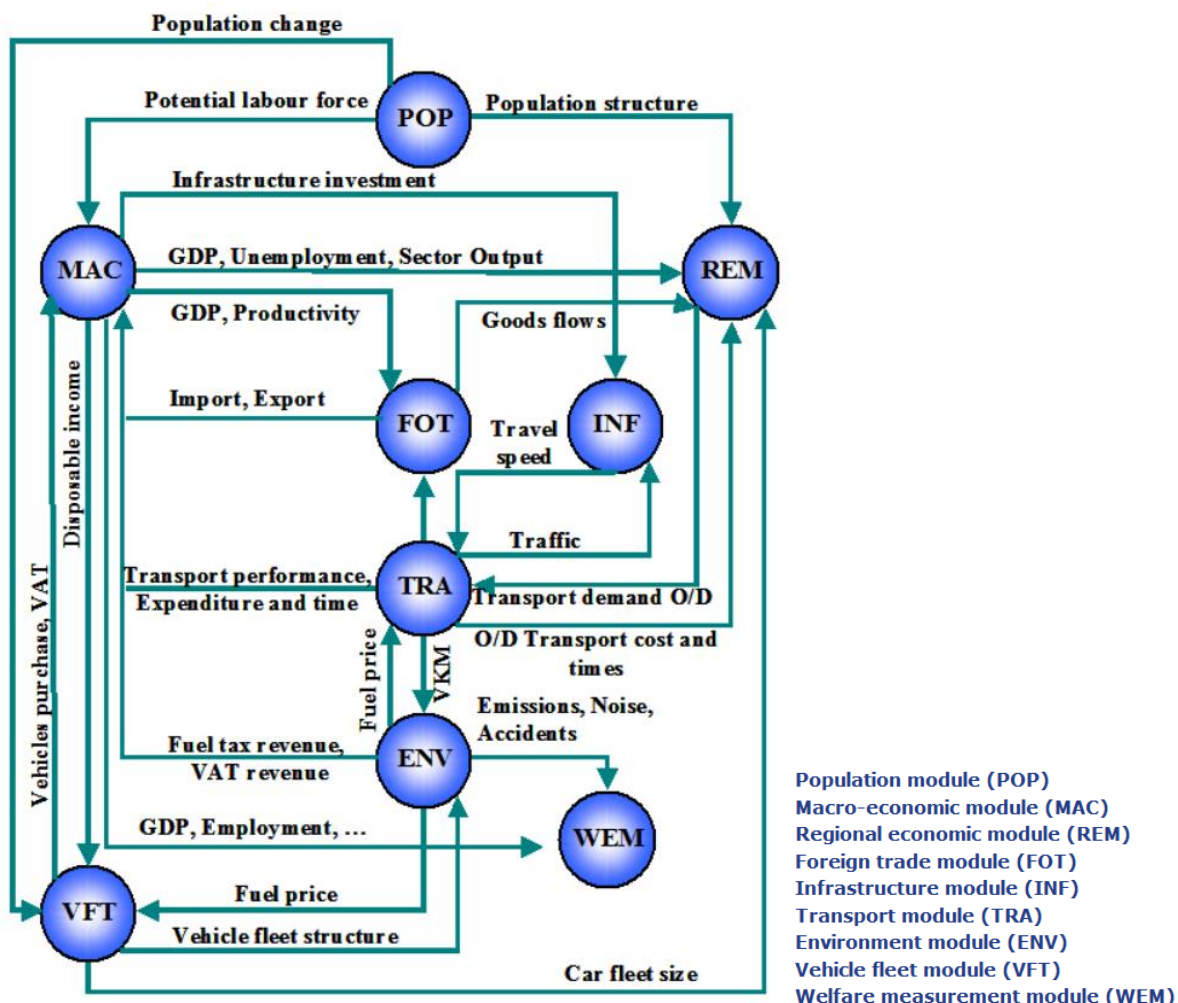


Figure B-9 ASTRA model basic structure

Source: <http://www.astra-model.eu/structure-overview.htm>

TREMOVE

TREMOVE is a policy evaluation model developed for the European Commission to study the impacts of different transport and environment policies on the emissions of the transport sector (De Ceuster et al., 2007). The model provides for the analysis of various transport policies, such as road pricing, Euro (5 and 6) emission standards, and transport demand management. It covers 31 countries (EU-27 plus Croatia, Norway, Switzerland and Turkey) and 8 sea regions, and includes road, rail, inland waterways and air transport. The modelling year is the period 1995-2030 (EC, 2012).

TREMOVE models each country in parallel; the model of each country consists of five interconnected core modules, namely: a transport demand, a vehicle stock turnover, and an emission and fuel consumption, a welfare cost, and a well-to-tank emissions' module. The outputs from these modules

are fed back into one another; for instance, outputs from the emission and the vehicle stock modules provide inputs into the demand module. The structure of TREMOVE is depicted in Figures 2-11.

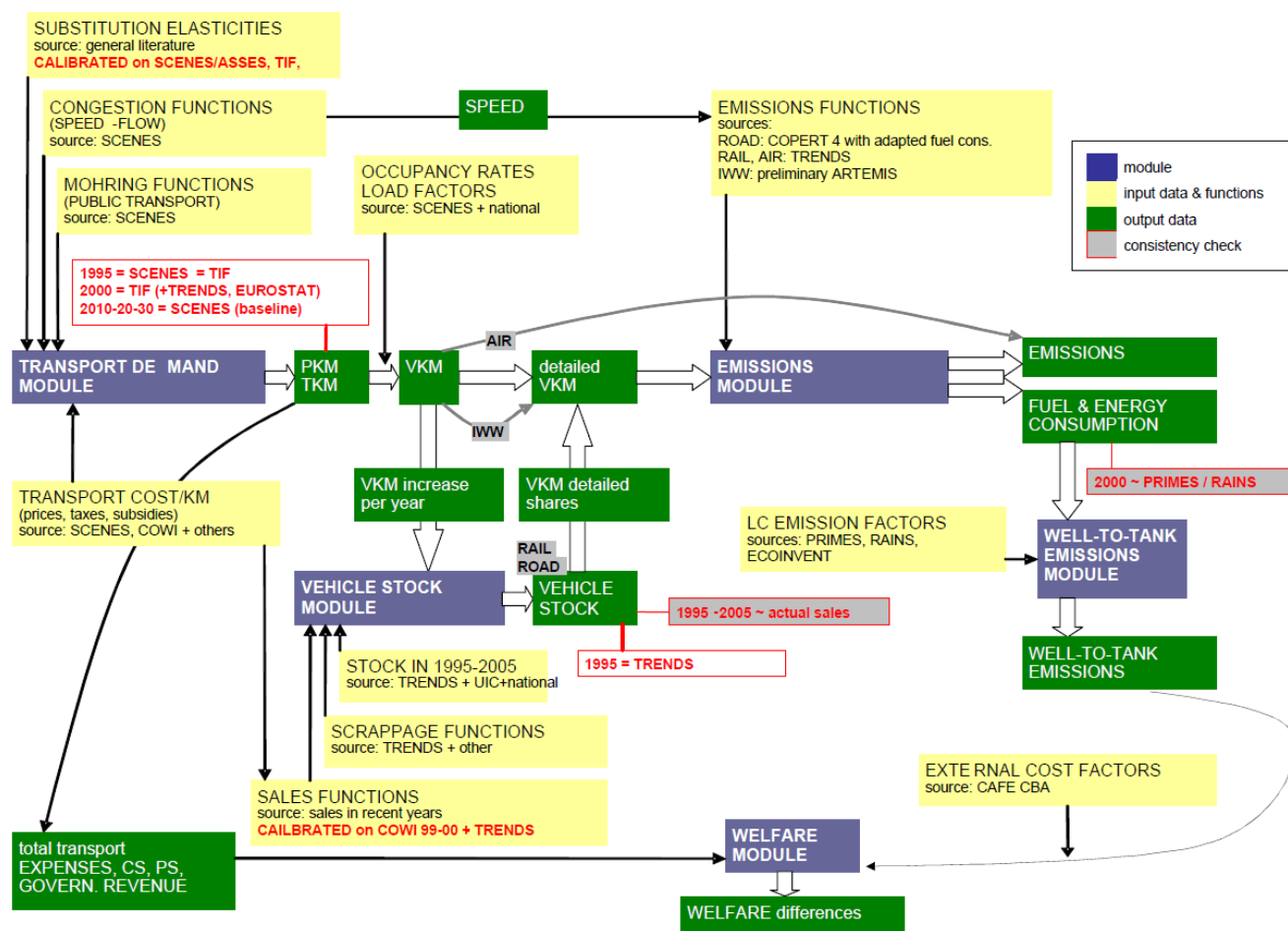


Figure B-10 TREMOVE model basic structure

Source: (De Ceuster et al., 2007, p. 15)

Since its inception, TREMOVE has been used to evaluate a wide range of policies within the EU. Consequently, the EC has commissioned a detailed review of the model by Annema, Hoen, & Turton (2006). The review found TREMOVE to be a valuable transport policy evaluation tool. It highlights the strength of the model as being its comprehensive economic policy assessment that can be applied to an extensive range of transport policies. In addition, the feedback mechanisms within the model enable it to capture rebounding and indirect effects of the policies in question. Nevertheless, the review points out several shortcomings of the model, which are:

- Restricted range of evaluation of policies that have small effects on incomes or production, such as general tax policies.

Appendix B: A suitable transport model for sustainable transport planning

- Several structures, assumptions, and treatment of uncertainty of the model indicate its potential weaknesses, such as the uncertainties in transport demand estimation and the assumed constancy of substitution n's elasticity across modelling counties.
- The current assumptions of the car choice module, in particular are inadequate to provide meaningful results for CO₂ reduction policy for car.
- The model is dependent on time-consuming and data intensive baselines, which make TREMOVE difficult to understand and its policy analysis inflexible.
- Its high complexity makes it difficult to manage thus limiting 'trust' in the model

In comparison with MARS, TREMOVE's economic policy assessment and the emission module are more superior. Nevertheless, TREMOVE's omission of slow modes makes it unsuitable to evaluate sustainable transport policy relating to non-motorised transport modes. Moreover, MARS's structure is more transparent and easier to understand than TREMOVE.

Transport and Environment Strategy Simulator (TRESIS)

TRESIS is an integrated micro-simulation urban transport model system, developed by Sydney University. The main objective of the model is to provide a decision-making support system to evaluate the impact of urban transport policies on a number of interrelated policy instruments. TRESIS has been applied to provide strategic policy assessment for the Sydney Metropolitan Area (Hensher & Ton, 2002).

TRESIS operates at a high level of spatial aggregation, as well as a high temporal resolution on an analysis horizon of up to 28-years. The structure of the model is shown in Figure 2-12.

The model structure consists of seven integrated systems; three of which provide specifications, such as household characteristic, modelling specification, and policy instruments information. These structures are linked into the iteration loops, where the supplies and demands of transport and land use, are interacted and balanced. The results are described comprehensively in the reporting system. The model considers six modes of transportation, including drive alone, ride share, train, bus, light rail, and bus way.

TRESIS is a static model, which produces a fully adjusted result when a policy is applied. However, the time-delay effects of a policy can also be simulated by the model, using a discount factor to impose the amount of change in each year of the simulation.

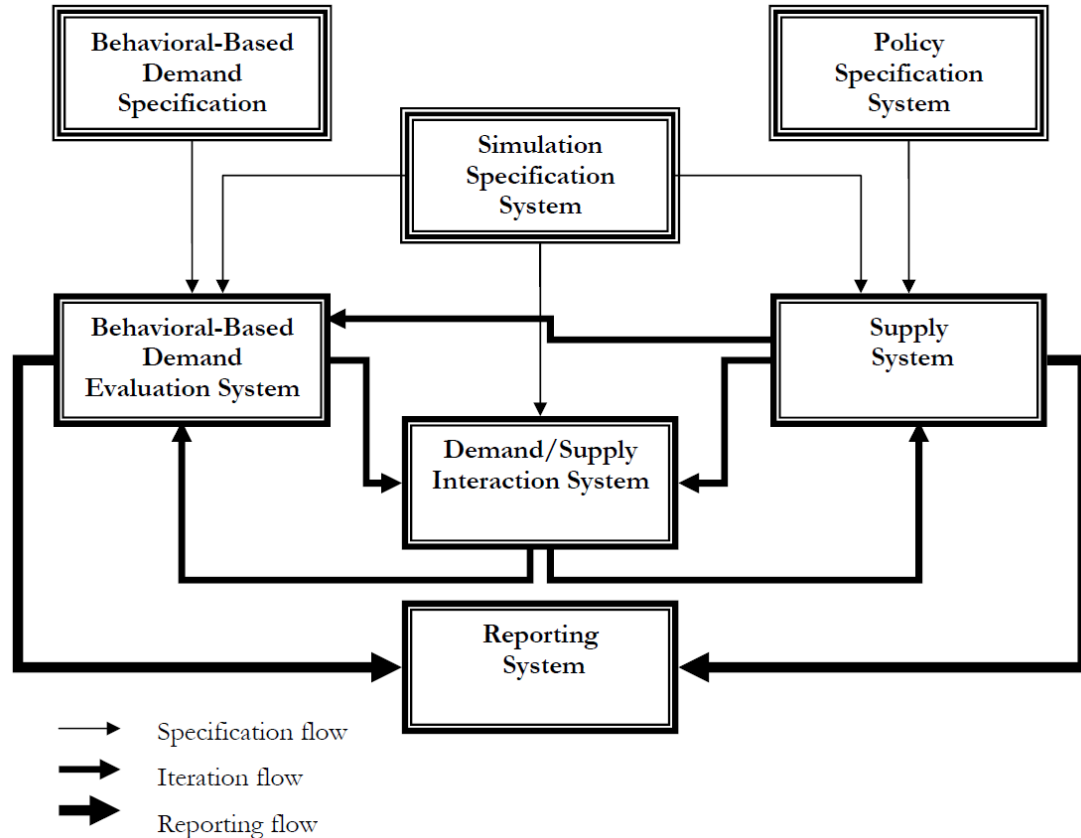


Figure B-11 TRESIS model basic structure

Source: (Hensher, Stopher, Bullock, & Ton, 2004, p. 3)

TRESIS has mainly been applied to Australian cities, namely Canberra, Sydney, Melbourne, Brisbane, Adelaide, Perth, and Sydney Metropolitan Area. It has also been applied at a regional level (New South Wales) under the R-TRESIS project. TRESIS Version 1.10, available online, shows a simple and easy to use interface, which conceals the complexity of the model. The lack of transparency in demonstrating how the system arrives at the results may have alienated some users from using it and the system has suffered from a “black-box” syndrome. Other apparent disadvantages of the model are its inability to assess non-motorised transport policy and the uncertainty in its transferability to other cities outside Australia.

UrbanSim

UrbanSim is an open-source dynamic micro-simulation model, which encompasses the interconnection between four different entities of urban areas; namely, land use, transport, economy and environment. The model was developed by Paul Waddell of University of California, Berkeley, with an aim of providing an unbiased and credible tool to support the planning and learning processes of urban

development. UrbanSim is constructed for a wide range of users; expert and non-expert, technical and non-technical users.

UrbanSim operates at a disaggregate level; it represents individual agents (agent-based model) as household, firms, person and jobs. The spatial scale of the model is also highly disaggregated, at user-specified resolution grid cell and building. The highly disaggregate nature of the model allows it to define accessibility as a positive economical attribute of housing at walking scale, which is different to a conventional model. This enables the model to assess non-motorised transport policy. Random utility theory and logit models are used in the software for its key demand components. In addition, its dynamic nature allows the model to analyse path dependent development trends. The structure of UrbanSim and the flow of data between different components are shown in Figure 2-13.

The structure of UrbanSim simulates the interactions between different agents within the urban system. These agents are replicated by the five model components within UrbanSim. The accessibility pattern is analysed from the vehicle ownership (the access model), the households and employment (the economic and demographic transition model), the choice of household and employment location (the household and employment location models), the new construction and redevelopment by developers (the developer model), and the land price (the land price model). The management of the individual model emanates from the software's coordinator components. The relationships between these model entities also represent the connections between land use and transport system of the urban area (The UrbanSim Project, 2011).

Appendix B: A suitable transport model for sustainable transport planning

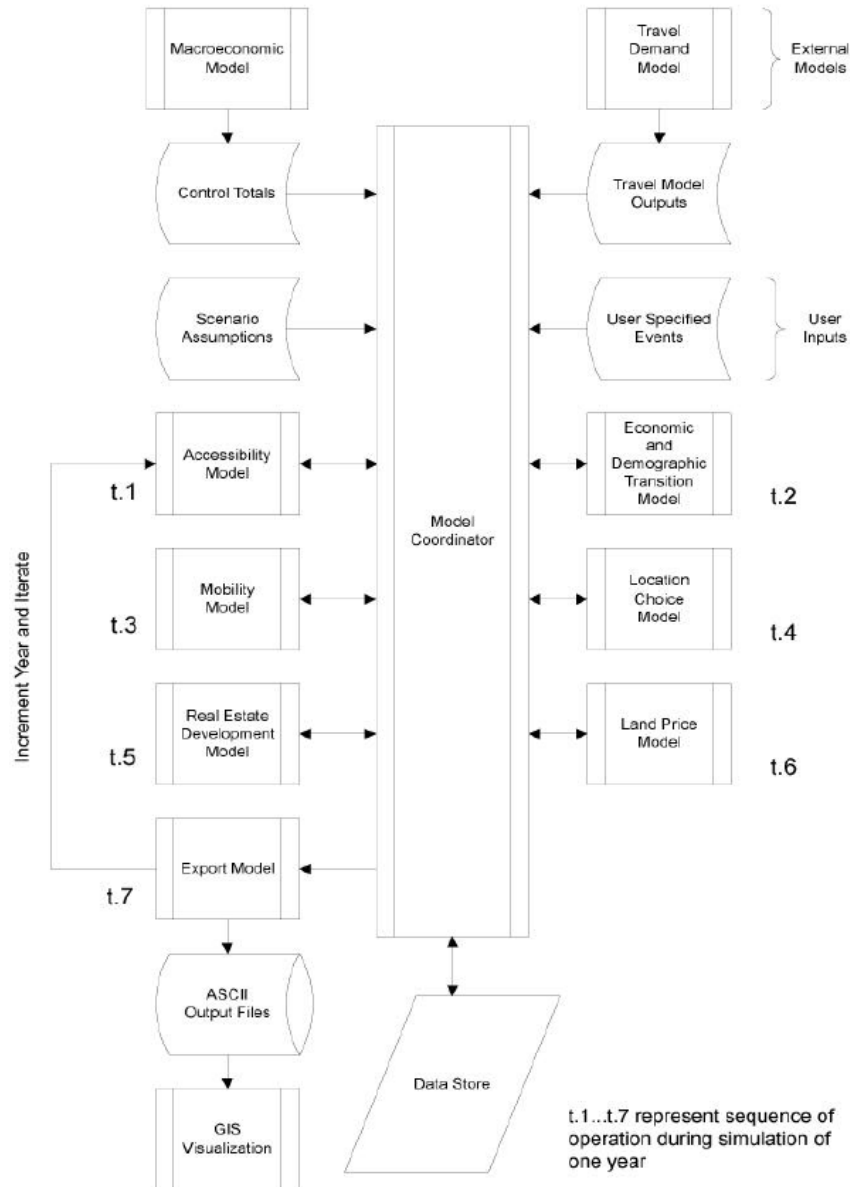


Figure B-12 UrbanSim model basic structure

Source:(The UrbanSim Project, 2011, p. 96)

The apparent strengths of UrbanSim are (a) its ability to provide a dynamic analysis of the urban area in disaggregate scale, such as individual job and household location, and (b) the availability of the software. Nevertheless, its detailed level of analysis may be excessive for strategic planning and is difficult to understand. Moreover, its policy analysis is not straightforward; a policy package must be coded into a scenario to evaluate its effect. In UrbanSim, a scenario is a defined set of assumptions that can be input into the model to assess their effects to the land use and transport.

In comparison with MARS, UrbanSim's exogenous models (i.e. travel demand model) may restrict the range of policies that can be studied (Johnston & McCoy, 2006). In addition, its data-intensive

nature may hinder successful implementation of the model in developing countries, such as Thailand, where the availability of transport and land use data is patchy.

PROPOLIS

PROPOLIS is a resinous substance collected from the buds of certain trees by bees and used as a cement or sealant in the construction of their hives. Hence the PROPOLIS model was developed as part of an EU-funded project to research, develop and test integrated land use and transport policies, planning tools and methodologies to deliver sustainability (TRIP, 2013). The model is used to evaluate a set of indicators developed for measuring urban sustainability. The time horizon of the model is 20 years. PROPOLIS is an integrated set of models, which combines land use and transport models with indicator, evaluation and presentation modules. The model has been applied to seven European urban areas, namely, Bilbao, Brussels, Dortmund, Helsinki, Naples, Swindon, and Vicenza.

The general structure of the PROPOLIS model is shown in Figure 2-14. It is apparent that the structure consists of three main parts: Input, Modelling and Output, each of which are subdivided further into Policies, Data input, Behaviour, Impacts, Indicators, and Results. The Input part feeds information into the modelling part, which processes and reports selected indicators to the Output part. Sustainability indicators are calculated from the outputs, evaluated, and presented alongside the background indicators, to illustrate the behaviour of the system.

The novelty of the model is its ability to adopt existing case studies which used LUTI models into its framework and harmonise their outputs, thus building on existing knowledge. It can adopt any of the three following LUTI models; namely, MEPLAN, TRANUS, and IRPUD. Other strong points of the model are its comprehensiveness, transparency, and its ability to suggest progressive sustainable policies based on a long time horizon (Lautso & Spiekermann, 2004).

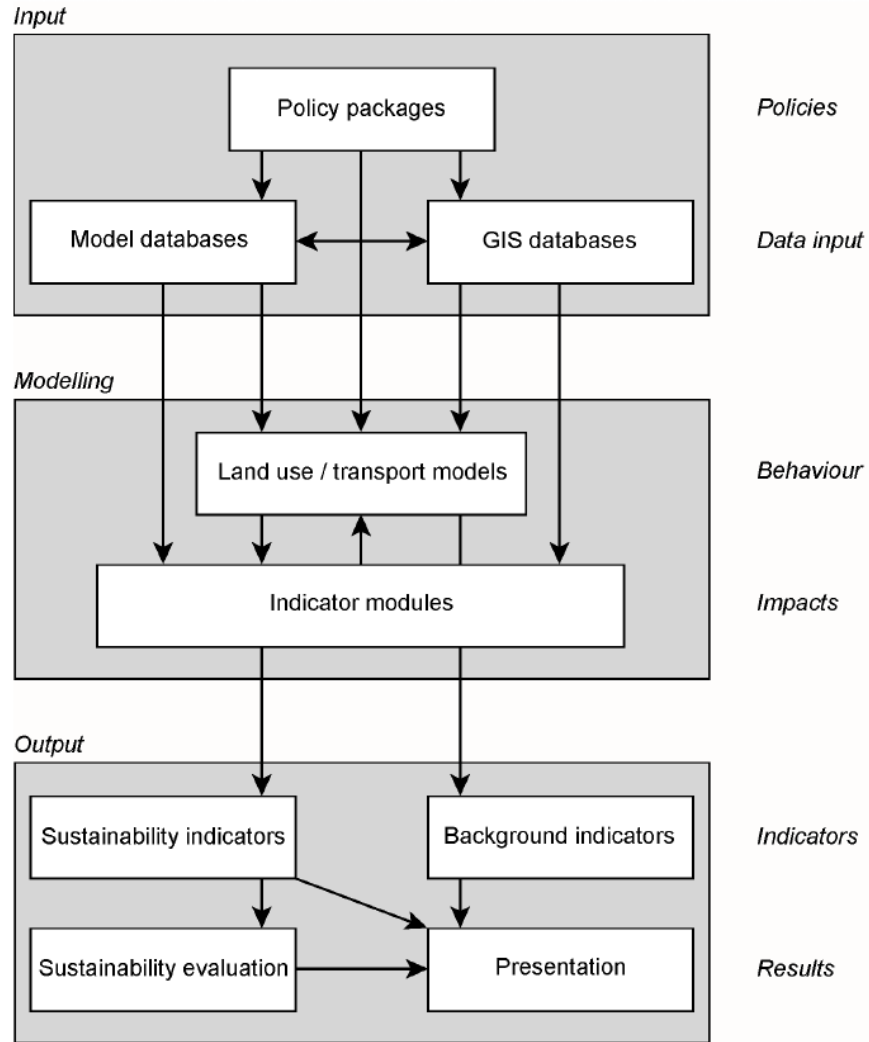


Figure B-13 PROPOLIS analytical framework

Source:(Lautso & Spiekermann, 2004, p. 73)

Appendix C: Chiang Mai mobility and transport survey (CM-MTS)

Introduction and Background

The Chiang Mai Mobility and Transport Survey (CM-MTS) is a household travel survey carried out in 2011/12. The survey captured mobility data that represents 19,385 trips carried out by 6,189 persons in 2,319 households within Chiang Mai city area. This data provides a comprehensive snapshot of the travel behaviour of the city's residents. It can be used as a basis for a wide range of analysis and policy planning.

There have been a number of transport-related surveys undertaken for Chiang Mai city over the past years. However, only a handful are focused on capturing the mobility and travel behaviour of the citizens. Before CM-MTS, there had been six mobility surveys previously carried out in the city. Efforts were made to obtain the data sets of these surveys, but it was apparent that none were available. This was largely due to the inability to trace the persons in charge and the secretive nature of the organisations responsible for the data.

The unavailability of any mobility data prompted the need to carry out a primary data collection in the form of a mobility survey. It was emphasized from the beginning that the survey must capture trips made by non-motorised modes, such as walking and cycling. Only one previous survey captured walking trips, namely the 2002-OCMLT and none of the previous surveys in Chiang Mai city included bicycles as a travel mode¹.

CM-MTS is a collaborative research project between the Infrastructure & Construction Management Research Unit (ICM) of Chiang Mai University and the Research Centre of Transport Planning and Traffic Engineering (IVV) of Technical university of Vienna. Fifteen academic institutions, organisations, and companies in the city took part in the survey. The undertaking was greatly supported by government sectors, such as municipalities within the principal plan area and by volunteers within villages and communities, who kindly dedicated their valuable time.

¹ The Traffic and transport master plan for Chiang Mai city, 2nd revision was adjusted later to include bicycle mode by HSRI (2003).

Comparison with other cities' mobility surveys

The CM-MTS is further compared against 21 other mobility surveys to put it into a global context. The details of these surveys are obtained from the surveys' report and secondary sources, such as Hyodo & Montalbo (2005), which provided information on thirteen surveys.

The total population of the cities included ranges from medium size (300k) to megacity (20 million). The city with the smallest population is Southampton and the largest, Cairo. Chiang Mai city is at the lower end of this scale. These surveys took place between 1987 (Hiroshima) and 2012 (Chiang Mai). The ratios of the sample size to the total population are between 0.2% and 7.0%. For the surveys with total households as their base unit the ratios range between 0.4% and 1.4%. CM-MTS sample size is 1.0% of its registered population and 0.8% of total households; it is also in the lower ends of the sample size range. Five of the surveys used some form of telephone interview and CATI² and 17 of them employed HIS³. City of London (Canada) and CM-MTS are the only two surveys that employed a self-completion survey, using the internet (City of London) and a questionnaire (CM-MTS) as their research mediums. CM-MTS is the only survey that gathered its data with face-to-face interview at workplaces. Out of twenty-two surveys only seven of them described their selection methods; and the CM-MTS was the only survey that did not randomise its samples (see CM-MTS report for detailed explanation).

² Computer-assisted telephone interviewing

³ Household interview survey

Table C-1 Comparison between mobility surveys other cities and CM-MTS (1)

#	1	2	3	4	5	6	7	8	9
City	CM-MTS	East Tennessee	Hong Kong	Kansas City Regional	London	Southampton	St. Louis region	Sydney	The city of London
country	Thailand	USA	RPRC	USA	UK	UK	USA	Australia	Canada
Level	GMA	Regional	City	City Region	GMA	City	Regional	GMA	GMA
Total population	602,170	n/a	6,756,100	n/a	7,825,000	304,400	n/a	4,507,000	376,590
Total HH	301,690	319,910	2,152,900	655,197	n/a	n/a	968,533	1,691,000	n/a
Survey year	2011-2012	2008	2002	2004	2009/10	2011	2002	2010-11	2009-2010
Total sample completed	Person	6,189	n/a	n/a	18,924	1,500	n/a	16,377	n/a
	HH	2,319	1,400	30,005	3,049	8,227	n/a	9,657	5,094
% of total Person	1.0%	n/a	n/a	n/a	0.2%	0.5%	n/a	n/a	4.3%
% of total HH	0.8%	0.4%	1.4%	0.5%	n/a	n/a	0.5%	0.6%	n/a
Method	HIS/ Workplace/ Self-complete	CATI	HIS (Only one member per household)	travel survey /CATI	HIS	CATI	Telephone interviews and travel log	HIS	CATI and internet (500samples)
Selection method	None	Random sample of households	Randomly selected within 4 mobility class users	Randomly drawn proportionate to the number of households	N/a	Tel. No. generated using random digit dial (RDD).	Random sample of households with telephones	N/A	Computer-assisted randomizing techniques and tabulation
Information collected	24h travel, /households	24h weekday travel, / households	24h weekday travel, / households	24h weekday travel, / households	24h trip diary	Travel habits, attitudes to transport modes and awareness of initiatives.	24h weekday travel, /households	24hr weekday travel, / households	24hr trips on the previous day
Source	(Jittrapirom & Emberger, 2013)	(NuStats, 2008)	(HK Transport department, 2002)	(NuStats, 2004)	(TfL, 2010)	(Mruk, 2011)	(NuStats, 2003)	(Bureau of Transport Statistics, 2012)	(AECOM, 2010)

Table C-1 Comparison between mobility surveys other cities and CM-MTS (2)

#	10	11	12	13	14	15	16	17	19	20
City	Belem	Bucharest	Cairo	Chengdu	Damascus	Hiroshima	Jakarta	KL	Manila	Phnom Penh
country	Brazil	Romania	Egypt	China	Syria	Japan	Indonesia	Malaysia	Philippines	Cambodia
Level	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total population	1,782,394	2,150,000	14,400,000	309,000	3,078,190	1,500,000	20,964,000	1,390,800	9,454,000	1,152,000
Total HH	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Survey year	2000	1998	2001	2000	1998	1987	2000	1998	1996	2000
Total sample completed	Person	24,043	67,509	136,070	31,188	38,490	423,237	80,560	231,889	18,664
	HH	6,889	32,888	41,962	14,537	17,202	100,864	27,331	60,752	6,446
% of total Person	1.3%	3.1%	0.9%	10.1%	1.3%	7.0%	2.0%	5.8%	2.5%	1.6%
% of total HH	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Method	HIS	HIS	HIS	HIS	HIS	HIS	HIS	HIS	HIS	HIS
Selection method	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Information collected	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.	See Hyodo et al.
Source	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)	(Hyodo & Montalbo, 2005)

Appendix D: Summary of decision maker's interviews

This subsection contains a summary of the interview transcriptions. It is the narrative data of the exercise and is condensed from the interview short notes. Efforts were made to ensure that this summary was accurately translated to provide a precise interpretation of the interviewees' responses. It should be noted that the order of the summary does not correspond to the CM-LTSS list in Chapter 6 to conceal each individual respondent's identity.

Respondent No. 1

The sustainability of Chiang Mai City depends on its economic stability, its investment attractiveness, and a low crime rate. The zoning of the city should be appropriate, making it liveable with sufficient green space and a clean water supply. The transportation system should be safe, low energy usage, and time-effective.

Chiang Mai city needs to adapt itself to ensure its sustainable future. It needs to develop public infrastructures that promote sustainable behaviours. Social awareness on this issue should be raised to convince people to change their behaviours.

Lack of human insight and a failure by the individual to understand their part in collective public responsibility are factors that reduce the sustainability of the city. Furthermore, the existing infrastructures do not effectively utilise our resources (time and money). The sustainability of the city can be maintained by developing and improving the city's infrastructure and its inhabitants' behaviours. The city is part of a bigger system, firstly within Thailand, then within the South East Asian region and, ultimately, the network of cities across the globe. Chiang Mai is hugely dependent on tourism to sustain its economic viability. If its sustainability is perceived by the outside world to standstill or, worse, suffer reduced levels its competitiveness decreases against other cities within the region, which adopt aggressive sustainability strategies in order to gain a greater share of the tourist market.

Sustainable and Sufficiency Economies have principals that are in harmony with each other. However, while the former seeks balance between the factors which achieve sustainability, the latter condemns capitalism and promotes the utilization of resource in a Buddhist way, i.e. in a sensible and adequate manner.

The transport problems in Chiang Mai may seem small in comparison to Bangkok. However, they are serious for a city of its size. The problems will aggravate and intensify in the future, especially during the festive seasons and the rush hours.

The causes of Chiang Mai transportation problems are:

Appendix D: Summary of decision maker's interviews

- the past and current development paths (that promote personal vehicles usage),
- the mismatch between infrastructure supply and demand (especially in the inner city area), and
- the inconsistency of the quality of the infrastructure (bottle necks and speed variations on road network)

The solution is (a) to provide effective public and non-motorised transport systems, (b) to promote mixed land use to reduce trip length, and (c) to alleviate traffic bottleneck points on the road network.

Respondent No. 2

To define the sustainability of Chiang Mai city is to define its prime point. There are various effects from its development that prohibit life styles and traditions and customs from the past that are considered good. A sustainable city is a city with a good plan that takes into accounts its growth and expansion. The plan should be able to accommodate current and future traffic volume, and distribute the city's public facilities evenly.

The development direction of Chiang Mai city is unclear; previously, it focused on cultural conservation. However, it recently changed in emphasis towards economic development. The city is at its turning point; it has to choose whether to return to its cultural roots or to modernise itself.

In order to maintain the sustainability of their community, city residents must choose the development path of the city, which inevitably leads to the restriction of rights or convenience. These two elements may seem complementary but they are opposing. The reduction of the city's sustainability will benefit external investors and negatively affect local people.

Sufficiency Economy is a principal to control demand. It is a way to manage desire and ensure a modest way of living. It is in accordance with Maslow's theory of the hierarchy of needs. Sufficiency Economy leads to sustainability, the pinnacle point or the highest state of happiness that is unchangeable.

Chiang Mai city's transportation problems arise from:

- the inner city's restrictive road layout,
- the rapid increase in the number of vehicles and population, and
- motorists' lack of discipline

These problems can be solved by relocating traffic attractors such as school and government facilities outside the inner city area. The inner city area should be protected and preserved. An effective public transport system should be provided to reduce the number of motorised vehicles.

The restriction of large vehicles from the inner city, motorised vehicle growth control, and a flexible working hour will also help to alleviate these problems.

Respondent No. 3

A sustainable city is a liveable city that attracts habitants and investors. It should have a transportation system that utilises the existing urban area effectively. It should not expand into the city's green areas.

Over a long term perspective, Chiang Mai city is on a downward slope; it is deteriorating. Common starting points and shared development objectives of the city are needed. A SWOT analysis of the city will help us understand its position and will enable its weaknesses to be addressed. The lack of long term goals and integrated efforts are deteriorating the city's sustainability.

It is necessary to establish a vision for the city. It will provide development directions and the restoration and preservation of the city. Today, it does not have such visions. Its development direction changes in accordance with the government's representatives who are rotated every 2-3 years.

The people will rise up one day if the city's sustainability and its living quality continue to deteriorate. At that time, the cost to restore and improve quality of life will be high. The people are not aware of such consequences, although they will be the worst affected. They are fed with biased news and are not taking any actions (to retain sustainability).

Sustainability and Sufficiency Economy are similar. They seek to balance demand and supply and to produce only what is needed (waste minimisation). Sustainability will arise from implementation of the system (which is the blue print) through the collective effort of Chiang Mai citizens (who are participants of the system).

The transportation problems in Chiang Mai are caused by the lack of management and the ineffectiveness of the system. The government sectors are defragmented and lack progressive thinking. They allow the private sectors to develop freely (e.g. private vehicles are affordable and easy to buy) and not subsidise essential public sector activities (such as bus services).

The government should subsidise the commuting of people. It should provide infrastructure and regulate public service to shift people from private vehicle to public transport modes. It should revise its policy structure against the private sector to avoid a head-to-head competition. It should promote public-private partnership or co-operatives. They need to have sincere and serious attitudes toward solving these problems.

Respondent No. 4

A sustainable city is a city with a balanced ecosystem and a quality environment. New arrivals to the city (e.g. Thais from other Provinces, immigrant labourers, and foreigners who choose to settle here) must understand the local traditions and way of living. The city should have a good and convenient way to travel.

It is the government's goal to make Chiang Mai city a sustainable city. The current vision of Chiang Mai is to become the most splendid city of culture. Factors that negatively affect its sustainability are a lack of appreciation for local culture and the unwillingness to change behaviours (such as switching from using private vehicles to other modes). The city's past planning has reduced its sustainability; for example, many past road projects did not consider the environmental impact and the social effects of their implementation

The reduction of the city's sustainability will degenerate the city; it will lose its identity, vitality, tradition and unique Lanna culture. The time horizon of our visions will determine how long our sufficiency can be sustained.

The transportation problems of the city arise from an increased population (due to tourism and immigration) and the expansion of the city's economy.

Respondent No. 5

A sustainable city is a city that has good land use and service distribution plan. The plan should provide good accessibility and sufficient parking spaces.

The amount of traffic in Chiang Mai is increasing. This will result in accessibility problems. Motorists' behaviour, their disciplines, and the conditions of the road network affect the sustainability of the city. In addition, the defragmentation of the city's governmental departments responsible for the infrastructures further aggravates these problems.

If the sustainability of the city continues to decrease, the financial cost of providing a public transportation service, and the environmental cost affecting the quality of life, will increase. This will affect the system as a whole and will damage our society. The city's sustainability can be maintained with a city plan enforced by law. Politicians should be prevented from interfering with development plans. Illegal developments that exploit public resources should be forbidden. It is essential to view problems from a system's perspective.

Sufficiency Economy and sustainability are complementing principals. They are based on the fulfilment of basic human needs. Sufficiency reduces competitiveness between conflicting agencies by seeking to distribute available resources evenly according to the needs of the city's plan for

sustainability. Sustainability creates confidence in people that the society in which they live can fulfil their needs. There will be chaos if people are uncertain about fulfilling their basic needs. We should view everything as interconnected.

The transportation problems in the city have resulted from the increased population, the high amount of private vehicles, and the high average number of trips per person. The relocation of people from the city centre to suburban areas has increased the average distance travelled per trip, because their workplaces and public/private services remain in the city centre. There is also a lack of quality public transport. The current users of public transport are those who cannot afford or do not have access to private vehicles.

The provision of quality public transport will reduce private vehicle dependency. The planning of the city should establish satellite centres with a mixed land use around the city centre. This will reduce the number of trips and the average trip distance.

Respondent No. 6

In the context of transportation, a sustainable city needs a transport system that is usable by, and acceptable to, the public. The existing situation of Chiang Mai city's transportation system is not as bad as it is perceived. Its transportation system has improved by leaps and bounds over the years. However, public transport within the city area remains ineffective. In contrast, the inter-districts and inter-provinces services are excellent. Consequently, there are more public transport users in the rural areas of Chiang Mai province than within the city. Those who use city public transport are mainly either visitors or tourists.

The current sustainability level of the city is acceptable. Transportation developments which are alien to the city's culture, such as tram, underground, or so called state-of-the-art developments, are not suitable. A large proportion of people do not have a sense of civic duty to preserve public services for the benefit of all. An example of this can be seen at the city's transport hub that was opened in early 2012. The facilities at the hub have been exploited for personal gain.

However, a monorail system may provide a suitable solution to improve the city's transport system. It can serve tourists and locals. It is appropriate form of transportation for a city with a medium density like Chiang Mai city.

The principals of sustainability and Sufficiency Economy ensure a lasting development. Sufficiency is to be self-reliable and to avoid being extravagant. In the context of transportation, it means utilising available resources effectively, in accordance with the local life style and traditions.

The city has transport problems. Their cause is the imbalance between supply and demand of road infrastructure. The city's development and its population have been growing rapidly over the

recent years, whereas the road length remains unchanged. The city also has a lot of motorcycles, the 2nd highest in Thailand after Bangkok.

A motorcycle uses a relatively larger amount of road space than a car as it has lower passenger capacity. In addition, it produces more pollution and has higher social and economic costs to the nation than other modes of transport (due to its vulnerability in accidents).

Solutions that seek to increase the transport system's efficiency such as car pool can help to alleviate these problems. The challenge in introducing public transport culture is to induce willingness to transfer (from private to public transport). Residents of the city are used to door-to-door service, provided by private vehicles. They will be more reluctant to switch to public services than those in Bangkok and other cities. The department of Land and Transport must improve the quality and range of transport modes available to increase the demand for public transport.

Transport and traffic regulations used in Bangkok may not be suitable for Chiang Mai as their densities are different. In addition, the vehicle fleets are older; many of them are over 30 years old yet still in use. The department of Land and Transport has not discouraged the use of such old vehicle fleets.

Furthermore, politics have, and continue to have, high influence over the city's land transport management. For example, the shared-taxi was initially registered with the department of Land and Transport as a fixed route service but operates as a free route service to maximise its earnings. It is difficult to manage them directly even though they break the regulations as they are supported by local and national politicians.

It would be interesting to promote the use of bicycles in the city area. The physical restriction of the road network in the city area means the speed of a bicycle and a motorcycle in this area are similar. Thailand uses a lot of petrol in its transportation sector but it is still at an acceptable level when compared with neighbouring countries.

Respondent No. 7

A sustainable city is a city with a good plan that has an appropriate zoning system. Chiang Mai city is currently not sustainable; it does not have a quality public transport system. The road infrastructure in the city is not sufficient, and more roads should be built to provide accessibility and convenience for people.

The number of vehicles in the city increases perhaps two or threefold annually. This increases the number of road casualties and contributes to air pollution. The development of Chiang Mai city is unplanned. It does not have any official guidelines. It also does not follow any suggestions from past research or government sponsored studies. The city's development is often

influenced by politicians who have personal agendas. The city needs more road infrastructure to support the increased number of vehicles. Roads will not necessarily encourage more vehicles; the number of vehicles depends on changing needs and expectations of the population; it is not influenced by infrastructure availability *per se*.

The sustainability of the city depends on the implementation of a good public transport system and the promotion of cycling. The reduction of its sustainability will see the city deteriorate in many aspects: social, economic, quality of life, health, and road safety.

Sustainability and Sufficiency Economy are closely related. The two concepts provide guidelines for co-existence; for example, greed or overconsumption reduces sustainability. In the context of transportation, sustainability can be thought of as a provision of public transport system whereas sufficiency can be equated to a reduction in private vehicle usage.

The lack of a good public transport system, an ineffective city plan, and insufficient budget to build and repair road infrastructures are the causes of Chiang Mai city's transportation problems. These problems can be solved with the provision of additional ring roads, an improvement in the public transport system, and an incremental rise in motorists' discipline, through education and law enforcement.

In addition, the current location of the city centre contributes toward the transport problem. The city is centred on the old city area that was not planned to support the number of people it has today. Its infrastructures are unsuitable for the current level of different activities. The activities underwent a significant growth spurt over the last 5 years vertically and horizontally. It is still possible to plan and manage its transportation system today, using the ring roads as the city boundaries.

The government sector is 'fire-fighting' the problems instead of taking a long term view and planning to solve the underlying problems. They have attempted to solve the symptoms with measures that worsen the problem; for example, they authorised more road building projects to solve congestion problems. It is also very easy to own a vehicle in Chiang Mai; they are inexpensive and the enforcement of traffic laws, including an insistence that those driving possess the required licence, is weak.

Respondent No. 8

A sustainable city needs to have an effective and efficient transportation system. It must have a high quality public transport system that is reliable and fast.

In comparison to Bangkok, the sustainability level of Chiang Mai city is still adequate. Nevertheless, it should be improved. There is nothing that is reducing the level of sustainability of

the city at the moment. The reduction of sustainability level will destroy the city socially, its tradition will change and so will its uniqueness. Leadership from top ranking officials is essential to maintain the city's sustainability; people need to lead by an example.

Sustainability and Sufficiency Economy are the same principle; they are complementary. An awareness of our needs will help to control our desires and hence our actions.

The transportation problems in the city are caused by high volumes of vehicles during the rush hours, the lack of public and school bus services, and the absence of urban plans. Motorised transport should be prohibited from the old city centre area. An underground public transport is not appropriate for the city; modes of transport that are unique to the city such as tricycle and bicycle are more suitable. It will help to save energy and promote tradition and culture at the same time. The development plan of the city should not focus on the city centre; the development should be distributed evenly.

Respondent No. 9

A sustainable city is a city that has its own unique identity and culture. Chiang Mai city has existed for over 700 years; it has a certain level of sustainability although this has begun to decrease recently. Sustainability of the city is rooted in its origins. The city may alter its characteristics but it will eventually return to its initial point.

Illegal exploitations of public land, rapid increase of modern and uncontrolled developments, and the lack of public consultation in government projects are all factors that reduce the sustainability of the city. Consequently, they will negatively affect the city's identity and its uniqueness and adversely affect the tourist industry. Public hearings and consultations are crucial to ensure that a development is sustainable. Law enforcement should be used to support the organisation of the city's land use.

Sustainability and Sufficiency Economy are inseparable. They can be applied to a wide variety of activities. Sufficiency means adequacy. It ensures that our choices in the consumption of resources are suitable.

The transportation problems of the city stem from its lack of an urban plan, social ethics, and, lack of road discipline by motorists. In addition, there is an insufficiency in the city's road infrastructure. Public services that should be provided by the government, such as school buses, are run by the private sector.

These problems can be solved by relocating the economic and work centres in the city centre area to the suburb area. The law must be enforced more strictly together with measures to promote

social and ethical responsibility. A public transportation system, which is in harmony with the local tradition and suitable for the city, must be implemented.

Respondent No. 10

A sustainable city, in the transportation context, must adopt a style and design that is recognisably local and adds, rather than detracts, from the tradition and culture. The sustainability level of Chiang Mai city is still high in comparison with other cities. Nevertheless, there are factors that threaten to reduce its sustainability such as new developments, lack of media quality, and unfettered disregard for zoning principles. The sustainability of the city can be maintained by encouraging school children, students and other young people to learn about the traditions of our forefathers and to understand the rich cultural heritage they have inherited and are responsible for preserving for future generations.

Sustainability and Efficient Economies are related to one another. Sufficiency will lead to sustainability; to be sufficient is to ensure sustainability. Sustainability and sufficiency are ethical precepts which, if adhered to prevent society from degenerating.

The causes of Chiang Mai's transport problems are (a) human behaviour, (b) the expansion of the city (urban sprawl), (c) the physical limitations imposed by the old city layout, and (d) the attachment to the shared-taxi. The shared-taxi is said to be a symbol of Chiang Mai city, although its history in the city started only 30 years ago.

Many public construction projects in the past have disregarded the social impact on local people. For example, road widening projects that cut off adjacent communities have effectively destroyed the social fabric at the heart of village life.

The city's transport problems can be alleviated by improving motorist behaviour, strengthening road discipline and enforcement, and improving the quality of road infrastructure and their physical layouts, including signage.

Respondent No. 11

In the transportation context, a sustainable city should have a good transport system with a high quality and standard. The enforcement of the system should be strong. The city should have a clear urban plan. Chiang Mai city's urban plan lacks clarity and direction. It is not a sustainable city. Its growth is exponential and overly dependent on an influx of foreign workers.

High and ineffective use of energy and the lack of discipline are the main factors that reduce the city's level of sustainability. The lack of integrations between private and government sectors and

the fragmentation and lack of co-operation between government bodies further aggravate these problems.

There are no significant differences between sustainability and Sufficiency Economic. Both are guidelines to fit our lives into the context of our society. Sustainability does not mean lack of progress. It is a principle that enables one to progress forward, while taking responsibilities for society and with regard to future generations.

The causes of Chiang Mai city's transportation problems are the rapid increase in ownership of private transport and subsequent vehicle usage. The city does not have sufficient road infrastructure. These problems can be mitigated by creating a public transport system, strengthening law enforcements, and reducing footpath clutter.

Respondent No. 12

A sustainable city is a city in which people can live happily and in harmony. It should give high priority to the needs of local people and focus on maintaining their cultural identity. It should prevent the local life style and traditions from changing. The sustainability of Chiang Mai city is currently improving. There are different groups of people working on the development and conservation of the city. It is essential that these conservation efforts deliver tangible benefits. Tourism is a main drive for development but it must take into account the needs of the local community.

The lack of a development master plan and a public transport system are the two main factors that reduce the sustainability level of the city. This reduction will cause the city to lose its identity, liveability, and competitiveness as a tourist destination. As a consequence the economic growth of the city will be negatively affected

To maintain its sustainability, the city should have a transport plan that promotes low energy use. Its transport system should use energy effectively. The development of the system should actively reduce car use and the area occupied by cars. The city's master plan should enforce zoning to ensure land is used appropriately.

Efficiency Economy is the foundation of sustainability. A sustainable development must be grounded on efficiency. Self-reliance, morality, and ethical choices are principles that guide our conduct as human beings.

The transportation problems of the city stem from its lack of a good public transport system, and the absence of a master plan for the city. The development of the city does not have a clear direction or adequate guidelines. It lacks enforcement that would help to shape the city. It is essential for the city to have a public transport system. We should decentralise and relocate facilities,

such as the city's hospital and official government and administrative buildings outside the city area. Cars and large vehicles should be prohibited from entering the old city area. A public transport system for Chiang Mai city must take into account the operation of the shared-taxi.

Cascading the national transport plan into regional and city plans can be ineffective due to the broad, sweeping nature of the national plan. The political agendas of local administrations, which are authorised to be departmentalised from the national plan, can also adversely affect implementation of a local plan. The city will need a centralised body that is responsible for its transportation to solve its transportation problem. The problem has been exacerbated in recent times by the extension of the boundaries of responsibility of many administrative bodies.

Respondent No. 13

A sustainable city is a city where most trips are made by public transport, the bicycle, and pedestrian modes. Encouragement to use these transport modes will enable long term control of traffic problems and ensure that changes necessary to infrastructure are minimised.

In this sense, Chiang Mai city is not a sustainable city. Its public transport system has suffered from a lack of improvement and is unsuitable for the city. The transportation problems of the city are increasing and there is no systematic plan to mitigate the underlying causes. The quality of the city's transport system needs to be improved. Its lack of quality encourages people to use motorcycles and private vehicles.

The existing infrastructures must be improved with an effective and high capacity public transport system. The existing public transport system may be used as a feeder service. Walking and cycling paths should be constructed to encourage non-motorised transport.

The decrease in the city's sustainability will increase traffic congestion. Commuting in the city will become more problematic, discouraging tourists and businesses from coming to the city. Consequently, the overall economic wealth of the city will be affected. In addition, the air quality will also be affected negatively.

Other cities which are tourism destinations but have less congestion will benefit from the decrease in the sustainability of Chiang Mai city. Moreover, the local citizens, public transport operators, and businesses will be negatively affected.

Sustainability and Sufficiency Economy are different. Sustainability is an ability to operate over a long term period without change. Efficiency Economy is an operation that increases the value of existing resources with minimal investment.

Chiang Mai city has transportation problems that stem from:

- poor public transport system (routing and system);

- high number of private transport vehicles in the city while its road infrastructure is limited;
- violation of traffic laws, the highway code and an overall lack of driving discipline

To solve these problems, we need a fixed route public transport system (with convenient connections), an intelligent transport system (such as traffic signal optimisation and information distribution system), and stricter enforcement of traffic and parking laws.

Respondent No. 14

To ensure its sustainability, a city must be governed by its local citizens. This will ensure the harmonisation between its policies, local life style and traditions. Chiang Mai city is not a sustainable city; it has been too focused on economic and convenient developments. Immigration of large numbers of people from other regions into the city is threatening its sustainability. Migration has also increased the number of vehicles on the roads and speeded growth of the city in an uncontrolled manner.

Those who will benefit from the decrease in the city's sustainability are businessmen while local people will lose out.

Chiang Mai city is faced with transportation problems. The causes of these problems are government policies (that encourage the use of the private transport modes such as tax breaks for young people under the age of 24 to help purchase their first car) leading to a decrease in public transport use, and encouragement of economic expansion without regard to other factors. For example, economic growth attracts immigration which leads to an increase in the city's population, and subsequently the number of vehicles in the city.

Implementation of a systematic policy to control use of private cars in the city centre area, improvements on the existing road network's throughput capacity, and a higher vehicle tax aimed at reducing the number of personal vehicles, are measures that will help solve the city's transportation problems.

Efficiency Economy and sustainability have similar meaning.

Appendix E: Definitions of Sustainability and Sufficiency Economy

Sustainability or Sustainable development

The origin of the concept of “Sustainability” can be traced back as far as the beginning of 18th century. ‘An essay on the principle of population’ was written by Thomas Malthus in 1798, demonstrating the unsustainable growth of the earth’s population in comparison to the growth of resources (Kelly, 2005). In more recent past there are several studies such as Carson (1960)’s *Silent Spring*, Hardin (1968)’s *Tragedy of the commons*, and Meadows, Meadows, Jørgen Randers, & Behrens (1972)’s *Limits to Growth* that address the subject prior to the WCED (1987)’s report. This latter work entitled *Our Common Future* is more commonly known as the Brundtland report. For the first time, the Brundtland report explicitly addressed Sustainability or Sustainable Development as we now know it, which Brundtland’s defines as;

“economic and social development that meets the needs of the current generation without undermining the ability of future generations to meet their own needs” (WCED, 1987)

The Brundtland report sets out the three principal pillars of sustainability: economic, social, and environmental considerations that should be taken into account during the planning phase. The report makes the point that these three pillars of sustainability are often in conflict, with differing goals and objectives, and yet remain interdependent. The rise of Sustainability can be seen as a result of the growing awareness of how human activities impact on the environment, incurring economic, social, and ecological costs. The combination of these costs, Brundtland argues, may ultimately hinder human development capacity (Litman & Burwell, 2006).

The report also sets out the concept of intergenerational responsibility. Simply put, the notion is that each generation has a duty to take account of needs of the next generation. For example, our generation may benefit from building nuclear power stations, but dealing with the nuclear waste created becomes the problem of several successive generations. The level of thought and care taken at the planning stage in how to deal with nuclear waste either results in the success story of the French model or a disaster such as Chernobyl.

This concept of intergenerational responsibility clearly demands that the time horizon to be considered at the planning stage is much longer than the conventional approach that advocates maximisation of benefit within a much shorter time period.

Moreover, it creates two additional challenging tasks. Firstly, it requires identification of the maximum level of externalities that will not limit future generations in meeting their needs and secondly, it requires planners to define what the needs of a future generation may be. The formal

challenge can be approached using the chaos theory, as advocated by Lautso & Spiekermann (2004). They define this maximum level as, “the extent of which a change exceeds nature’s capacity to assimilate the change or to influence the cause of the change”, leading to “an inevitable deflection from the equilibrium” (Lautso & Spiekermann, 2004, p. 27). In other words, exceeding this limit will result in unpredictable consequences, affecting the potential of a future generation.

The second challenging task is to define the “needs”. At its broadest, these can be objectively defined as the essential requirements demanded by the world’s population to satisfy the essential necessities of life on an on-going basis. However, this approach can only yield a primitive prediction of the level of consumption, while in reality there is an element of subjectivity in any attempt to define the basics of life.

Rising to the challenge of these two demanding tasks emphasises the difficulties in defining sustainability quantitatively and putting theory into practise. Since the inception of sustainability, several government and non-government agencies appreciate the concept’s merit and see it as “the new paradigm of development” (Lele, 1991, p. 1), yet the difficulties of putting its broad and far-reaching concepts into practise are well documented. For example, the UK government’s official reflection on the Brundtland report, reads as follows:

“The [Brundtland] Report defines sustainable development as meeting the needs of the present without compromising the ability of future generations to meet their own needs. There can be no quarrel with this as a general definition. The key point is how to translate it into practice, how to measure it, and to assess progress towards its achievement.”

((DOE, 1988, p. 13) cited by (Corkindale, 2011)).

The 1992 United Nations Conference on Environment and Development (UNCED) in Rio was the first significant event after the Brundtland Report. The event formulated a sustainable development blue print, the Rio Declaration on Environment and Development, more commonly known as Agenda 21. This picked up the mantle of the Brundtland report’s legacy and further developed the concepts of sustainability. In particular, it emphasised the importance of considering the environmental factors and social impacts of development (Sathirathai & Piboolsravut, 2004). The Rio Declaration embodies sustainable development by stating in its Principle 4 that:

“In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.” (UN, 1992)

Another challenge in the application of sustainability is whether trading between the different capital elements of sustainability should be allowed or not. There are various views at either end of the spectrum. Two camps have emerged arguing the relative merits of adopting ‘weak’ or ‘strong’ sustainability (Ayres, Bergh, & Gowdy, 1998; Kelly, 2005; Lautso & Spiekermann, 2004; May & Minken, 2003). The difference between the two camps lies in their contrasting views on use of the component parts of what is called total capital. Total capital is the sum of *natural capital*, *man-made capital*, *human capital*, and *social capital* (Table E-1).

Table E-1 Type of capital in sustainability

Type of Capital	Description
Natural capital	Environmental resources, e.g. natural resources, ecosystem services, and subjective values, such as the beauty of nature
Man-made capital	Artificial infrastructure, such as roads and buildings
Human capital	Education, training, and skills within the labour market
Social capital	Connections between people and their families, neighbours, local community and government

Source: (Kelly, 2005)

In weak sustainability, substitution between different types of capital, such as natural and man-made capital is permitted, as long as the sum of all capitals (total capital) remains constant or is increased. The concept is best understood by using an example. Much of Thailand’s coastline, both on the mainland and on the islands, used to be home to large tracts of mangrove forests (natural capital). For generations these forests were harvested by local people to provide firewood, charcoal and animal feed. But in recent years much of the coastal mangrove forests have been cleared to build tourist resorts and prawn farms (man-made capital). The construction of tourist resorts required an increased level of skills within the local workforce – e.g. English as a second language, customer service skills, hygiene and food preparation skills (human capital) – to meet the expectations of foreign tourists. Through the eyes of the proponents of weak sustainability, the profits and jobs generated by man-made capital, together with the consequent boost to human capital, would off-set the loss of the mangrove forests (natural capital)

Advocates of weak sustainability rely on neoclassical theory that assumes everything has a market price and is tradable. It is thought there are several flaws within this assumption, including:

- The conflicting and often irreconcilable nature of the different capital components
- The monetisation of resources, which are often difficult to quantify in financial terms, and the value of which is often subjective, and
- The unidirectional of the exchange between capital components.

Advocates of strong sustainability would not have allowed Thailand's coastal mangrove forests to be destroyed and in 2004 they were proved right when a huge earthquake in the Indian Ocean triggered a tsunami which hit the coastlines of several countries, and destroyed many of the Thai island tourist resorts with the loss of human life running into thousands. Had the mangrove forests still existed, the force of the tsunami would have been absorbed and the tragic loss of human life would have been considerably lessened⁹⁷.

Despite the fallacies in the arguments of weak sustainability, the benefits of strong sustainability are unclear, especially in the context of urban environment, where the trading between different types of capital is inevitable (Lautso & Spiekermann, 2004). For example, if urban sprawl, which eats into natural capital, was not allowed by those in favour of strong sustainability, cities and towns would become even more overcrowded with a subsequent detrimental effect on human capital, as increased stress, less available personal space, and a deteriorating quality of life, took its toll.

Looking at the two extremes of the arguments, it is not surprising that Beckerman (1994, pp. 191–209) argued *weak sustainability is, "redundant and illogical". He holds that sustainability only makes sense in its 'strong' form, but that "requires subscribing to a morally repugnant and totally impracticable objective."*

Sufficiency Economy

Sufficiency Economy is a development principle first coined by King Bhumibol Adulyadej in his 1997-1998 annual speeches (NESDB, 2007). It was given by the King as a guideline for the Thai people to recover from the 1997 national economic crisis (Sathirathai & Piboolsravut, 2004). It is often referred to and used in Thai governmental development policies such as the National Economic and Social Development plan (NESDP). The concept is based on the Buddhist principle of following the middle path; Figure E-1 depicts the fundamental concept of this philosophy.

⁹⁷ <http://www.fao.org/docrep/010/ag127e/ag127e06.htm> and <http://www.umich.edu/~esupdate/library/99.3-4/murray.html>

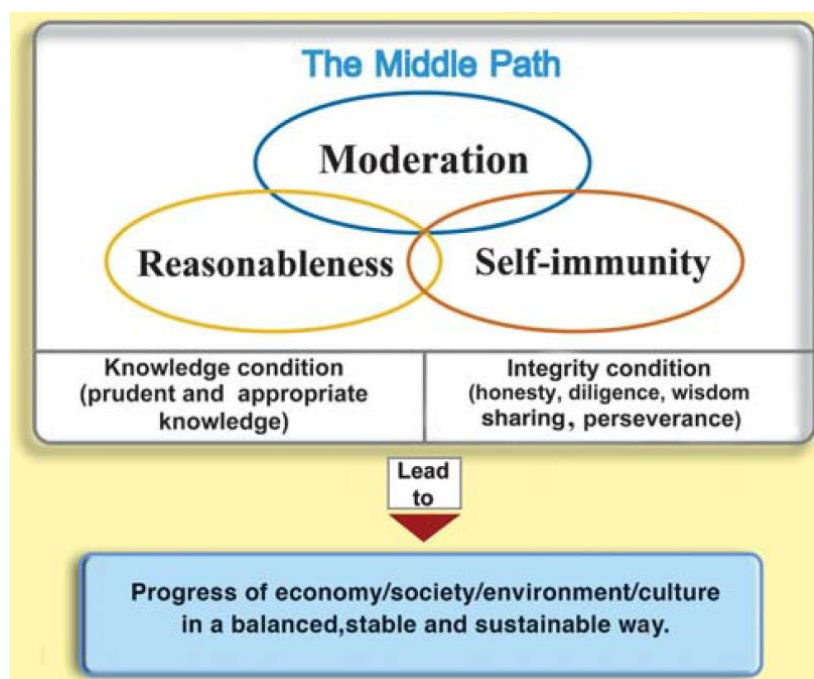


Figure E-14 Philosophy of Sufficiency Economy

Source: (NESDB, 2007)

Sufficiency Economy philosophy can be applied at all levels; from global, national, regional, city, town, village, street, neighbours and family to the level of the individual. It proposes that the three elements of moderation, reasonableness and self-immunity, provide protection against “impacts arising from external and internal changes” (NESDB, 2007, p. 14). Sufficiency Economy is also seen as a counter policy against conventional market-oriented and infrastructure-focus policies that the country has adopted since its first NESDP in 1961 (Isarangkun & Pootrakool, 2007).

Many spheres of Sufficiency Economy overlap the Sufficiency Development concept, such as the distinction between growth and development, and their shift in focus away from consumerism. However, the main difference between the two concepts lies in the Sufficiency Economy’s focus on creating internal balance to cope with external and internal changes. In other words, Sufficiency Economy’s goal is to increase resilience, whereas, the Sufficiency Development’s emphasis is to reach a balanced development. Sufficiency Economy does not reject the need for a balanced development or progress *per se*, but they are seen as an effect of Sufficiency Economy and not as a goal in itself. This difference is subtle, as demonstrated by the unanimous agreement of interview respondents in Chapter 6 who thought that the two concepts were interchangeable. The subtle differences between these two philosophies is summarised in Figure E-2

<p>Sustainable Development</p> <p>A balanced development that takes into account environment, society, and economy</p>	<p>Sufficient Economy</p> <p>A balanced state, based on the Middle Path, moderation, reasonableness and self-immunity</p>
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Figure E-15 Sustainable Development and Sufficiency Economy

An example of how these subtle differences might be seen in practice is as follows. The focus of Thailand transport development over the past five decades has been intensely focused on its road-based infrastructure. Consequently, the nation's passenger and cargo movements are dominated by road transport. However, there has been a growing interest in rail transport, especially in high speed rail (HSR) projects over recent years. Four high-speed rail routes consisting of 1,400 kilometres tracks have been approved by the government as part of its infrastructure investment package worth 2,000 billion Baht (52.2 Billion Euro).

These developments are expected to reduce the nation's transport cost, its energy usage, the CO₂ emission, and the number of traffic accidents. Additionally, the HSR should provide a viable step to transform the nation toward oil independence. Moreover, the HSR development is considered as a key element to provide movement of goods and people between countries within the ASEAN Economic Community (AEC) and China as part of the Trans-Asian Railways network. However, the capital for this project will come solely from loans, most of which will be spent on importing technology and foreign know-how, because Thailand does not have the knowledge base or sufficiently skilled personnel who can support the development of HSR itself.

Although, the project itself will improve the sustainability of the country's transport system, it will take time to reach the state of self-sufficiency. In contrast, if Sufficiency Economy is the principle employed, the focus will be to utilise measures that increase the nation's balance state by enhancing the existing infrastructures, promoting non-motorised transport modes, and developing know-how on required technology for rail transport. The end-results maybe the same as the foregoing; however, the nation will always be in a balanced state with Sufficiency Economy.

Appendix: F MARS model concise descriptions

The fundamental principle of MARS is the qualitative analysis of transport systems using causal loop diagramming and sub-model diagrams. MARS can be divided into two sub-models at the highest level of aggregate: the transport and land use sub-models as shown in Figure F-1.

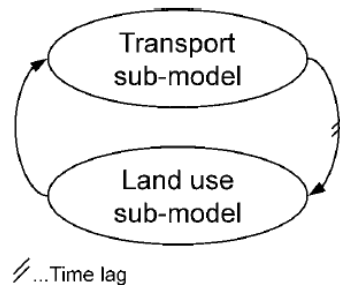


Figure F-16 MARS sub-models at the highest aggregate level

Source: (Pfaffenbichler, 2003, p. 49)

The connections between the two sub models are based on an assumption that changes in land use affect changes in transport, and *vice-versa*, although the effects of transport on land use changes are delayed.

Figure F-2 shows a more detailed level of MARS transport and land use sub-models.

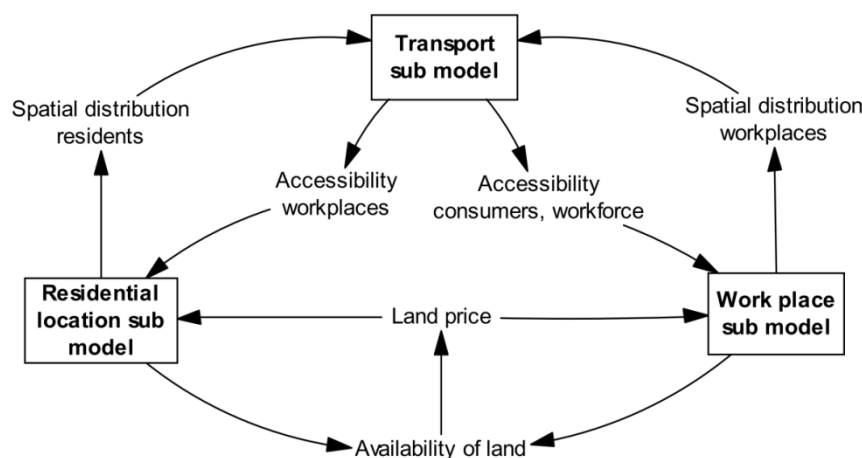


Figure F-17 MARS transport sub-model and two land use sub-models

Source: (Mayerthaler, 2009)

The land use sub-model is divided further into a residential and a work place location sub-model. The two sub-models compete for limited land and are connected by the availability of land and price. The spatial distributions of work places and residents are the land use sub-model's outputs into the transport sub-model. Levels of accessibility, a function of time taken to access work place or services, are the outputs from the transport sub-model into the land use sub-models. The number of work places and residencies and accessibility of the year t are used to calculate the work place distribution and accessibility for the year $t+1$ for each zone (See Section 7.17).

Transport sub-model

MARS transport sub-model is an aggregate model; it simplifies the transport connections between each zone into one link for each origin-destination (OD) pair. Consequently, the assignment or the route choice stage is omitted.

MARS considered two types of activities: Work and Others⁹⁸, which result in four origin-destination groups being considered in MARS:

- Home-Work (HW)
- Work-Home (WH)
- Home-Other (HO), and
- Other-Home (OH).

The tour-based concept used in MARS defines a tour as a simple round trip between home and destination. There are two different types of tours considered:

- Home-Work-Home (HWH), and
- Home-Others-Home (HOH).

It is thought that the two types of tours considered cover a sufficient percentage of daily mobility for the strategic nature of MARS⁹⁹. See (Pfaffenbichler, 2003, p. 50) for more information on the transport sub-model.

Land use sub-model

The land use sub-model contains two parts: residential and workplace location sub-models. Each part can be divided further into four sub-models: (1) a (building stock) development model, (2) a moving-out model, (3) a moving-in model, and (4) a redistribution model. ¹⁰⁰. See (Pfaffenbichler, 2003, p. 60) for more information on land use sub-model.

⁹⁸ The Other trip comprises of shopping and visiting relatives trip purposes

⁹⁹ The 1991 and 1995 mobility surveys in Vienna show that the two types of tours made up 58% (1991) and 71% (1995) of the daily trips (Pfaffenbichler, 2003).

¹⁰⁰ The 1991 and 1995 mobility surveys in Vienna show that the two types of tours made up 58% (1991) and 71% (1995) of the daily trips (Pfaffenbichler, 2003).

Friction factor and subjective valuation principles

The trip distribution and mode choice sub-model in MARS uses the friction factors for each mode and each OD pair to distribute the travel time available to all destination and all modes.

The friction factor is a sum of subjective travel time and subjective travel cost for each mode per each OD pair. The concept of subjective valuation used in MARS is based on (Walther, 1991), cited by (Pfaffenbichler, 2003)), which proposed that there are variations in levels of resistance in cost and time. These variations result from “fundamental subjective human attitude to these supply parameters”(Walther, 1991).

The travel time in MARS is weighted in relation to the time-evaluation functions, which follow linear functions for personal vehicles and exponential functions for public transport and non-motorised transport modes. The variations in travel cost resistances are dependent on the net household income. Walther (1991) utilised several actual observations from Germany to validate his results. see (Pfaffenbichler, 2003, p. 231) for details.

Walking and cycling trips

The friction factors for walking and bicycle trips are the subjective values of time only.

Public transport (PT) trips

For a public transport trip, five component parts are considered:

- Walking from the origin to the public transport stop or the point of embarkation (i-I)
- Waiting time at public transport stop (I)
- Public transport in-vehicle time between the boarding points and the disembarking points (I-ch and ch-J)
- Changing time, if any (ch)
- Walking from the disembarkation point to the final destination (J-j)

These components are depicted graphically by Pfaffenbichler (2003) in Figure F-3

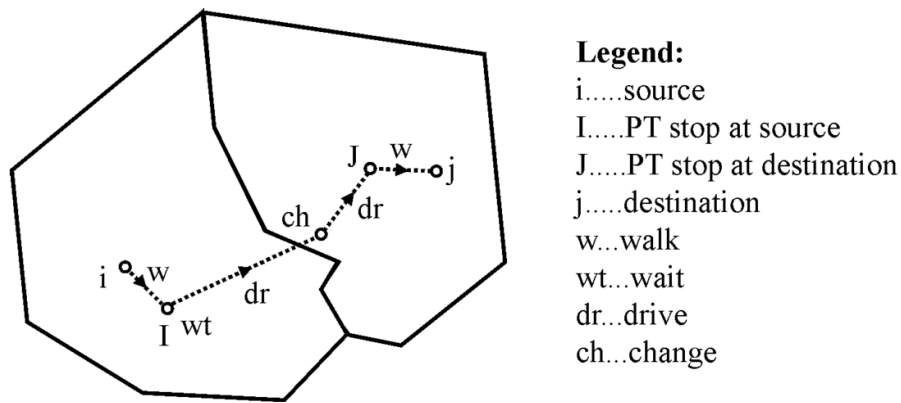


Figure F-18 Components of a public transport trip from origin i to destination j in MARS

Source: ((Walther et al., 1997, p. 20) cited by (Pfaffenbichler, 2003, p. 77))

Private vehicle trips

A private vehicle trip (made by car or motorcycle) can be divided into four different parts as follows:

- Walking from the origin to the vehicle parking place (i-I)
- Driving or in-vehicle part between the parking place and the destination (I-j)
- Searching for a parking space (j-J)
- Walking from the parking place to the destination (J-j)

These components are depicted graphically by Pfaffenbichler (2003) in Figure F-4

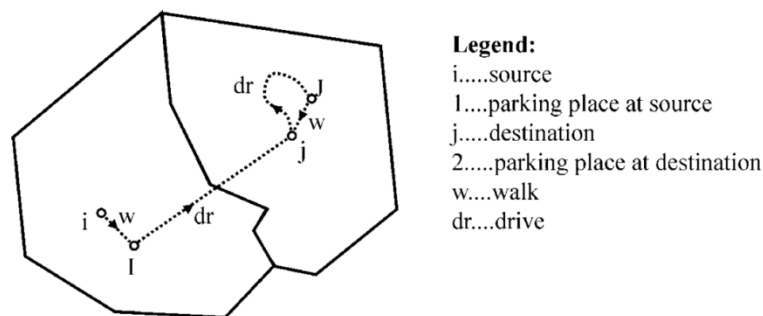


Figure F-19 Components of a public transport trip from origin i to destination j in MARS

Source: (Pfaffenbichler, 2003, p. 79)

Together with the constant total travel time budget (TTB), the subjective friction factors influence trip distribution and mode choice in MARS model. There are two components of the friction factors used in MARS, i.e. the cost and the time components. Each component is influenced by different factors, Table F-1 summaries the influences of the cost and time components of the friction factors for each mode.

Table F-1 Factors affecting cost and time components of the friction factors

Mode	Cost	Time
Private vehicle (PV)	<ul style="list-style-type: none"> • fuel costs • other operating costs • parking charges • road charges • (subjective assessment of willingness to pay within the context of household income) 	<ul style="list-style-type: none"> • walking time from origin • in-vehicle time • parking place search time • walking time from parking place to destination • (different subjective values for each trip stage)
Walking	<ul style="list-style-type: none"> • None 	<ul style="list-style-type: none"> • walking time (subjective)
Bicycle	<ul style="list-style-type: none"> • fixed cost (usually assume 0) 	<ul style="list-style-type: none"> • cycling time (subjective)
Public transport (PT)	<ul style="list-style-type: none"> • cost for PT trip between i and j • (subjective by value of time and household income) 	<ul style="list-style-type: none"> • walking time from origin • waiting time • in-vehicle time • changing time • walking time from parking place to destination • (different subjective values for each trip stage)

MARS's applications of the constant TTB assumption and the different subjective values for each trip imply that the total time spent on each trip remains constant at the macro scale. Therefore, to vary the time component part of the friction factor, the proportion of time allocated to different trip stages must be changed. This principle has been utilised in practice in the form of the Equi-distance parking organisation proposed by Knoflachner (1981).

Accessibility

Accessibility values are the outputs from the transport sub-model into the land use sub-model. They connect the interaction between the two sub-models. It is assumed that the accessibility of workplace is a function of the number of workplaces within a zone and the time taken to get to them during the peak period. A similar assumption is made for shop accessibility, which is a function of the number of shops within a zone and the time taken to get to them during off peak periods (using the assumption that non-work trips take place during non-peak periods).

Connection between subsystems in each iteration

The connection of the sub-models in each iteration are shown in Figure F-5

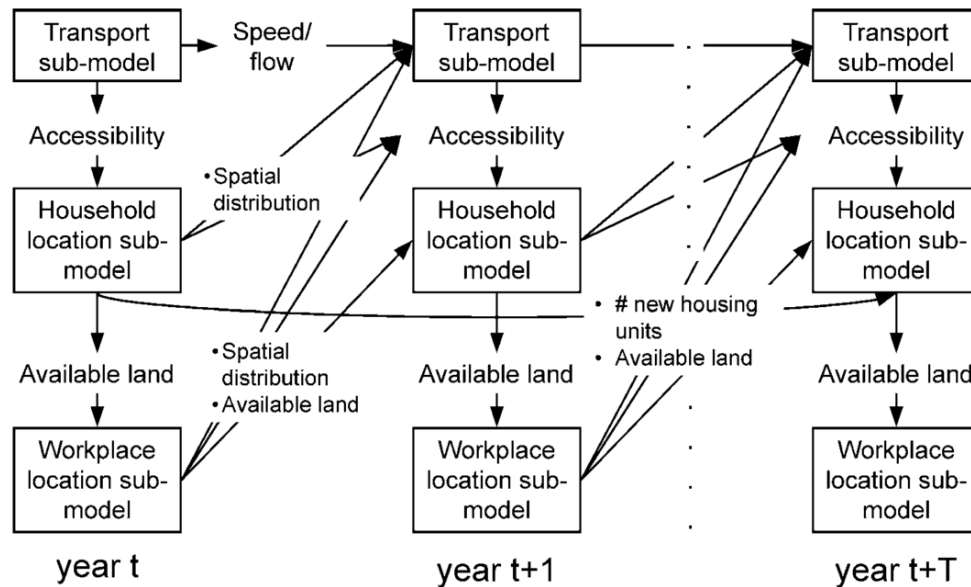


Figure F-20 Connection of MARS sub-models in different time steps

Source: (Pfaffenbichler, 2003, p. 71)

In each iteration the calculations within the Transport sub-model begin first. The output of the transport sub-model, Accessibility, is then input into the household location sub-model. The household location sub-model uses the accessibility for each zone to calculate land availability and feeds its output into the workplace location sub-model.

The following information is passed between the sub-models from each iteration to the next:

- The transport sub-model reports the speed flow calculation results over to the next iteration.
- The residential spatial distribution from the household location sub-model is passed to the transport sub-model and the household location sub-model of the next iteration.
- The numbers of new housing units developed are retained within the household location sub-model until the time lagged period $t+T$ when a particular number of housing units are ready.
- The work place spatial distribution and land availability information, from the work place location sub-model, are passed to the transport sub-model, the household location sub-model, and the workplace location sub-model of the next iteration.

Use of MARS model in strategic Land use and transport planning

MARS models have been used in various projects to simulate the development of land use and transport systems under various development policy frameworks, including policies to develop a sustainable transport system. It was the core of the PROSPECTS project (Procedures for

Recommending Optimal Sustainable Planning of European City Transport Systems), which sought to develop a strategic-level model that embedded a decision making process on land use and transport policies. Figure F-6 shows how MARS is embedded into transport and land use policy appraisal framework.

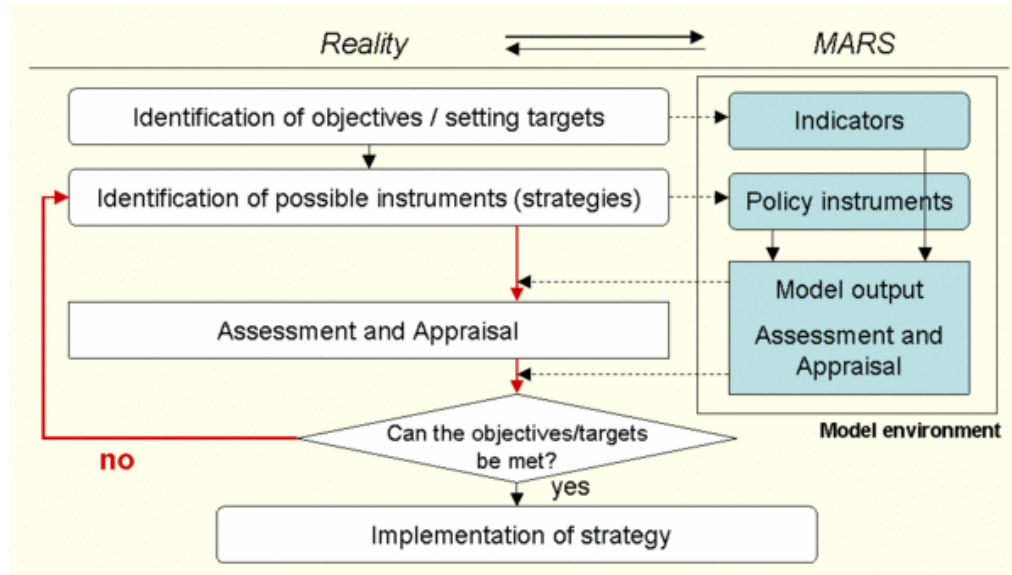


Figure F-21 Application of MARS in land use and transport policy appraisal framework

Source: <http://www.ivv.tuwien.ac.at/forschung/mars-metropolitan-activity-relocation-simulator/introduction-mars/decision-making-process.html>

MARS has the ability to simulate possible development paths of the study area under different policy instruments. The model inputs, such as the demographic transition and the vehicle ownership model, can be adjusted to replicate different background conditions of the study area. The policy instruments are other model inputs that can be altered to simulate desired land use and transport policies. The model outputs, such as generalised costs (in terms of monetary factors and time), kilometres travelled by different modes, and vehicular emissions, enables the policies to be evaluated quantitatively.

Appendix G: Fuel consumption and emission Equations

Emission (CO² g / km)

Car: $y = 0.0441x^2 - 5.363x + 279.51$

Motorcycle: $y = -0.0145x^2 - 0.6723x + 48.386$

Shared-taxi: $y = 0.1067x^2 - 10.197x + 389.62$

Bus: $y = 0.3942x^2 - 45.066x + 1820$

Fuel consumption (km/l)

Car: $y = -0.0033x^2 + 0.4436x + 6.1713$

Motorcycle: $y = 0.0053x^2 - 0.3948x + 43.298$

Shared-taxi: $y = -0.0057x^2 - 0.5335x + 4.1114$

Bus: $y = -0.0008x^2 + 0.1003x + 1.2905$

Appendix H: About the author



- Was born in Chiang Mai, Thailand 1981
- Master in Civil Engineering, University of Bristol, UK.
- Worked for leading engineering consultants in the UK for 7 years in the transport sectors
- Ph.D. Candidate at the TUW-IVV
- Researcher for Club of Vienna
- Assistant to Thailand's industrial permanent mission to Europe and a policy Analyst for the Office of Industrial Affairs, Thai Embassy in Vienna

Peraphan began his work in the transportation field as Highway Engineer with Mott McDonald, an international consulting firm in 2003. He transferred to Colin Buchanan, a consultant firm specialised in transportation in 2004, during which he acquired skills in traffic and transport engineering, transport modelling, and junction design. He was seconded to Transport for London (TfL) in 2007 to work on various projects such as the Parliament square improvement project. In 2009, he joined the Office of Transport and Traffic Policy and Planning, Thailand as a trainee for three months before began his Ph.D. study titled: Sustainable transport planning for Chiang Mai city, a system dynamic approach.

He worked for the Club of Vienna in 2013 as a researcher in urban growth and became an assistant to Thailand's industrial permanent mission. He attended together with the permanent mission, United Nations Industrial Development Organization (UNIDO) meetings, and reports their progresses to the capital. He writes reports on EU industrial sector and is the author of *kamanakom.wordpress.com*, a transport engineering resource blog in Thai.

Email: peeratop<at>gmail.com

Bibliography

- Abbas, K., & Bell, M. (1994). System dynamics applicability to transportation modeling. *Transportation Research Part A: Policy and Practice*, 28(5), 373–390. Retrieved from <http://www.sciencedirect.com/science/article/pii/0965856494900221>
- ADB. (2009). *Changing Course - A NEW Paradigm for Sustainable Urban Transport. Image* (Rochester, N.Y.) (Vol. 2010). 2008. Retrieved from http://sti-india-uttoolkit.adb.org/mod4/se5/006_2.html
- Adelaide City Council. (n.d.). Tindo factsheet, 2. Retrieved from http://www.adelaidecitycouncil.com/assets/acc/Environment/energy/docs/tindo_fact_sheet.pdf
- AECOM. (2010). *City of London Working Paper: Household Travel Survey 2030 Transportation Master Plan: SmartMoves*.
- Allen, A. (2009). Sustainable cities or sustainable urbanisation? *Palette UCL's Journal of Sustainable Cities*. Retrieved from <http://www.cnmd.ac.uk/sustainable-cities/results/gcsc-reports/allen.pdf>
- Altenergymag.com. (2012). Green Innovation - Fukuoka Hydrogen Town. Retrieved from <http://www.altenergymag.com/emagazine/2012/04/green-innovation?-fukuoka-hydrogen-town/1876>
- Annema, J. A., Hoen, A., & Turton, H. (2006). *Scientific Review of TREMOVE: A European Transport Policy Assessment Model* (pp. 1–35). Retrieved from <http://pblweb.prolocation.net/sites/default/files/cms/publicaties/500076003.pdf>
- Anusarnsoonton. (1902). Photo collection. (T. P. R. from U. intersection, Ed.). Chiang Mai.
- Aronson, D. (1996). Overview of systems thinking. *The Thinking Page*. Retrieved from http://resources21.org/cl/files/project264_5674/OverviewSTarticle.pdf
- Arunotong, P. (1991). *Application of Spatial Interaction Model in Chiang Mai, Thailand*. Asian Institute of Technology.
- Ayres, R., Bergh, J. van den, & Gowdy, J. (1998). Viewpoint: Weak versus strong sustainability. Retrieved from <http://people.deu.edu.tr/sedef.akgungor/ayres.pdf>
- Bacon, G. (1873). *Siam: The Land of the White Elephant, as it was and is*. Retrieved from <http://books.google.com/books?id=PbYXAAAAYAAJ>
- Bank of Thailand. (2013). National Economic Database. Retrieved from <http://www2.bot.or.th/statistics/ReportPage.aspx?reportID=409>
- Bates, J., Hensher, D., & Button, K. (2000). History of demand modelling. ... of *Transport Modelling*. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:History+of+demand+modelling#0>
- Batty, M., Besussi, E., & Chin, N. (2003). Traffic, urban growth and suburban sprawl. Retrieved from <http://eprints.ucl.ac.uk/216>

Bibliography

- Batty, S., Davoudi, S., & Layard, A. (2001). *Planning for a sustainable future* (p. 352). Routledge. Retrieved from http://books.google.com/books?hl=en&lr=&id=WaFEGUK3y4MC&oi=fnd&pg=PR7&dq=Planning+for+a+Sustainable+Future&ots=aQi4D6_A6m&sig=YBI8yYpSjPB9n_ReKqNh9f8ZVPM
- Bayly, M., Regan, M., & Hosking, S. (2006). *Intelligent transport systems and motorcycle safety* (pp. 1–9). Retrieved from <http://www-nrd.nhtsa.dot.gov/pdf/esv/esv20/07-0301-O.pdf>
- Beckerman, W. (1994). "Sustainable development": is it a useful concept? *Environmental Values*. Retrieved from <http://www.jstor.org/stable/10.2307/30301447>
- Black, W. (1996). Sustainable transportation: a US perspective. *Journal of Transport Geography*, 6923(96). Retrieved from <http://www.sciencedirect.com/science/article/pii/0966692396000208>
- Black, W. (2010). *Sustainable transportation: problems and solutions*. Retrieved from <http://books.google.com/books?hl=en&lr=&id=ijc9SlvmZDUC&oi=fnd&pg=PA3&dq=Sustainable+Transportation:+Problems+and+Solutions&ots=OGqXV4a8lz&sig=HWsEDQIMt1sIJCWJeoOjYGfpilQ>
- Blackmon, D. (2014). Dr. Morris Adelman And Peak Oil Theory. Retrieved December 01, 2014, from <http://www.forbes.com/sites/davidblackmon/2014/06/10/dr-morris-adelman-and-peak-oil-theory/>
- Boarnet, M., & Sarmiento, S. (1998). Can land-use policy really affect travel behaviour? A study of the link between non-work travel and land-use characteristics. *Urban Studies*. Retrieved from <http://usj.sagepub.com/content/35/7/1155.short>
- Borisutthiyangkun, T. (2006). *Feasibility of solving traffic problems in Chiang Mai Municipality by bus system*. Chiang Mai University. Retrieved from http://library.cmu.ac.th/digital_collection/etheses/fulltext.php?id=16143
- Bowring, J. (1857). *The Kingdom and People of Siam: With a Narrative of the Mission to that Country in 1855*. J. W. Parker. Retrieved from <http://books.google.com/books?id=NskoAAAAYAAJ>
- Brody, S. (2013). The characteristics, causes, and consequences of sprawling development patterns in the United States. *Nature Educ Knowl*. Retrieved from <http://www.nature.com/scitable/knowledge/library/the-characteristics-causes-and-consequences-of-sprawling-103014747>
- Broughton, P., & Stradling, S. (2005). Why ride powered two wheelers. *Behavioural Research in Road Safety* 2005, ..., (November). Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.127.3045&rep=rep1&type=pdf#page=68>
- Bureau of Transport Statistics. (2012). 2010 / 11 Household Travel Survey Key Indicators for Sydney, 2010–2013.
- Campbell, C., & Laherrère, J. (1998). The end of cheap oil. *Scientific American*, March 1998(March). Retrieved from http://www.sciamdigital.com/gsp_qpdf.cfm?ISSUEID_CHAR=E5F23461-5B81-4D02-A413-2EA7A6AAC7A&ARTICLEID_CHAR=C316E8E5-706F-41A4-9CF1-060B7E7B8F9

Bibliography

- Carson, R. (1960). *Silence spring. Athens, Greece: Kaktos Publishing*. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Silence+Spring#3>
- CDIA. (2011). Informal public transportation networks in three indonesian cities, (June).
- Chansri, K. (1994). *Traffic in Chiang Mai Municipality: Problems and Guidelines for Solution*. Chiang Mai University. Retrieved from http://library.cmu.ac.th/digital_collection/etheses/fulltext.php?id=2354#
- Charoenmuang, D. (2007). Sustainable Cities in Chiang Mai: A Case of a City in a Valley, 690. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Sustainable+Cities+in+Chiang+Mai:+A+case+of+a+city+in+a+valley#1>
- Charoenmuang, D. (2009a). *Climate change and transportation sector* (p. 230). Chiang Mai: Chiang mai sang sin.
- Charoenmuang, D. (2009b). *ผังเมืองเชียงใหม่เป็นมาอย่างไร*. Retrieved from www.oknation.net/blog/print.php?id=477500
- Charoenmuang, T. (1986). *700 year Chiang Mai*. Chiang Mai: กรุงเทพฯ : อักษรสยามการพิมพ์, 2529.
- Cherry, C. (2007). Electric two-wheelers in China: analysis of environmental, safety, and mobility impacts. Retrieved from http://web.utk.edu/~cherry/Site/Publications/full_dissertation-ITS-Copy.pdf
- Cherry, C. (2013). Electric bikes: what experiences in China can tell us. *The Guardian*. Retrieved from <http://www.theguardian.com/local-government-network/2013/nov/20/lessons-electric-bikes-china>
- Chiang Mai Municipality. (2011). *แผนยุทธศาสตร์การพัฒนาศาสนาและวัฒนธรรมเชียงใหม่(2554-2558)*. Retrieved from <http://www.cmcity.go.th/Plan+Strategy/Strategy54.php>
- Chiang Mai Province. (2010). *สรุปสาระสำคัญแผนพัฒนาจังหวัดเชียงใหม่ 4 ปี(พ.ศ.2554-2557)*. Retrieved from <http://www.chiangmai.go.th/upfiles/1640f8ffbc.pdf>
- Choovuthayakorn, C. (2005). *Model of trip production and attraction using landuse GIS*. Chiang Mai University.
- Chuanchuen, N. (1996). *Attitudes of Chiang Mai People toward Public Transportation System*. Chiang Mai University. Retrieved from <http://www.sri.cmu.ac.th/~transportation/show-details.php?type=research&id=11>
- City of Vienna. (2013). *Vienna in Figures 2013*.
- Clements, T. (2011). Transportation and Housing Costs. *Policy*, (January), 2010–2011. Retrieved from https://www.tfhr.gov/livability/fact_sheets/transandhousing.pdf
- CM-DLT. (2012a). CM-DLT History. Retrieved from www.chiangmaidltd.go.th/main.php

Bibliography

- CM-DLT. (2012b). Department of Land Transport , Chiang Mai statistic. Retrieved from http://apps.dlt.go.th/statistics_web/statistics.html
- CMNews. (2012). CM-DLT organised shared taxi route. *CM.News*, p. 1. Chiang Mai. Retrieved from <http://www.chiangmainews.co.th/page/?p=136396>
- CMnews. (2012). กรม.ยิ่งลักษณ์ สัญจร เชียงใหม่ ผ่าน 128 โครงการ 3.87 แสนล้าน (ตอนที่ 1). Chiang Mai. Retrieved from <http://www.chiangmainews.co.th/page/?p=66921>
- CMU. (2012a). *Pilot project to organise Red car route to improve energy efficientcy in Chiang Mai city*. Chiang Mai.
- CMU. (2012b). *Pilot study project to manage Song Teaw of Chiang Mai to improve energy efficiency*. Chiang Mai.
- Corkindale, J. (2011). Fifty Years of the Town and Country Planning Acts. *Iea.org.uk*, (11). Retrieved from <http://www.iea.org.uk/sites/default/files/publications/files/upldbook383pdf.pdf>
- Crane, R., & Crepeau, R. (1998). Does neighborhood design influence travel?: A behavioral analysis of travel diary and GIS data. *Transportation Research Part D: Transport and ...*, 3(4), 225–238. doi:Doi: 10.1016/s1361-9209(98)00001-7
- Daishonin, N. (1999). *The Writings of Nichiren Daishonin, volumn 1*. Tokyo: Soka Gakkai. Soka Gakkai. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+Writings+of+Nichiren+Daishonin#0>
- Damrikul, S. (2012). Doi Suthep and Chiang Mai city plan. *Faculty of Fine Arts, Chiangmai University*.
- De Ceuster, G., Herbruggen, B. van, Ivanova, O., Carlier, K., Martino, A., & Fiorello, D. (2007). TREMOVE, Service contract for the further development and application of the transport and environmental TREMOVE model Lot 1 (Improvement of the data set and model structure) - Final report, 1(16).
- Department for Transport. (2005). Transport Analysis Guidance (TAG): Land-Use / Transport Interaction Models TAG Unit 3.1.3, (June). Retrieved from www.webtag.org.uk
- Dictionary.com. (2012a). problem. Retrieved from <http://dictionary.reference.com/browse/problem>
- Dictionary.com. (2012b). transport. Retrieved from <http://dictionary.reference.com/browse/transport>
- DOE. (1988). *A Perspective by the United Kingdom on the Report of the World Commission on Environment and Development*. London.
- Droege, P. (2010). 100% Renewable Energy and Beyond for Cities. Retrieved from http://opus.kobv.de/zlb/texte_eingeschraenkt/2011/11743/
- EC. (2010). "Sustainable development indicators introduced" - Statistics Explained. Retrieved from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Sustainable_development_indicators_introduced#

Bibliography

- EC. (2012). TREMOVE: an EU-wide transport model. Retrieved April 16, 2013, from <http://ec.europa.eu/environment/air/pollutants/models/tremove.htm>
- Emberger, G. (2009). Sustainable Transport - and how structure influences behaviour. In *International Symposium on Transport Planning and influence of climate change*. Ho Chi Minh City, VN.
- ERSO. (2011). Traffic Safety Basic Facts 2011, 1–20.
- EXAT. (1997). *Feasibility study for the master plan of the mass transit system in Chiang Mai*.
- Forrester, J. (1961). *Industrial dynamics*. Retrieved from <http://en.scientificcommons.org/37518962>
- Geurs, K., & Wee, B. van. (2004a). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, 12(2), 127–140. doi:10.1016/j.jtrangeo.2003.10.005
- Geurs, K., & Wee, B. Van. (2004b). Land-use/transport interaction models as tools for sustainability impact assessment of transport investments: review and research perspectives. ... *of Transport and Infrastructure Research*. Retrieved from http://www.ejtir.tudelft.nl/issues/2004_03/pdf/2004_03_05.pdf
- GIZ. (2009). *Clean Air for Smaller Cities in the ASEAN Region: Chiang Mai city*.
- Glaeser, E., & Kahn, M. (2004). Sprawl and urban growth. *Handbook of Regional and Urban Economics, IV*. Retrieved from <http://www.sciencedirect.com/science/article/pii/S1574008004800130>
- Greene, D. L., & Wegener, M. (1997). Sustainable transport. *Journal of Transport Geography*, 5(3), 177–190. doi:10.1016/S0966-6923(97)00013-6
- Hansen, R., & Kahne, S. (1975). A transportation ecology model-Conceptual developments. *Systems, Man and Cybernetics, IEEE* Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5408469
- Hansen, W. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners*. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/01944365908978307>
- Hardin, G. (1968). The Tragedy of the Commons. *Journal of Natural Resources Policy Research*. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/19390450903037302>
- Harris, R. (2002). Creative thinking techniques. *Creative Problem Solving: Creative Thinking*, 1–12. Retrieved from http://idsa.sjsu.edu/Archive documents/Creative_Thinking_Techniques.pdf
- Hassapak, W. (1997). *Relationship between outer and inner city wall of Chiang Mai, a study*. Silpakorn University.
- Haworth, N. (2012). Powered two wheelers in a changing world—Challenges and opportunities. *Accident Analysis & Prevention*, 44(1), 12–18. doi:10.1016/j.aap.2010.10.031
- Hayashi, Y., Doi, K., Yagishita, M., & Kuwata, M. (2004). Urban transport sustainability: Asian trends, problems and policy practices. ... *Journal of Transport and* Retrieved from http://www.ejtir.tudelft.nl/issues/2004_01/pdf/2004_01_02.pdf

Bibliography

- Hazel, G. (1989). The estimation and effect of new transferred and pass-by private car trips to retail centres. *PLANNING AND TRANSPORT RESEARCH AND* Retrieved from <http://trid.trb.org/view.aspx?id=334716>
- Hensher, D., Stopher, P., Bullock, P., & Ton, T. (2004). TRESIS (transport and Environmental Strategy Impact Simulator): Application to a Case Study in NE Sydney. *Institute of Transport Studies* Retrieved from <http://trid.trb.org/view.aspx?id=704828>
- Hensher, D., & Ton, T. (2002). TRESIS: A transportation, land use and environmental strategy impact simulator for urban areas. *Transportation.* Retrieved from <http://link.springer.com/article/10.1023/A:1016335814417>
- HK Transport department. (2002). *Hong Kong Travel survey.*
- HSRI. (2003). *A study for health impact assessment: a case study of city and transport development of Chiang Mai* (Vol. 1). Chiang Mai. Retrieved from <http://hdl.handle.net/123456789/1405>
- Hsu, T., Sadullah, E., & Dao, I. (2003). A comparison study on motorcycle traffic development in some Asian countries—case of Taiwan, Malaysia and Vietnam, (October). Retrieved from <http://www.easts.info/activities/icra/2001/ICRA-ComparisonStudyMotorcycleDevelopment.pdf>
- Hussain, H., Umar, R., Sohadi, R., Farhan, A., & Dadang, M. (2005). Key components of a motorcycle traffic system: A study along the Motorcycle Path in Malaysia. *IATSS Research.* Retrieved from [http://www.safetylit.org/citations/index.php?fuseaction=citations.viewdetails&citationIds\[\]=citjo_urnalarticle_20582_19](http://www.safetylit.org/citations/index.php?fuseaction=citations.viewdetails&citationIds[]=citjo_urnalarticle_20582_19)
- Hyodo, T., & Montalbo, C. (2005). Urban travel behavior characteristics of 13 cities based on household interview survey data. *Journal of the Eastern ...*, 6, 23–38. Retrieved from http://www.easts.info/on-line/journal_06/23.pdf
- IEA. (2013). *World Energy Outlook Special Report 2013:Southeast Asia Energy Outlook.* Retrieved from http://www.iea.org/publications/freepublications/publication/WEO_Special_Report_2013_South_east_Asia_Energy_Outlook_Executive_Summary.pdf
- IET. (2010). *Rebound - Unintended consequences from transport policies and technology innovations.*
- Intapun, S. (1994). *Impact of Vehicle Increase on Chiang Mai city's traffic.* Chiang Mai University. Retrieved from http://library.cmu.ac.th/digital_collection/etheses/fulltext.php?id=2531
- Isarangkun, C., & Pootrakool, K. (2007). Sustainable economic development through the sufficiency economy philosophy. *National Institute of Development* Retrieved from <http://v-reform.org/wp-content/uploads/2012/06/SUSTAINABLE-ECONOMIC-DEVELOPMENT.pdf>
- Jankao, S. (2008). เมื่อทักษิณทำผิดทักทายความซัดจึงบังเกิด. Retrieved from www.thaingo.org/cgi-bin/content/content2/show.pl?0399
- JICA. (2002). *The study on improvement of road traffic environment in Chiang Mai City in the Kingdom of Thailand : final report* (Vol. 02–120, p. 1 v. (various pagings) ; 30 cm).
- Jindawattananon, C., & Pradipasen, W. (2009). *Non-Motorized and Public Transport Development Plan in the Urban Area Chiangmai, Thailand* (Vol. Lund Unive).

Bibliography

- Jittrapirom, P. (2009). SUSTAINABLE TRANSPORT SYSTEM AND PARKING ORGANIZATION: A CASE STUDY OF BANGKOK'S PARKING STANDARD. *ATRANS RESEARCH*, 1–10. Retrieved from <http://www.atransociety.com/2012/pdf/pdfjournal/ATRANS-journal-2010-11411.PDF#page=58>
- Jittrapirom, P., & Emberger, G. (2011). Off-street residential parking organisation – a review of current practices. In *EAST 2011* (Vol. 8).
- Jittrapirom, P., & Emberger, G. (2013). *Chiang Mai city Mobility and Transport Survey* (p. 155). Retrieved from <http://www.ivv.tuwien.ac.at/forschung/projekte/international-projects/cm-mts.html>
- Johnston, R., & McCoy, M. (2006). Assessment of integrated transportation/land use models. ... and Policy, University of California Davis. Retrieved from http://www.caltrans.ca.gov/research/researchreports/reports/2008/final_report_assement_of_integrated_transportation_land_use_models.pdf
- Kakizaki, I. (2013). *Rails of the Kingdom: History of Thai Railways* (p. 214 pages). White Lotus Co Ltd.
- Kelly, C. (2005). Origins of Sustainability. Report for Task. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Origins+of+Sustainability#4>
- Kenworthy, J., & Laube, F. (1999). Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy. *Transportation Research Part A: Policy and ...*, Transporta. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0965856499000063>
- Kepaptsoglou, K., & Milioti, C. (2011). An Empirical Investigation of Motorcycle Ownership and Usage. *T&DI Congress 2011*, 1075–1084. Retrieved from [http://ascelibrary.org/doi/pdf/10.1061/41167\(398\)103](http://ascelibrary.org/doi/pdf/10.1061/41167(398)103)
- Kheawsanun, C. (2004). *Towards the promotion of mass transportation in inner city: case study on trip behaviour of private car users in Silom Business Area*. King Mongkut's Institute of Technology Ladkrabang.
- Khuat, V. (2007). Traffic management in motorcycle dependent cities. Retrieved from http://tuprints.ulb.tu-darmstadt.de/epda/000767/Dissertation_main_report.pdf
- Kindergan, A. (2014, October). Oil Slick: Slip-Sliding Prices. *The Financialist*. Retrieved from <https://www.thefinancialist.com/oil-slick-slip-sliding-prices/>
- Kirby, R., Bhatt, K., Kemp, M., McGillivray, R., & Wohl, M. (1974). Para Transit: Neglected Options for Urban Mobility. Retrieved from <http://trid.trb.org/view.aspx?id=134916>
- Knoflacher, H. (1981). Human energy expenditure in different modes: implications for town planning. *International Symposium on Surface Transportation ...*, 1. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Human+Energy+expenditure+in+different+modes:+Implication+for+town+planning#0>
- Knoflacher, H. (1987). *Verkehrsplanung für den Menschen*. Wien: Wirtschaftsverlag Dr. Anton Orac.

Bibliography

- Knoflacher, H. (2003). A new parking organisation: the key for a successful sustainable city of the future. *The 11th European Parking Congress, London*, 1–21. Retrieved from http://www.ivv.tuwien.ac.at/fileadmin/mediapool-verkehrsplanung/Bilder/Forschung/2003_2.pdf
- Knoflacher, H. (2006). A new way to organize parking: the key to a successful sustainable transport system for the future. *Environment and Urbanization*, 18(2), 387–400. doi:10.1177/0956247806069621
- Knoflacher, H. (2013). *Virus Auto: die Geschichte einer Zerstörung*. Retrieved from [http://kfb.graz-seckau.at/upload/file/AUTOVIRUS_von_Hermann_Knoflacher_Rezension_Oekonews_doc-43\(2\).PDF](http://kfb.graz-seckau.at/upload/file/AUTOVIRUS_von_Hermann_Knoflacher_Rezension_Oekonews_doc-43(2).PDF)
- Kodmhai.com. (2012). พระราชบัญญัติ คณะกรรมการจัดระบบการจราจรทางบก (ฉบับที่ 2) พ.ศ. 2535. Retrieved December 20, 2012, from <http://www.kodmhai.com/m4/m4-2/Nthailaw4-2/N823.html>
- Kongboontiam, P. (2010). *AN INTEGRATED SYSTEM DYNMAIC MODEL FOR TRANSPORTATION ENERGY PLANNING AND MANAGEMENT IN REGIONAL AREA OF THAILAND*. Chiang Mai University.
- Kongboontiam, P., & Udomsri, R. (2009). A System Dynamic Model of Transportation Energy Consumption in Regional City of Thailand : A Case Study of Chiang Mai Urban Area. In *National Civil Engineering Conference, Thailand*. Nakorn Rachasrima: Suranaree University.
- Kwasniewski, L., & Bojanowski, C. (2009). Crash and safety assessment program for paratransit buses. *International Journal of ...* Retrieved from <http://www.sciencedirect.com/science/article/pii/S0734743X0800119X>
- Lautso, K., & Spiekermann, K. (2004). Planning and research of policies for land use and transport for increasing urban sustainability. *Final Report, LT* Retrieved from http://www.timo-flieger.de/projekte/irpud/PROPOLIS_Abstract_Summary.pdf
- Lawson, C. (2007). Household Travel Survey Research.
- Lee, E. (1989). Planning and control of paratransit services in Hong Kong. *Transport Reviews*, 9(4), 279–303. doi:10.1080/01441648908716731
- Lee, T., Polak, J., & Bell, M. (2009). New approach to modeling mixed traffic containing motorcycles in urban areas. *Transportation Research Record: ...*, 2140(-1), 195–205. Retrieved from <http://trb.metapress.com/index/C92Q8180456K4841.pdf>
- Lele, S. (1991). Sustainable development: a critical review. *World Development*, 19(6), 607–621. doi:10.1016/0305-750x(91)90197-p
- Lin, J.-J., & Yang, a.-T. (2009). Structural Analysis of How Urban Form Impacts Travel Demand: Evidence from Taipei. *Urban Studies*, 46(9), 1951–1967. doi:10.1177/0042098009106017
- Litman, T., & Burwell, D. (2006). Issues in sustainable transportation. ... *Journal of Global Environmental Issues*, 6(4), 331–347. Retrieved from <http://inderscience.metapress.com/index/A7M314BU3RTE2CB4.pdf>

Bibliography

- Liu, B., Ivers, R., & Norton, R. (2008). Helmets for preventing injury in motorcycle riders. ... *Database Syst Rev*, (1), 1–3. doi:10.1002/14651858.CD004333.pub3. Copyright
- Liu, S., Li, X., & Zhang, M. (2003). Scenario analysis on urbanization and rural-urban migration in China. ... *Institute for Applied Systems Analysis*, Retrieved from <http://webarchive.iiasa.ac.at/Publications/Documents/IR-03-036.pdf>
- Lowry, I. (1964). A model of metropolis. Retrieved from <http://www.rand.org/cgi-bin/Abstracts/e-getabbydoc.pl?RM-4035>
- Lukaszewicz, R. (n.d.). *System Dynamics as a Realization of the Systems Approach*. Retrieved from <http://systemdynamics.org/dynamica/articles/31/4.pdf>
- May, A., Karlstrom, A., Marler, N., & Matthews, B. (2003). Developing Sustainable Urban Land Use and Transport Strategies-A Decision Makers' Guidebook. *Institute for Transport* Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Developing+Sustainable+Urban+Land+Use+and+Transport+strategies+-+A+Decision+Makers'+Guidebook#0>
- May, A., & Minken, H. (2003). Developing Sustainable Urban Land Use and Transport Strategies: A Methodological Guidebook. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Developing+Sustainable+urban+land+use+and+transport+strategies+a+methodological+guide+book#1>
- Mayerthaler, A. (2009). A land-use/transport interaction model for Austria. *Proceedings of the 27th ...*, 1–22. Retrieved from <http://www.systemdynamics.org/conferences/2009/proceed/papers/P1239.pdf>
- McNally, M. (2000). The four-step model. *Handbook of Transport Modelling*. Retrieved from <http://books.google.com/books?hl=en&lr=&id=tbbAS0GxcNUC&oi=fnd&pg=PA35&dq=The+Four+Step+Model&ots=clf1xwQ2pq&sig=hK4HT4VNLIHadFz5ysOSPxTjfw4>
- Meadows, D. (2012). It Is Too Late For Sustainable Development. Retrieved November 30, 2014, from <http://energyskeptic.com/2014/dennis-meadows-collapse-is-inevitable-now-2015-2020/>
- Meadows, D., Meadows, D., Jørgen Randers, & Behrens, W. (1972). *The Limits to Growth. Handbook of the Sociology of Education* (p. 205). Universe Books.
- Melosi, M. (2004). The automobile shapes the city. *Automobile in American Life and Society*. Retrieved from <http://schoolwires.henry.k12.ga.us/cms/lib/GA01000549/Centricity/ModuleInstance/47301/The+Automobile+Shapes+The+City.docx>
- Miller, E., Kriger, D., & Hunt, J. (1998). TCRP Web Document 9: Integrated urban models for simulation of transit and land-use policies: Final report. *University of Toronto Joint Program in Transportation* Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Integrated+Urban+Models+for+Simulation+of+Transit+and+Land-Use+Policies,+Final+Report#1>

Bibliography

- Minh, C., Sano, K., & Matsumoto, S. (2006). MODELS OF MOTORCYCLE DECELERATION BEHAVIOR AT SIGNALIZED INTERSECTIONS. *Infrastructure Planning*, 23(4), 927–936. Retrieved from <http://infra.nagaokaut.ac.jp/members/sano/paper/MC>
- Ministry of Transport. (2007). *Transport for Thailand's sustainable development (Sustainable Transport White paper)*. Bangkok, Thailand. Retrieved from <http://portal.mot.go.th/images/White Paper En.pdf>
- Mokhtarian, P., & Chen, C. (2004). TTB or not TTB, that is the question: a review and analysis of the empirical literature on travel time (and money) budgets. *Transportation Research Part A: Policy and ...*, 38(9-10), 643–675. doi:10.1016/j.tra.2003.12.004
- Morichi, S., & Acharya, S. (2012). Transport development in asian megacities. doi:10.1007/978-3-642-29743-4
- Mruk. (2011). *Southampton City Council Travel Survey Report*.
- na Chiangmai, S. (1995). *Trade Centers and Trade Routes in Lanna 1296-1899*. University of Chiang Mai.
- Namwong, O. (2002). *Occupational group formation in Tricycle's Pedal for ecotourism at Mueang District, Chiang Mai Province*. Chiang Mai University.
- Neis, P., & Burnand, E. (1880). Voyage dans le haut Laos. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Voyage+dans+le+haut+Laos#0>
- Nernhard, A. (2009). *Chiang Mai 2512 (1969)*. Chiang Mai: Nopburi Publishing.
- Nernhard, A. (2010). History of Chiang Mai. Retrieved from <http://www.thainews70.com/index-culture-arnu.php>
- NESDB. (2004). *Sustainable development index for Thailand project, final report*. Bangkok, Thailand.
- NESDB. (2007). *Sufficiency economy Implications and Application*. Bangkok, Thailand: Sufficiency Economy Movement Sub-committee. Retrieved from <http://www.jstor.org/stable/10.2307/25773806>
- NESDB. (2009). *Shadow population in Rayong area report*.
- NESDB. (2010). 60 year NESDB. Retrieved from <http://www.nesdb.go.th/Md/book/60yNESDB.zip>
- Newman, P., & Kenworthy, J. (1991). Transport and urban form in thirty-two of the world's principal cities. *Transport Reviews*, 11(3), 249–272. doi:10.1080/01441649108716787
- Newman, P., & Kenworthy, J. (1996). The land use—transport connection: An overview. *Land Use Policy*, 13(1), 1–22. doi:10.1016/0264-8377(95)00027-5
- Newman, P., Kenworthy, J., & Vintila, P. (1995). Can we overcome automobile dependence?: Physical planning in an age of urban cynicism. *Cities*, 12(1). Retrieved from <http://www.sciencedirect.com/science/article/pii/026427519591865D>

Bibliography

- Nguyen-Hoang, P., & Yeung, R. (2010). What is paratransit worth? *Transportation Research Part A: Policy and ...*. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0965856410001278>
- Nielsen, G. (2009). Indicators for sustainable urban transport – state of the art, (0349).
- Nimnual, S., Srisakda, L., & Satayopas, B. (1980). *Studies of Traffic Volumes and Travel Speeds*. Chiang Mai University.
- Noordzij, C., Forke, E., Brendicke, R., & Chinn, P. (2001). Integration of needs of moped and motorcycle riders into safety measures.
- NuStats. (2003). *St. Louis Metropolitan Area Household Travel Survey*.
- NuStats. (2004). *KANSAS CITY REGIONAL HOUSEHOLD TRAVEL SURVEY, Final Report* (Vol. 78746).
- NuStats. (2008). *2008 East Tennessee Household Travel Survey Final Report*.
- OCMLT. (2002). *Traffic and transport master plan for Chiang Mai city, 2nd revision*.
- OCMRT. (1994). *Master Plan for the Management of Traffic in the City of Chiang Mai, Revision 1*. Chiang Mai.
- OECD. (1974). Urban traffic models: possibilities for simplification: a report. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Urban+traffic+models:+possibilities+for+simplification#8>
- Olubomehin, O. (2012). The development and impact of motorcycles as means of commercial transportation in Nigeria. *Research on Humanities and Social Sciences*. Retrieved from <http://iiste.org/Journals/index.php/RHSS/article/view/2395>
- Orski, C. (1975). Paratransit: the coming of age of a transportation concept. *Transportation*. Retrieved from <http://www.springerlink.com/index/J374N15208563111.pdf>
- OTP. (2005). *Transport Master plan for Chiang Mai city, a regional aviation hub of the northern region*.
- OTP. (2006). *Master plan for Chiang Mai mass transit system project, Final report*.
- OTP. (2012). Walkability index survey of Chiang Mai city centre. Retrieved from <http://demo.artiligent.com/GreenTransport/Front/News/NewsDetail.aspx?rid=13&CatId=11>
- Pantamit, N. (2000). *The Demand for A Mass Transit System in Chiang Mai Municipality*. Chiang Mai University.
- Panyasan, J. (2003). *Development Potential of Public Transportation System in Chiang Mai Municipality*. Chiang Mai University. Retrieved from <http://www.sri.cmu.ac.th/~transportation/show-details.php?type=research&id=13>
- Patiphantharkarn, P. (2007). *Mass Transit System Preference for Chiang Mai city*. King Mongkut's Institute of Technology Ladkrabang.

Bibliography

- Peperna, O. (1982). *Die Einzugsbereiche von Haltestellen öffentlicher Nahverkehrsmittel im Straßenbahn- und Busverkehr*. Vienna University of Technology.
- Pfaffenbichler, P. (2003). *The strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Activity Relocation Simulator) - Development, testing and application. Beiträge zu einer ökologisch und sozial verträglichen Verkehrsplanung* (Vol. PhD). Vienna: Vienna University of Technology. Retrieved from http://www.ivv.tuwien.ac.at/fileadmin/mediapool-verkehrsplanung/Diverse/Forschung/Publikationen/Online/MARS_smallest_size.pdf
- Pfaffenbichler, P., & Circella, G. (2009). The role of motorized 2-wheelers in an energy efficient transport system, 1345–1354.
- Pinch, P., & Reimer, S. (2012). Moto-mobilities: Geographies of the Motorcycle and Motorcyclists. *Mobilities*, 7(3), 439–457. doi:10.1080/17450101.2012.659466
- Pintapun, W. (2002). *Comparison of Concrete Pavement and Asphalt Concrete Pavement for Highway Design in Thailand*. Kasetsart University, Thailand.
- Pongthanaisawan, J. (2003). *Travel Demand Model of Urban, Suburban, and Rural Residents in Chiang Mai Town Planning Area*. Chiang Mai University. Retrieved from http://library.cmu.ac.th/digital_collection/etheses/fulltext.php?id=10307#
- Prabnasak, J., & Taylor, M. (n.d.). STUDY ON MODE CHOICE AND VEHICLE OWNERSHIP IN A MEDIUM-SIZED ASIAN CITY, 1–12.
- Prachakitkornrajak, P. (1961). *Yonok Annals*. (ฉบับหอสมุดแห่งชาติพงศาวดารโยนก, Ed.). Bangkok: Silapabunnakran.
- Prachatham.com. (2012). เชียงใหม่เปิดตัว สื่อแสดงประจําทางนําร่อง3เส้นทาง 10-15บาทตลอดสาย. *Prachatham.com*. Chiang Mai. Retrieved from http://www.prachatham.com/detail.htm?dataid=9441&code=n6_05112012_01&mode=th
- Prathumthip, M. (2002). *Interaction Modelling of Transportation and Land use in Chiang Mai city*. Chiang Mai University. Retrieved from http://library.cmu.ac.th/digital_collection/etheses/fulltext.php?id=8827#
- Richardson, G. (2011). Reflections on the foundations of system dynamics. *System Dynamics Review*, 27(3), 219–243. doi:10.1002/sdr
- Rimmer, P. J. (1984). THE ROLE OF PARATRANSIT IN SOUTHEAST ASIAN CITIES. *Singapore Journal of Tropical Geography*, 5(1), 45–62. doi:10.1111/j.1467-9493.1984.tb00145.x
- Rodrigue, J.-P. et al. (2012). The Geography of Transport Systems. Retrieved from <http://people.hofstra.edu/geotrans>
- Roess, R. (2011a). Speed-Flow Curves for Freeways in the 2010 HCM. *90th Annual Meeting of the Transportation Research Board*, (July 2010). Retrieved from <ftp://ftp.hsrc.unc.edu/pub/TRB2011/data/papers/11-0543.pdf>

Bibliography

- Roess, R. (2011b). Speed-Flow Curves for Freeways in the HCM: A Historical Perspective. *90th Annual Meeting of the TRB*, (718). Retrieved from <ftp://ftp.hsrc.unc.edu/pub/TRB2011/data/papers/11-0542.pdf>
- Roger, N. (2008). *Trends in Motorcycles Fleet Worldwide*. Retrieved from <http://www.internationaltransportforum.org/jtrc/safety/Lillehammer2008/Lillehammer08Rogers.pdf>
- Rose, G., Thompson, R., Amani, B., & McClure, R. (2012). Understanding Ownership and Use of Powered Two Wheelers in Melbourne. ... *Transport Research Forum* (...), (September). Retrieved from http://www.atrf.info/papers/2012/2012_Rose_Thompson_Amani_McClure.pdf
- Rothengatter, W., & Schade, W. (2000). *Assessment of Transport Strategies - ASTRA, Final report. diva-model.net* (pp. 1–48). Retrieved from http://diva-model.net/fileadmin/ecf-documents/news-events/2008-05_wachstum-beschaefigung-und-klimaschutz/astra_ein-systemdynamik-modell-zur-integrierten-bewertung-von-langfristigen-politikstrategien.pdf
- Ryus, P., Vandehey, M., Elefteriadou, L., Dowling, R. G., & Ostrom, B. K. (2011). *Highway Capacity Manual 2010*. (National Research Council (U.S.). Transportation Research Board, Ed.) *Trans Res Board*. Transportation Research Board, 2010. Retrieved from <http://onlinepubs.trb.org/onlinepubs/trnews/rpo/rpo.trn129.pdf>
- SafetyNet. (2009). Powered Two Wheelers.
- Salinger, N. (2006). Compact city replaces sprawl. *Crossover: Architecture, Urbanism, Technology*, 1–14. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.157.1747&rep=rep1&type=pdf>
- Sallery, B. (2014). Oil and Gas Production: Has oil reached its peak? Retrieved from <http://www.busiweek.com/index1.php?Ctp=2&pI=1807&pLv=3&srI=61&spI=117&cl=20>
- Saltzman, A. (1973). Para-transit: taking the mass out of mass transit. *Technology Review*. Retrieved from <http://trid.trb.org/view.aspx?id=132882>
- Sangawongea, S., Prabudhanitisarna, S., Karjangthimapornb, E., Sangawonge, S., Prabudhanitisarn, S., & Karjangthimaporn, E. (2011). Agricultural Land Use Change and Urbanization in Thailand. In *IT International Conference "Innovation and sustainability transitions in Asia"* (pp. 1–10).
- Satayopas, B., Khamjina, S., & Arunotayanun, K. (2001). *Characteristics and Organisation of Public Transportation in Chiang Mai City*. Chiang Mai.
- Sathirathai, S., & Piboolsravut, P. (2004). Sufficiency economy and a healthy community. *Proceedings at the Third IUCN ...*, 1–24. Retrieved from http://pikul.lib.ku.ac.th/FullText_SE/SE010224.pdf
- Sattrapai, B. (2011). Lanna pictures from the past. Retrieved from http://library.cmu.ac.th/ntic/picturelanna/picture_trails.php
- Sayeg, K. (2010). *Measuring Walkability in Smaller Asian Developing Cities: A Case Study Approach*. October.
- Schade, W. (2008). Presentation on ASTRA model Assessment of Transport Strategies.

Bibliography

- Schafer, A. (2000). Regularities in travel demand: an international perspective. *Journal of Transportation and Statistics*, 3(3). Retrieved from <http://ntl.bts.gov/lib/10000/10900/10907/1schafer.pdf>
- Schafer, A., & Victor, D. (2000). The future mobility of the world population. *Transportation Research Part A: Policy and Practice*, 34(3), 171–205. doi:10.1016/S0965-8564(98)00071-8
- Schiller, P., Bruun, E., & Litman, T. (2012). *An Introduction to Sustainable Transportation:“ Policy, Planning and Implementation.”* Retrieved from http://books.google.com/books?hl=en&lr=&id=JTQGD0evGq0C&oi=fnd&pg=PR5&dq=An+Introduction+to+Sustainable+Transportation:+Policy,+Planning+and+Implementation&ots=6EVPtiywVH&sig=YKMrb7ORUis-EaQXNN5_deQvCqM
- Shepherd, S. P. (2014). A review of system dynamics models applied in transportation. *Transportmetrica B-Transport Dynamics*, 2, 83–105. doi:10.1080/21680566.2014.916236
- Sherwood, D. (2002). *Seeing the forest for the trees: a manager's guide to applying systems thinking.* Retrieved from <http://books.google.com/books?hl=en&lr=&id=vQcvzuKfB0oC&oi=fnd&pg=PR15&dq=Seeing+the+Forest+for+the+Trees:+A+Manager's+Guide+to+Applying+Systems+Thinking&ots=90UtbiAP7v&sig=L3n7Lv7FAEFylg1JW8jTIUXK8dU>
- Shimazaki, T., & Rahman, M. (1996). Physical characteristics of paratransit in developing countries of Asia. *Journal of Advanced Transportation.* Retrieved from <http://onlinelibrary.wiley.com/doi/10.1002/atr.5670300203/abstract>
- Silcock, D. (1981). Urban paratransit in the developing world. *Transport Reviews*. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/01441648108716456>
- Simpson, H., & Mayhew, D. (1990). The promotion of motorcycle safety: training, education, and awareness. *Health Education Research.* Retrieved from <http://her.oxfordjournals.org/content/5/2/257.short>
- Siri, C. (2007). *The trade of Lanna from the end of the thirteenth to mid-sixteenth centuries.* Faculty of Arts. Silpakorn University, Bangkok.
- Sivak, M. (2014). Mortality from road crashes in 193 countries: a comparison with other leading causes of death. Retrieved from <http://deepblue.lib.umich.edu/handle/2027.42/102731>
- Solere, R. De. (2010). Analysis of the mobility of the powered-two wheelers in France. *12th World Conference on Transport ...*, 1–12. Retrieved from <http://www.motocicletasyseguridadvial.com/Presentaciones/Informes y Estudios/Analysis of the mobility of powered two-wheelers in France.pdf>
- Srisakda, L. (1989). *Accessibility by conventional bus transport system, Chiang Mai* (p. 67). Chiang Mai.
- SRT. (2012). History of Thai Railway. Retrieved from www.railway.co.th/home/srt/about/history.asp
- Stadtwerke, W. (2012). Vienna city Modal split. Retrieved from <http://www.nachhaltigkeit.wienerstadtwerke.at/daseinsvorsorge/oepnv/modal-split.html>

Bibliography

- Statistics Bureau. (2013). Population Census. Retrieved from <http://www.stat.go.jp/english/data/nenkan/1431-02e.htm>
- Stead, D., & Marshall, S. (2001). The Relationships between Urban Form and Travel Patterns . An International Review and Evaluation.
- Steg, L., & Gifford, R. (2005). Sustainable transportation and quality of life. *Journal of Transport Geography*, 13(1), 59–69. doi:10.1016/j.jtrangeo.2004.11.003
- Sterman, J. (2000). *Business dynamics: systems thinking and modeling for a complex world*. Irwin/McGraw-Hill. Retrieved from <http://books.google.com/books?id=CCKCQgAACAAJ>
- Sterman, J. (2002). All models are wrong: reflections on becoming a systems scientist. *System Dynamics Review*, 18(4), 501–531. doi:10.1002/sdr.261
- Stopher, P., & Greaves, S. (2007). Household travel surveys: Where are we going? *Transportation Research Part A: Policy and ...*, 41(5), 367–381. doi:10.1016/j.tra.2006.09.005
- Sukkan, P. (2008). *The perioded linkage of time in historical space case study Chiang Mai royal plaza*. Silpakorn University.
- systemdynamics.org. (2013). The Field of System Dynamics. Retrieved April 05, 2013, from http://www.systemdynamics.org/what_is_system_dynamics.html
- Talley, W., & Anderson, E. (1986). An urban transit firm providing transit, paratransit and contracted-out services: a cost analysis. *Journal of Transport Economics and Policy*. Retrieved from <http://www.jstor.org/stable/20052793>
- Tanner, J. (1961). Factors affecting the amount of travel. Retrieved from <http://www.getcited.org/pub/101455404>
- TfL. (2010). Travel in London, Supplementary Report: London Travel Demand Survey (LTDS).
- Thairath. (2011). Five high speed train routes of Thailand - how far are we? *Thairath*, pp. 1–3. Retrieved from <http://www.thairath.co.th/page/trainPage>
- The Economist. (2014, December). Why the oil price is falling. Retrieved from <http://www.economist.com/blogs/economist-explains/2014/12/economist-explains-4>
- The Guardian. (2014a). Limits to Growth was right. New research shows we're nearing collapse. Retrieved from <http://www.theguardian.com/commentisfree/2014/sep/02/limits-to-growth-was-right-new-research-shows-were-nearing-collapse>
- The Guardian. (2014b). UK's first "poo bus" hits the road. Retrieved December 03, 2014, from <http://www.theguardian.com/environment/2014/nov/20/uks-first-poo-bus-hits-the-road>
- The UrbanSim Project. (2011). *The Open Platform for Urban Simulation and UrbanSim Version 4.3 - Users Guide and Reference Manual*.
- The World Bank. (2014). *Global Economic Prospects Commodity Market Outlook 2014. January 2013*. Retrieved from

Bibliography

- http://www.worldbank.org/content/dam/Worldbank/GEP/GEPcommodities/commodity_markets_outlook_2014_october.pdf
- Tilburg, C. Van. (2007). *Traffic and congestion in the Roman Empire*. Retrieved from http://books.google.com/books?hl=en&lr=&id=0i5LHy4b6kgC&oi=fnd&pg=PP1&dq=Traffic+and+congestion+in+the+Roman+Empire&ots=qZjMxARfha&sig=R44NWW8ZeBH_Tiugteu1uYevAf8
- Topp, H. H. (1994). The role of parking in traffic calming: Car traffic balances are essential to parking schemes and the lessening of traffic in urban centres. *World Transport Policy & Practice*, 1(3), 17–22.
- TRB. (1994). *Highway Capacity Manual - Special report 209*. Washington DC,.
- TRB. (2007). *Metropolitan Travel Forecasting: Current Practice and Future Direction*. Retrieved from <http://books.google.com/books?hl=en&lr=&id=whZqvdkbbsC&oi=fnd&pg=PA1&dq=METROPOLITAN+TRAVEL+FORECASTING+Current+Practice+and+Future+Direction&ots=SF-1llg5c1&sig=bfawlsDyWgVeMaQcgpHAK6vCbM4>
- TRB. (2012). *Transportation Benefit-Cost Analysis*. Retrieved from <https://sites.google.com/site/benefitcostanalysis/acknowledgements>
- TRIP. (2013). PROPOLIS project details. Retrieved April 19, 2013, from http://www.transport-research.info/web/projects/project_details.cfm?ID=4385
- Tuptong, T. (2012). Land transport during my grand father's period. Retrieved from http://www.autoinfo.co.th/page/th/article_event/detail.php?id=285
- Udomsri, R., & Kongboontiam, P. (2003). Fuel Consumption Models of Household Vehicles in Chiang Mai Urban Area. *Journal of the Eastern Asia Society for Transportation Studies*, 5, 2408–2421.
- UN. (1992). Report of the United Nations conference on environment and development. *Rio de Janeiro (3–14 June 1992) A/CONF.* Retrieved from <http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm>
- Upayokin, A. (2001). *Travel Choice Model for Bus and Other Modes in Chiang Mai Urban Area by Using Stated Preferences Data*. Chiang Mai University. Retrieved from http://library.cmu.ac.th/digital_collection/etheses/fulltext.php?id=8553#
- Valipodom, S. (2002). *Chiang Mai city's physical characteristic in Lanna Kingdom*. Bangkok, Thailand: Matichon Group.
- Vien, L. L., Hashim, W., Ibrahim, W. W. W., Car, D., Leong, L. V, Wan Ibrahim, W. H., & Mohd, A. F. (2008). Effect Of Motorcycles Travel Behaviour On Saturation Flow Rates At Signalized Intersections In Malaysia. *Most*, 1–11. Retrieved from <http://eprints.usm.my/13524/>
- VoiceTV. (2012). สื่อแดงเมืองเชียงใหม่ แก้ปัญหาจราจรอย่างยั่งยืน. *VoiceTV*. Chiang Mai. Retrieved from <http://news.voicetv.co.th/thailand/59467.html>
- VTPI. (2010). *Transportation Cost and Benefit Analysis II – Travel Time Costs*. *Transportation Research* (pp. 1–22).

Bibliography

- Walther, K. (1991). Maßnahmenreagibler Modal-Split für den städtischen Personenverkehr- Theoretische Grundlagen und praktische Anwendung. *VEROEFFENTLICHUNGEN AUS DEM* Retrieved from <http://trid.trb.org/view.aspx?id=1005657>
- Walther, K., Oetting, A., & Vallée, D. (1997). Simultane Modellstruktur fuer die Personenverkehrsplanung-auf der Basis eines neuen Verkehrswiderstands. ... *INSTITUTES DER TECHNISCHEN* Retrieved from <http://trid.trb.org/view.aspx?id=961946>
- Wannavichit, N. (2004). *Transportation Development and Land Use Dynamics in Chiang Mai Urban Fringe*. Chiang Mai University. Retrieved from http://library.cmu.ac.th/digital_collection/etheses/fulltext.php?id=13300
- Watthanakul, P. (2008). *Politics of Chiang Mai Mass Transportation System. Master of Arts (Political Science)*. Chiang Mai University, Chiang Mai.
- WCED. (1987). Report of the World Commission on environment and development: "our common future." *Sustainable Development*. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Report+of+the+World+Commis sion+on+Environment+and+Development:+Our+Common+Future#0>
- Wee, B. van, Rietveld, P., & Meurs, H. (2006). Is average daily travel time expenditure constant? In search of explanations for an increase in average travel time. *Journal of Transport Geography*, 14(2), 109–122. doi:10.1016/j.jtrangeo.2005.06.003
- Wegener, M. (2004). Overview of land use transport models. *Handbook of Transport Geography and Spatial* Retrieved from http://books.google.com/books?hl=en&lr=&id=WMO06zpfUy8C&oi=fnd&pg=PA127&dq=OVER VIEW+OF+LAND-USE+TRANSPORT+MODELS&ots=QwEiIa-4hx&sig=kxM4vn-9f1J6t_JDPl-yxpv-kLY
- Wegener, M. (2012). The future of mobility in cities: Challenges for urban modelling. *Transport Policy*, 1–18. doi:10.1016/j.tranpol.2012.07.004
- Weinert, J., Ma, C., & Cherry, C. (2007). The transition to electric bikes in China: History and key reasons for rapid growth. *Transportation*, 34, 301–318. doi:10.1007/s11116-007-9118-8
- Wichaikatika, T. (1986). *Chiang Mai wall*. (The municipality of ChiangMai printing, Ed.). Chiang Mai: The municipality of Chiang Mai.
- Wichiankhieo, A. (1996). *History of local governance: principal of Chiang Mai city constrution*.
- wideurbanworld. (2011). What is a city? Definitions of the urban. Retrieved from <http://wideurbanworld.blogspot.co.at/2011/02/what-is-city-definitions-of-urban.html>
- Wulf, G., Hancock, P., & Rahimi, M. (1990). Motorcycle conspicuity: an evaluation and synthesis of influential factors. *Journal of Safety Research*. Retrieved from <http://www.sciencedirect.com/science/article/pii/002243758990025X>
- Yannis, G., & Golias, J. (2007). Mobility patterns of motorcycle and moped riders in Greece. ... *Record: Journal of the ...*, 2031(-1), 69–75. doi:10.3141/2031-09

Bibliography

- Younghusband, G. (1888). *Eighteen hundred miles on a Burmese tat: through Burmah, Siam, and the Eastern Shan states*. Retrieved from http://books.google.com/books?hl=en&lr=&id=LR8xXesp2kIC&oi=fnd&pg=PP15&dq=Eighteen+hundred+miles+on+a+Burmese+tat:+through+Burmah,+Siam,+and+the+eastern+Shan+States&ots=IfDxwxg_jD&sig=7xEwaWH7PH04yxV0tcaGNBxh2M
- Yuparaj. (2005). *Memorial Book for 100 year Yupraraj Wittayarai* . (นามพระราชทาน""พระบารมีปกเกล้าฯ ยูพราช วิทยาลัย ๑๐๐ ปี, Ed.). Chiang Mai.
- Zavitsas, K., Kaparias, I., Bell, M., & Tomassini, M. (2010). Transport problems in cities. *ISIS*, (1). Retrieved from [http://www.conduits.eu/Documents/Deliverables/D_1.1 - Transport problems in cities - v3.pdf](http://www.conduits.eu/Documents/Deliverables/D_1.1_-_Transport_problems_in_cities_-_v3.pdf)