Professional MBA
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Development of an automation concept for complex process machines under the aspects of Low Cost Automation and Lean Management

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by

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Köln, 20. 04. 2017

Affidavit

I, **JÜRGEN BESIROGLU**, hereby declare

1. that I am the sole author of the present Master's Thesis, "DEVELOPMENT OF AN AUTOMATION CONCEPT FOR COMPLEX PROCESS MACHINES UNDER THE ASPECTS OF LOW COST AUTOMATION AND LEAN MANAGEMENT", 60 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 20.04.2017

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Signature

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List of abbreviations

CTP	Cologne Transmission Plant
CNC	Computerized Numerical Control
LCA	Low Cost Automation
LM	Lean Management
TPS	Toyota Production System
M/C	Machine

Abstract

The continuously focusing on cost and investment reduction, profit increase, efficiency improvements and chasing for market shares within the automotive world leads to a change in the perspective, approaches and mind set for production systems. With the revolutionary development of the Toyota Production System with its lean management aspects and approaches, it became to a prime example of efficiency and productivity within the automotive industry. Despite of following the Toyota Production System with its lean approach, still various manufacturing companies have to deal with high complexity and sophistication one side and investment reduction and efficiency improvement on the other side.

This thesis concentrates on both aspects. The investment and life cycle cost reduction under the consideration and integration of the following criteria, usage of own expertise, integration of low cost components and implementation by own people. And efficiency and productivity improvement by involvement of flexible and simple automation with low grade of automation, a clear separation between manual handling and automation and process orientation due to modular and simple machine structure, always in context with Lean Management.

A research on state of the art in the field of low cost automation and lean management with its methods and principles will be the basis for the concept development. Finally the low cost automation concept for complex process machines will be developed based the application of the derived and selected methods and principles. A structured qualitative validation in from of an expert interview guided by a validation matrix with the above derived criteria and a certain weighting will validate the developed and implemented concept.

As a summary it can be stated according the result of validation by the experts that the concept achieves the objective of investment reduction and efficiency improvement. From the low cost automation point of view and lean management aspect is the concept also absolutely efficient and applicable. It is recommended to follow up on the defined approach of low cost automation.

1 Introduction

In times where the automotive industry is mostly continuously driven by cost reduction, efficiency improvement, sustainability and the struggle for market share gains or successfully last on the market, a changing of perspective in production system has become main focus. Since the revolutionary development of the Toyota Production System with all their lean management aspects, a new era for the automotive industry has been initiated. Not only in the automotive world but also within the total production industry and even in the service industry, TPS has been leaded to a mind change. Especially in the last decades the lean production philosophy and their aspects has been taken part as a basement for each strategic decision and alignment. Always under the approach of costumer orientated material flow, elimination of waste, continuous improvement and finally a continuous reduction of lead time in the foreground. Another important perspective and part of the Toyota Production System is the Lean Automation approach, also named low cost automation (LCA). What is in contrast to high sophisticated production equipment another interesting and important lean aspect. But also the minimized investment and life cycle cost reduction, not forget the human and operating factor incl. the grade of automation and maintainability makes this kind of automation system very efficient.

Aim of this Thesis is to develop an automation concept for complex process machines which on one side minimize the investment and life cycle cost under the consideration and integration of the following criteria, usage of own expertise, the integration of low cost components and implementation by own people. And on the other side improvement of the efficiency and productivity by involvement of flexible and simple automation with low grade of automation, a clear separation between manual handling and automation and process orientation due to modular and simple machine structure, always in context with lean management. For that the various process steps, methods and principles of the respective fields of application needs to be researched based on state of the art. These defined process steps, methods and principles will be appropriate selected, accordingly redefined and applied to the environment of a complex process machine. Improvement of the ergonomic work condition for manual handling is an aspect which will also be considerate including specified quality restriction based on the criteria of no contact of functional surfaces and touching each other, minimization of manual handling and usage of automation where ever reasonable and possible. The validation of the consideration and implementation of the defined criteria will be the basis for the aim achievement of this thesis.

Structure of the thesis

So a proper automation system is as essential as a proper efficient production system. Low cost automation or high complexity and sophistication? First part of this thesis gives an overview about the definitions and characteristics of low cost automation. Followed by a detailed section about state of the art in lean management and low cost automation in chapter three, where the reader get a deeper understanding and knowledge about lean management, the Toyota Production System including their principles and methods in the first part. The second part is completely dedicated to low cost automation with its various methods and principles.

Chapter four concentrates on the approach of low cost automation and lean management on complex process machines. And which also includes an overview about the characteristics about complex process machines, selected methods and simplification of the complexity. The part of concept development and proposal for a dedicated production area with defined manufacturing processes is dedicated to chapter 5 followed by the concept validation in chapter 6.

Finally this master thesis will finish with a conclusion and recommendation for the researched production area and which is the contribution to the company.

2 Definition and Characteristics

2.1 Definition of Low Cost Automation

What is the meaning for LCA? To give a better understanding from the definition point of view, the term will be divided into low cost and automation.

Low Cost

Splitting the two words the meaning is low and cost so equal to less cost.

Automation

Transfer of functions for production processes, in particular process control and regulation activities, from human to machine.[1]

Grade of automation

The percentage of the automatized functions from the total production system, is according DIN IEC 60050-351 the grade of automation.[2]

Low Cost Automation

Summarizing this means following: Low cost automation can be described as very simple, cheap and practical production equipment. It is quite easy, fast and cost-efficient to implement and where applicable from own resources.

[1] [2] http://wirtschaftslexikon.gabler.de/Archiv/72569/automatisierung-v7.html

2.2 Characteristics of Low Cost Automation

What is characteristic for a LCA? It can be described in a few concise characteristics which are essential for the development of a low cost automation system.

LCA Characteristics:

- Simple construction & implementation(simplicity)
- Standardized
- Cost efficient(Investment & fix cost)
- Compact & practicable
- Easy to use(semi – skilled or unskilled people)
- Easy interaction between human and automation
- Developed & manufactured by own people(in best case)
- Low grade of automation(reasonable)
- Failure detection & error security

These listed characteristics are the basic guideline for each LCA development and implementation.[3] [4]

[3] Takeda, H.: LCIA – Low Cost Intelligent Automation, 2011.
[4] Takeda, H.: Automation ohne Verschwendung, 1996.

3 State of the art

In this chapter the reader will get an overview about state of the art within the topic low cost automation and lean management. Which methods and principle are currently known and which approaches might have not been considered in total.

3.1 Lean Management

Since the revolutionary change of thinking within the automotive world which was started with the development of "Toyota Production System" after the Second World War, their lean management aspects has become the basic for each approach.

Definition of Lean Management

Simply described, "Lean" means reducing waste in each form and increasing value for costumer within the supply chain. Lean Management stays for continuously managing, following and implementing the lean thinking. Focusing on optimize and improve total value stream to finally reduce the "Lead Time".[5] [6]

A comment from Taiichi Ohno[7] named it very simple:

"Everything what we are doing is to take care about the "lead time". From the beginning of the costumer order until the moment when we've received the money. We're reducing the lead time whilst eliminating each part of not added value within the production chain."[8]

(Taiichi Ohno)

[5] http://www.lean.org
[6] Womack James P., Jones Daniel T.: Lean Thinking, 3. Ed., 2013.
[7] Taiichi Ohno (1912-1990), Manager at Toyota and founder of TPS
[8] Liker, Jeffrey K.(2013): Der Toyota Weg, 2013, 31.

3.1.1 Toyota Production System(TPS)

The Toyota Production System was founded by Toyota to be more precise by Taiichi Ohno and Shigeo Shingo[9]. Their pioneering development is the basement for a lean production environment. Whereas mass production concentrates on improving efficiency of individual processes and focusing on high volume with low unit costs (Economies of Scale), the Toyota Production System concentrates on eliminating not added value of the production processes. And its main focus is always reduction of the lead time and elimination of not added value.[10]

If the manufacturing companies are able to reduce the lead time by ¼ could that comply with fifty percentage increase of productivity and cost reduction by twenty percent. To summarize that outcome it leads to that all the efforts for optimization should be concentrated on the total value stream process with focus on lead time reduction and quality improvement and not only on segments. The factor cost will be the benefit for the improvements of the total value stream chain.[11]

The mindset has to be completely adjusted according a continuous value added flow principle included a continuous improvement (kaizen) thinking. It has to become a totally "Lean Thinking". On the other hand to reduce continuously not value add within the production chain (muda) the consequence is automatically a reduction of lead time as already mentioned. Conversely, that leads to benefits and improvements like:

a. Quality
b. Cost reduction
c. Inventory reduction
d. Profit increase

[9] Dr. Shigeo Shingo (1909-1990), founder of TPS
[10] Liker, Jeffrey K.(2013): Der Toyota Weg, 2013, 32
[11] Liker, Jeffrey K., Meiser, David P., Praxisbuch – Der Toyota Weg.

"When you buy bananas all you want is the fruit not the skin, but you have to pay for the skin also. It is a waste. And you as a customer should not have to pay for the waste."
(Shigeo Shingo)[12]

Another essential part of Toyota Production System is the philosophy and approach of leadership and people involvement. To makes the philosophy of the Toyota Production System with his principles very clear and illustrative for their partners, Fujio Cho[13] developed and visualized a diagram in form of a house, called the TPS – House. It's a symbol of the modern manufacturing process.

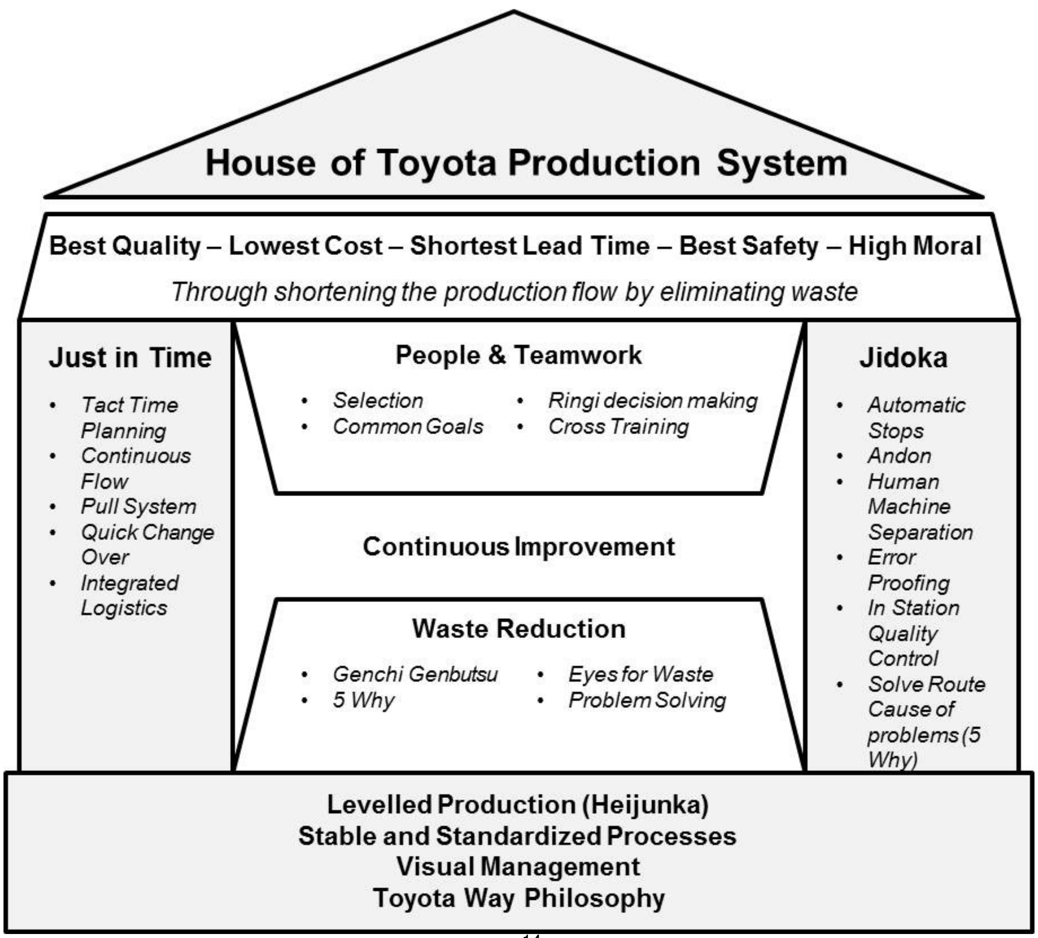

Fig.1: House of Toyota Production System[14] (own drawing)

[12] http://www.process-improvement-japan.com/shigeo-shingo.html
[13] Cho, Fujio. Student of Taiichi Ohno.
[14] Liker, Jeffrey K.(2013): Der Toyota Weg, 2013, 64, 65

The structure of the TPS – House is very simple. It's categorized in four sections, the roof with its targets, the outer walls with their principles and characteristics, the center, which is also separated in three important aspects with their focus on employees and teamwork, continuous improvement and waste reduction. Last but not least, the foundation with its essential and fundamentally basis elements. Each segment is related to each other, means that if all segments are stable, the whole system is stable. If one of the segments got a weak point the whole system will suffer of the weakness. The next sections will give a detail overview about the principles and methods of lean management which are partial shown in the TPS – House.[15]

[15] Liker, Jeffrey K.(2013): Der Toyota Weg, 2013, 64, 65

3.1.2 Principles and Characteristics of Lean Management

Throughout the various literatures the principles are named of different ways but the outcome is nearly the same. To reflect the aspect from James P. Womack and Daniel T. Jones in his publication (Lean Thinking), their perspective leads to a practical and simple explanation shown the following diagram.[16]

Fig.2: Key Principles of Lean Management (own drawing)

These explanations of lean management principles can also be transferred in the meaningful keywords like:[17]

- Value – Define the Value in the eye of the costumer
- Value Stream – Understand the value stream and eliminate waste
- Flow – Organize & maximize the value stream to a synchronized flow
- Pull – The customer demands and it will be delivered at the right time
- Perfection – Pursuit to perfection (continuous improvement, kaizen)

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[16] Womack, James P., Jones, Daniel T. (2013): Lean Thinking – Ballast abwerfen, Unternehmensgewinne steigern, 16.
[17] Womack, James P., Jones, Daniel T. (2013): Lean Thinking – Ballast abwerfen, Unternehmensgewinne steigern, 16, 24, 28, 29

3.1.2.1 Principle of Value

The value is based on the principle that only the customer can define the value of a specific product. The manufacturer is responsible to produce the right part in a specific quality for a defined price and deliver it at the right time.[18]

3.1.2.2 Principle of Value Stream

The value stream simple described consists all manufacturing process activities (value added and none value added) which are needed to produce a respective product. It's the complete throughput of the whole production processes, from the delivery of raw material via the dispatch and up to the delivery of the finished product to the costumer. Due to the detailed recording of the value stream and thus resulted transparency, the manufacturer is able to detect the wastage throughout the whole production processes. It's essential that each manufacturer identify and understand his value stream.[19]

3.1.2.3 Principle of Flow

The flow principle said that, a defined product flies from the first production process throughout the whole production chain until the delivery to the costumer without any interruptions and rejections in any kind. It is a continuous movement through the complete chain and the challenge is to achieve and secure that continuous material flow.[20]

3.1.2.4 Principle of Pull

The opposite of the push principle is the pull principle and they differ completely from each other. The material will be pushed into the production process chain, starting with the delivery of raw material, whereas in the pull system the costumer gives the tact of production with his ordering of material. From that starting point the material will be pulled through the respective production processes. In a pull system it starts always with the ordering by costumer and the last manufacturing process is

[18] [19] [20] Womack, James P., Jones, Daniel T. (2013): Lean Thinking – Ballast abwerfen, Unternehmensgewinne steigern, 30, 31, 34, 35, 36.

the starting perspective at the manufacturer backwards until the first processing operation and delivery of raw material. To be more precise it goes even back to the supply chain of the supplier. The pull principle is one of the essential principles of lean management and the TPS.[21]

3.1.2.5 Perfection

To strive for perfection is the key for a continuous improvement mentality also named kaizen according the origin. Translated it means, Kai for changes and Zen for the good or to better, together it stands for change to be better. And that kind of perfection leads to a continuous identification and elimination of waste within the whole value stream. For that the people are the key for success, it is more than important that philosophy and principle for perfection flies throughout the whole staff of a company, with the one joined mindset. Striving for perfection, to follow and implement the Lean Thinking according their principles.[22]

3.1.3 Methods of Lean Management

The following sections give a detailed overview about the eighth kind of waste also called Muda and two another variants of waste named Muri and Mura, including the various method of lean management.

3.1.3.1 Eight kind of Waste(Muda)

As already several times mentioned, waste is the worst thing which can exists in a manufacturing company and to go one step further, everywhere. The Japanese got a special term for it, Muda. So each activity in some ways, without any outcome of values is waste and therefore Muda. Taiichi Ohno described and defined seven different kind of Muda's which are still valid. But in the meanwhile he added another kind of Muda the eighth one. It is the not applied knowledge of the employees. All lean methods are oriented and aimed to eliminate all kind of waste.[23]

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[21] [22] Womack, James P., Jones, Daniel T. (2013): Lean Thinking – Ballast abwerfen, Unternehmensgewinne steigern, 51.
[23] Liker, Jeffrey K., Meiser, David P., Praxisbuch – Der Toyota Weg, 66, 67.

Hereafter listed and described the seven kind of Muda:[24] [25]

- **Overproduction** – Produce more than costumer demands
- **Excessive Inventory** – Raw material, work in progress or finished parts which are not needed therefore having none Value add
- **Unnecessary Waiting** – People or material are unnecessary waiting for next process step
- **Unnecessary Motion** – People, material or automation are unnecessary moving to the next process step
- **Unnecessary Transport** - People, material or automation are unnecessary transport within a process step
- **Rework** – Parts which needs to be correct because not finished properly by the first time.
- **Over Processing** – Process is developed and implemented over the required standard by the costumer.
- **Not applied knowledge of employee** – The unused creativity and knowledge by not engaging and learning the employees

[24] http://leanmanufacturingtools.org/77/the-seven-wastes-7-mudas/
[25] Liker, Jeffrey K., Meiser, David P., Praxisbuch – Der Toyota Weg, 66, 67.

According TPS there next to Muda also there other kind of M's where the focus is on to become a lean. All three M's are in relation and affecting each other.[26]

- **Muri** – Overloading of people and machines, means demanding and running over their limits.

- **Mura** – Imbalance of production systems that includes people, machines and material leads to an imbalance of the production volume and level.

It is not rocket science to identify waste. It is everywhere, it needs just an open eye and concentrating on not value added activities in each from. Elimination of waste along the value stream is the essential method to become a lean factory. The structured approach is always the same, Identification of wastage, development of a plan for elimination and finally implementation.

3.1.3.2 Value Stream Mapping

The value stream analysis is an excellent method to visualize the whole value stream of your manufacturing factory. The benefit of this kind of method is the total transparent picture which will be visualized. It shows next to the production processes and material flow also the Information flow. This allows a clarification between the interfaces of the production processes and the business processes.[27]

The detailed description and visualization of the manufacturing process gives a detailed overview about the uncovered weaknesses and waste with the respective value stream, which can be appropriate eliminated. It is also the basement for understanding the current situation from the value stream perspective and for discussion and development of the future state. To summarize Value Stream Mapping is an essential method of lean management and the starting point to become a lean company.[28]

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[26] Liker, Jeffrey K.(2013): Der Toyota Weg, 171.
[27] Liker, Jeffrey K., Meiser, David P., Praxisbuch – Der Toyota Weg, 74,75,76.
[28] Erlach, Klaus (2010): Wertstromdesign – Der Weg zur schlanken Fabrik, 8, 9.

3.1.3.3 Leveled Production (Heijunka)

Leveled production or Heijunka is nothing else than leveling the production volume and product mix to avoid fluctuations. Due to that production leveling, the total production system, value stream, will be kept relatively stable and the inventory will be reduced on a specific limit. It is the basement for a permanent implementation of a continuous flow and pull system.[29]According Heijunka the products will be produced after a certain methodology, means not caused by the order request of the costumer but caused by the order volume over a certain time period. The result is a leveled production plan which gives a leveled amount, product mix and sequence over the certain time period, for example a week or month.[30]

Consistency is a very important for a lean and stable production system. As already stated imbalance and inconsistency is blocking each attempt for implementation a lean production.

Taiichi Ohno explained it simple:
The slower but consistent tortoise causes less waste and it is more desirable than the speedy hare that races ahead and the stops occasionally to doze. The Toyota Production System can be realized only when all the workers become tortoise.
(Taiichi Ohno, 1912 – 1990)

[29] [30] Liker, Jeffrey K.(2013): Der Toyota Weg, 2013, 172, 173, 174.

3.1.3.4 Kanban

Kanban is a Japanese word and means something like sign, card, poster or placard. It follows the principle of self controlled control loop for provision of material like in a supermarket. A product will be automatically ordered after it has been taken out of the rack. With that systematic it is the fundament for a pull system. According the pull system the material flow is forward directed and the information flow backward. This systematic shows a costumer oriented production principle, means only what the costumer requires or demands will be produced.[31] The ordering size depends on the required package size and the amount which has been consumed. A tool for that kind of self controlled control loop is the Kanban – Card. On that card, all respective important information will be documented. For implementation of a Kanban system certain conditions and requirements need to be complied. [32]

- Small range of variants
- High consumption rate
- Small or no fluctuations on demand

In case of any deviations from the mentioned requirements for any reasons it will caused the following negative effects.

- Increasing of the range of variants will cause more space for storage
- Reduction of consumption rate will cause an increasing of range
- Increasing of fluctuations on demand will cause an increasing of inventory

From the total perspective, any changes from the preconditions will have an effect on the total system. But to assure also smooth self controlled control loop defined Kanban rules has to follow.[33]

[31] [32] Erlach, Klaus (2010): Wertstromdesign – Der Weg zur schlanken Fabrik, 190, 191.

[33] Erlach, Klaus (2010): Wertstromdesign – Der Weg zur schlanken Fabrik,197.

Kanban rules:

- Only Material has to be ordered what is exactly needed
- No ordering of Material before usage
- No production on stock
- No passing of defect parts
- Equal utilization of production processes
- As less Kanban cards with the system as possible
- Performing a Kanban card check on regular base
- Delivery and production of material according Kanban card in sequence and amount

3.1.3.5 Jidoka

As already visualized in the TPS House as one of the outer walls is Jidoka a method which responsibility it is to stop a defect before it will move to the next process step. Another aspect of its aim is to separate the worker from machine or machining process. To stop a process immediately in case of any defects is linked to a zero defect strategy which is absolutely in line with the lean thinking. To avoid unnecessary inspections, repair and rework is priority for a continuous flow and leads to produce a part with the right quality with the first attempt.[34]

The following tools supporting the method of Jidoka:

- **Andon System** – That kind of system will visualize with a lightning or similar systems in case of a machine stop caused by a defect part. Usually of involvement of an acoustic signal[35]

- **Poka Yoke** – Is a tool for failure detection. With that kind of detection it is almost impossible for an occurred defect. Usually it is a standardized Poka Yoke Device especially for a dedicated production process. In case of any

[34] Liker, Jeffrey K.(2013): Der Toyota Weg, 2013, 191.
[35 36 37] Liker, Jeffrey K.(2013): Der Toyota Weg, 2013, 192, 193, 196, 198.

defect or not following the standard in that dedicated production process the failure detection device will activate a defined alarm.[36]

- **5 Why** – It is a failure analysis tool for route cause identification. Simple described the question why has to be raised several times until the reason for defect has identified. It can be applied in various fields where a structured failure analysis is necessary.[37]

3.1.3.6 Standardized Work

Standardized Work is simple described a detailed description of each working activity. So the procedure for performing the job is always according structured scheme. The total work process is detailed broken down, so it can be sequenced and repeatedly performed.

Standardized work contents the following three elements:

- **Tact Time** – Describes the in which time a product needs to be processed according costumer demand
- **Job Sequence** – Detail description what the operator needs to do in according a defined sequence
- **Required Inventory** – Describes the standard Inventory which is mandatory for operating the process

Standardization is a key element of a lean company. It makes sure that the respective operator is able to perform the job always in sequenced, organized and repeatedly way.[38]

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[38] Liker, Jeffrey K., Meiser, David P., Praxisbuch – Der Toyota Weg.

3.1.3.7 Visual Factory

That method, visualize each kind of information in a clear, transparent, structured and easy way. So complex information can be easily visualize, in a simple way to makes it understandable for everyone. A traffic sign is a good example for visualization. But also visual control is a kind of visual factory. It shows immediately if something is wrong or not. It is a kind of standardization in terms visualization. For example a visualized place for a tool or a min max level for inventory. It can be easily recognized if the tool is on his dedicated place or the inventory is on min or max level. So it can be stated that visual factory belongs also to the essential methods of Lean management.

3.1.3.8 6S

To understand the sense of 6S it needs to be understood where it comes from and why. The Japanese are following the mind set and philosophy that order and cleanliness are a matter of attitude and proudness. That inner attitude is also reflected to the outer world. Toyota developed a program which ensures that philosophy and mind set to order and cleanliness will be strict accordingly followed and implemented. The named it 6S and it became one of the key elements for elimination of waste. The following schematic view shows the six various elements of the 6S method including explanation. It starts with the first element seiri (sort) and ends with the last element shukan (sustain). All elements are linked followed according the shown cycle.[39]

[39] [40] Liker, Jeffrey K. (2013): Der Toyota Weg.

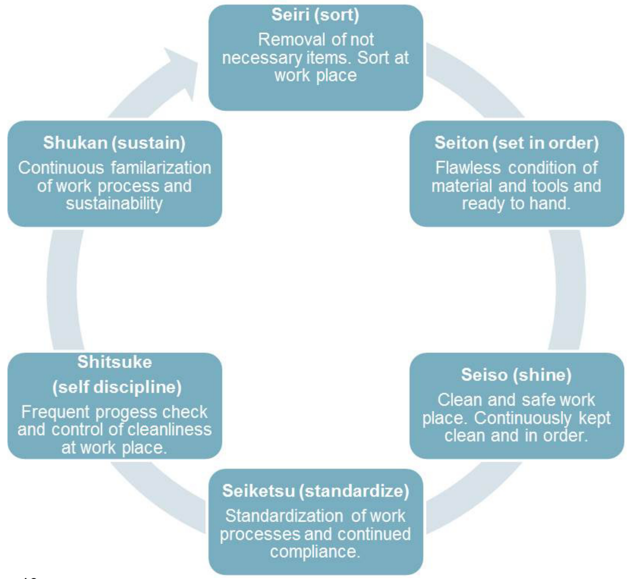

Fig.3: 6 S Method[40] (own drawing)

3.1.3.9 Kaizen

The Japanese word KAIZEN is separated in to terms “KAI” and “ZEN” which means “change” and “good” or “better”. Together it is a synonym for continuous and steady improvement and means “change to be better”. Kaizen is more a philosophy and attitude of a stepwise improving mentality. To follow strict that philosophy and bring it to a systematic continuous improvement system a robust method needs to be developed and implemented. A strong tool is the PDCA Cycle or called Deming Cycle which has been developed by Deming W.E[41]. It is a method for failure analysis, identification and implementation of counter measures and exact that tool which integrate the philosophy of KAIZEN.[42]

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[41] Deming W.E. (1900 – 1993), Ph.D. at yale, founder of the PDCA/Deming Cycle and approaches to Quality Management.
[42] Bunner, Franz J.(2008): Japanisches Erfolgskonzept,7, 11.

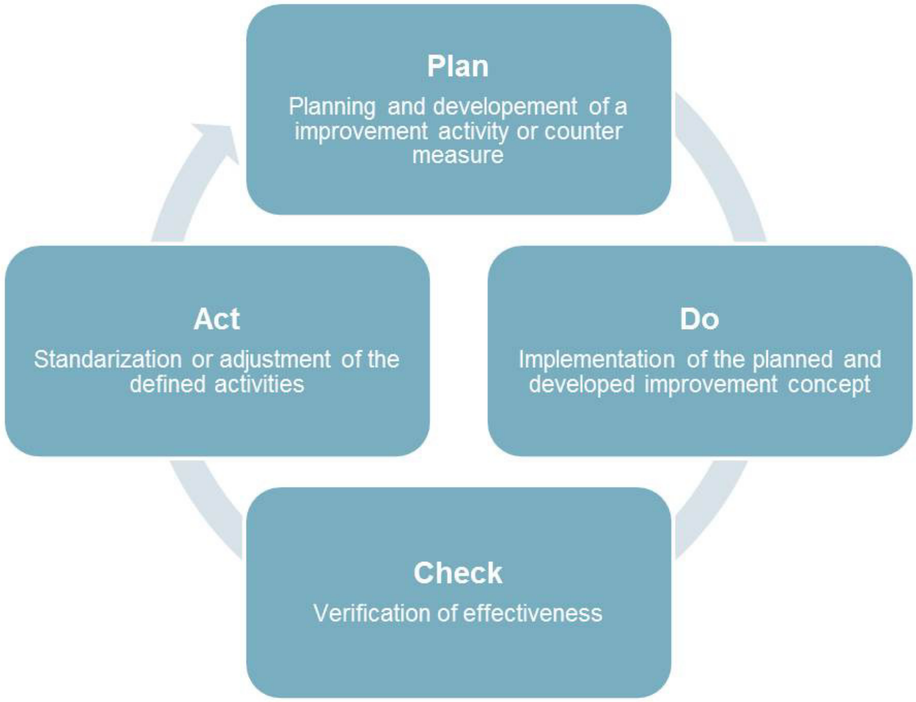

Fig.4: PDCA - Cycle[43] (own drawing)

The PDCA – Cycle follows a simple methodology. The first step is the planning and development of improvements or counter measures for a certain problem, followed by the implementation of the defined improvements. After a certain time period the implemented improvements needs to be checked according the efficiency. If that is the case the improvements needs to be standardized and involved in the official process as step four, if not, the improvements will be adjusted and it starts again by the first step.[44] Mostly the implementation of such KAIZEN activities will be conducted by performing of so called KAIZEN – Workshops, where a defined group of people from the various fields will work on the dedicated problem and improvement. That approach supports also the stabilization of the KAIZEN philosophy and mindset.

[43] [44] Bunner, Franz J. (2008):Japanische Erfolgskonzepte, 6, 7.

3.2 Low Cost Automation

In 1970 low cost automation has been developed caused by the oil and financial crisis where the Japanese had to cope with. They were looking for creative, cheap and simple alternative solutions for their production equipment. With performing of Kaizen Workshops, Hitoshi Takeda was able to develop that kind of equipment what they were looking for and which he called "Low Cost Automation". [45]

Now almost five decades later low cost automation has become an essential element of lean manufacturing. And the influence on design of new and current automation systems is increasing within the western automotive world. And not only driven by the mind-set change that these kind of automation can bring a competitive advantage. From the cost and efficiency perspective a low cost automation takes an investment of just 10% to 20% of the regular automation systems under almost the same grade of efficiency.[46] [47]

3.3 Methods of Low Cost Automation

The field of methods for LCA in the manufacturing sector can be dissected in 3 areas: assembly line, mechanical component production also named single – item production and transport systems – logistics. In each of these different areas of application are the approaches and the outcome almost the same, always with perspective of the LCA principles. But of course the principle of low cost automation can be used wherever it is useful. According Hitoshi Takeda, there are different structured process steps for identification of potentials to implement a low cost automation system. Within this chapter the respective structured process steps for the above mentioned methods will be explained.[48] Which methods in the low cost automation are known or unknown? These questions need to be investigated. For each area of application there are different kind of methods and approaches described in the literature. But these descriptions are only a recommendation for implementation with reference to the LCA principles.

[46 46 47] Takeda, H.: Automation ohne Verschwendung(1996), 15, 16, 17, 22, 26.

[48] Dickmann, Philipp (2009):Schlanker Materialfluss, 43.

3.3.1 Methods of LCA in Assembly

Assembly activities mostly concentrated on manual handling. Of course there are also automatic operations e.g. robots or drilling stations. For these automatic stations should be always a business case given, which needs to be properly investigated. But in general it can be stated that manual handlings are in the foreground.[49] For implementation of a low cost automation in a dedicated assembly station, the total equipment should be analyzed in detailed and separated between manual and automatic activities. Based on the assessment and evaluation of the manual operations to identify potential activities for a low cost automation implementation, the operator should always have a work simplification and workload reduction.

The following process step structure are typical for a assemble station. The defined process steps are categorized in four activities (1. put away, 2. take / pick, 3. search and 4. do).[50]

- Receive work piece – pick / take
- Select component – search
- Pick up component – pick / take
- Positioning – search
- Pick up tool – pick / take
- Assemble – do
- Put back tool – put away
- Verify – do
- Remove work piece – put away

[49] [50] Takeda, H.: Automation ohne Verschwendung (1996), 36.

The starting point of development a low cost automation to transfer a manual process to an automated, should always the activity with the lowest grade of automation. Means in that case based on the philosophy beginning with removing of component – put away. Why? Removing the finished component is a simple movement, so the grade of automation is almost zero. That activity has to be investigated in detail to develop a concept for low cost automation of manual handling for the worker.

Hereafter are listed known concepts for assembly:

- Positioning of component at the optimized grab point
- Modification of basic tools to dedicated specialized tools
- Implementation of visual management
- Transfer of manual activities to small machines
- Integration of both hands separately within the manual process
- Utilization of the operator on his workplace – combination of manual and automated station
- Involvement of ejector devices at the last operation process
- Connection between output device and input device from next operation
- Creation of modules and kits (modularization)
- Part feeding in production magazines
- One grasp for change over
- Standardized hand movement

These mentioned concepts are different approaches to implement LCA Systems in the respective process steps.[51] [52]

[51] Takeda, H.: LCIA – Low Cost Intelligent Automation, 2011, 36.
[52] Takeda, H.: Automation ohne Verschwendung, 1996.

3.3.2 Methods of LCA in mechanical component production

In the mechanical production or component production is the manufacturing process much more complex and automated compare to the assembly operations. The skill level of the operator is also much higher caused by the needed know how for operating a complex processing machine including a complex loading and unloading system. The change from high sophisticated production equipment to a certain grade of automation which follows the LCA Principles within the component production needs a complete different view and open mind.

In the following there will be described known methods and approaches of low cost automation within the mechanical production. Similar like in the assembly station there are structured process steps which are also typical for a very simple mechanical manufacturing process. [53]

- Receive work piece
- Insert work piece
- Clamping work piece
- Start machining process
- Feed motion
- Stop machining process
- Move to basic position
- Remove work piece
- Verify
- Transport

According the above mentioned process steps there is also a structured approach to identify potentials for development and implementation of a low cost automation system. Also in this case the activity with the lowest grade of automation is the one with the biggest potential. So that means "clamping work piece". Of course the grade of automation needs to be evaluated in advanced. The focus is more on changing simple human activities to simple automated solutions.

[53] Takeda, H.: LCIA – Low Cost Intelligent Automation, 2011, 112.

In the following there are known concepts for a LCA in mechanical component production for simple constructed manufacturing equipment. Each of these concepts can be dedicate to one or more of the above mentioned structured process steps[54]

- Mechanism for interjection
- Simple automatize of hand work
- Automatize of clamping process
- Feed, stop and move to basic position are automatized processes
- Just insert activities for Operators (chaku chaku principle)
- Output of one process step is the input for the next process step
- Quality check next to the process with a simple measurement device
- Process start automated with a dedicated switch
- Modular construction of equipment

Today complex cnc processing machines took over mostly all of the above mentioned concepts. But that kind of production equipment has nothing to do with a low cost automation. It is more a full automated high sophisticated production equipment including complex loading and unloading automations.

3.3.3 Methods of LCA in Transport Systems

In general it is stated that transports are not value added activities. It is just needed to move material from one point to another or bridging a certain distance for further processing or further value added activities. The benefit of Low Cost Automation in transport systems is reduction of work in progress, what is material, inventory or parts which are not completed finish, and unnecessary movements in each variant.[55]

[54] [55] Takeda, H.: LCIA – Low Cost Intelligent Automation (2011), 112, 156

The perspective for implementation of Low Cost Automation can be considered in two fields of application, material transport and movement of parts straight to processing position. Material transport involves just two different views of matter. First, movements of material out of the processing machine or manual station, this kind of transport system can additionally distinguished between activities within and out of a manufacturing plant.

And second, movements of parts straight to processing position means that the part will be guided in the position where the processing step can directly begin and the other way around. That way of transport systems can also be referred to the field of mechanical component production, because this field of LCA is like already described completely concentrated on processing equipment involving all process steps including loading and unloading. What is already determined in this thesis and means that this section will focus on pure transport of material.[56] Even in the field of Transport Systems are structured process steps which are important to automatize manual transport activities. This means that activities carry out by human intervention will be transferred to process steps done without human intervention and without high sophisticated automation systems.

Hereafter are listed the structured process steps for transport systems.[57]

- Touch
- Packing
- Load
- Move
- Unload
- Store

[56] [57] Takeda, H.: LCIA – Low Cost Intelligent Automation (2011), 156.

Like described in sections manual assembly and mechanical component production the approach of identification for potentials to implement a LCA is also followed the same procedures. Also here there are known concepts which can be assigned to the respective typical process steps.[58]

- Use narrow material boxes
- Standardize packages / bundles
- Cluster necessary material for transport
- Loading and unloading of material on standardized height
- Pull System
- Clear and simple transport routes
- Increase transport frequency
- Automatize transports
- Integration of empty boxes within the transport flow
- Transport of defined quantities on unregularly basis
- No hoists, cranes or forklifts
- Continuous movement of material

[58] Takeda, H.: LCIA – Low Cost Intelligent Automation (2011), 156.

3.4 Principles of Low Cost Automation

In this chapter the area of focus is defined in respective principles of Low Cost Automation.

3.4.1 Chaku Chaku Principle

Chaku Chaku embodies the basic idea of a low cost automation and involves almost all characteristics from the loading perspective. It is derived from the Japanese and means “loading – loading”, which result from the dedicated work process of the operator which is only concentrated on loading activities. Means that, the manual activities are only, loading of the work piece and starting the machining process. Finally the operator just moves through his dedicated production or assembly line and is doing manual loading activities.[59]

The complement to the Chaku – Chaku principle is the Datsu – Datsu principle which means “unloading – unloading”. From the perspective of regular production and assembly operations without a full automatized loading and unloading system, the Datsu / Chaku – Datsu / Chaku principle (unloading/loading – unloading/loading) is the basis of technical understanding for such kind of systems. The operator is concentrated on manual loading and unloading activities but for a full implementation of a Chaku – Chaku system the unloading process needs to be fully eliminated.[60] [61]

[59] Eberhard, Daniel (2013): Fertigungsorganisation nach dem Chaku – Chaku – Prinzip, Bachalorarbeit, Zugl. Helmut Schmidt Universität – Universität der Bundeswehr Hamburg, Hamburg.

[60] Takeda, H.: Automation ohne Verschwendung, 1996.

[61] Baudin, Michael (2007): Working with Machines: The Nuts and Bolts of Lean Operations with Jidoka, Productivity Press, New York.

The field of application can be divided in two areas of production operations, assembly stations and within the mechanical component production. Each of these areas got a similar approach for implementation but the conditions of application are mostly the same.

The conditions of application are as followed listed:

- Short distances
- Multiple hand movements in a row
- U shape arrangement working place
- Standardized work processes
- Standardized buffers
- Automatically unloading system
- Work piece automatically ejected from previous station

The following figure shows a simple schematic diagram of the manual process steps and movement flow of the operator in a chaku chaku production line. Its separated in two views, with a ejector principle and without.

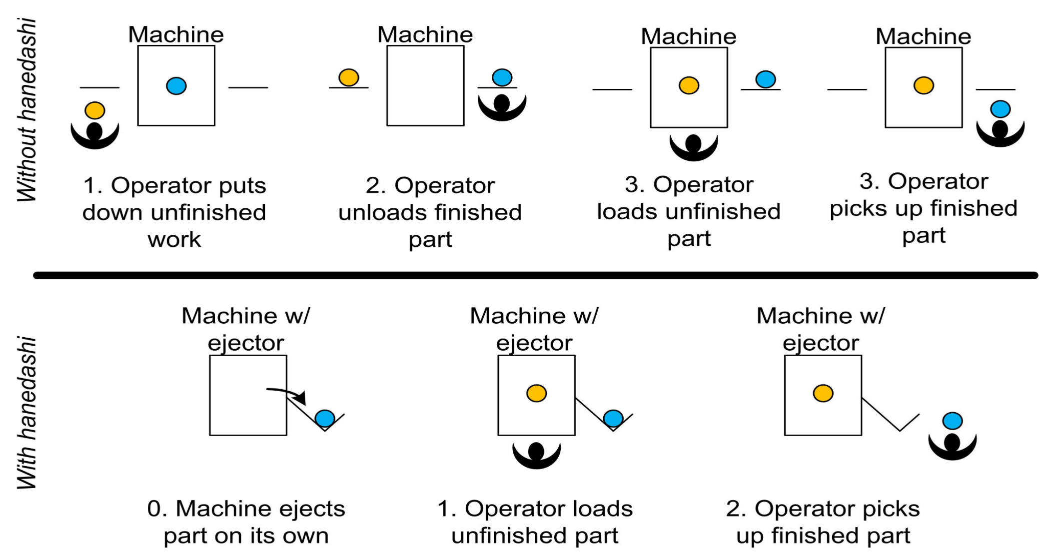

Fig.5: Schematic diagram of the Chaku Chaku Principle (http://www.leanindonesia.com/tag/chaku-chaku)

3.4.2 Karakuri Principle

Karakuri has its origin in Japan at the eighteenth century based on the creation of dolls which became famous by the respective development of constructions for the diverse automated movements. These movements were done without any intervention of manual activities. Transferring that concept to the manufacturing perspective it means nothing else than just using elementary forces to move or transport the respective object e.g. a work piece to a defined position or spot. The following elementary and mechanical forces are predestined for application in the Low Cost Automation systems.[62]

- Force of gravity
- Clamping force
- Radial force
- Tensile force
- Spring force
- Hydropower

In the literature and internet the term Karakuri is often stated in combination with Kaizen. That refers to the lean and the continuous improvement philosophy. Development and implementation of a Karakuri system in relation with a low cost automation system is always seen under the scope of lean operation and their principles. To follow the Karakuri approach following characteristics needs to take into account.

- Movement without human forces instead automatically movement
- No Investments in term of money
- Application of the equipment force
- Application of elementary forces and mechanical principals for automation
- Use the intelligent and creativity of the worker and operator at the workplace to automate processing equipment

[62] https://www.quality.de/magazin/karakuri-kaizen/

4 Approach for LCA and LM for complex process machines

The comprehensive approach and concept of low cost automation is according the state of the art operator oriented. Means elimination of manual activities, handled by the operator, with simplified, practical and efficient automation systems. As already described in chapter 3, these different methods are concentrated on mostly the same conceptual approach. Take an existing work place or field of application, analyze the manual process steps and develop according the grade of automation a low cost automation concept for reduction or elimination of the manual working content. So this Thesis follows another kind of approach for a low cost automation, the elimination or reduction of high technical sophisticated feeding, loading/unloading systems for complex processing machines, and replacement with low cost automation in combination lean management. Therefore, necessary methods and principles of low cost automation and lean management need to be combined. Important aspects are coming together, the aspect of simplification with the aspect of high sophistication and complexity. The new approach distinguishes the named aspects into simplification for the feeding and loading/unloading system and high technical sophistication for the complex processing machine. The approach and solution of low cost automation for complex process machines is following four steps

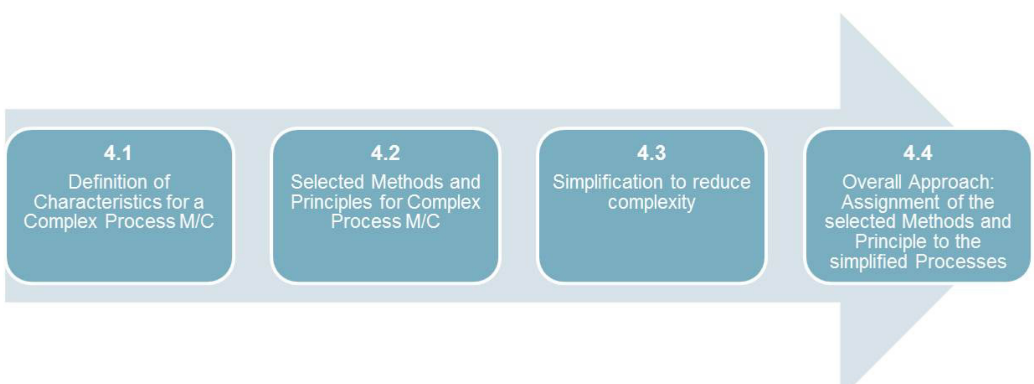

Fig.6: Four steps towards the solution for a low cost automation (own drawing)

4.1 Characteristics for a complex process machine

The following section gives an overview about the characteristics and shows a graphic of a complex process machine.

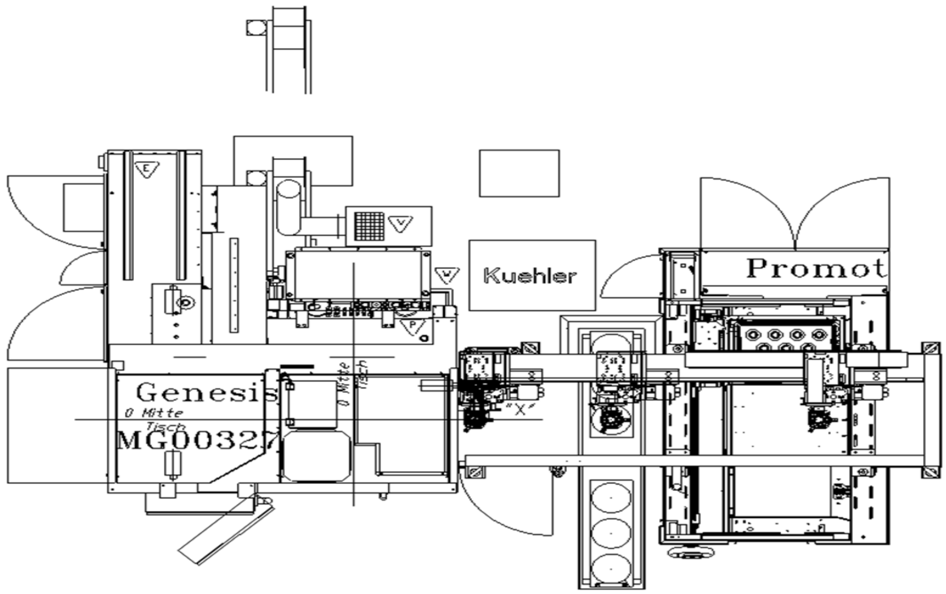

Fig.7: Graphic of a complex process machine (Extract from Production Layout GFT – CTP)

Here after are listed the characteristics:

- Consisting of multiple components
- High productivity and low flexibility
- Multiple processing task – multiple interaction of axles
- Automatic work piece change required
- Automatic tool change required
- Insitu process and post process measuring

4.2 Selected methods and principles of Low Cost Automation for complex process machines

In the following, the existing methods from various fields of application for low cost automation (assembly, mechanical component production and transport systems) are accordingly selected, combined and reassigned under the new approach, which can be integrated into a respective dedicated concept.

Field of Assembly	Field of Mechanical Component Production	Field of Transport System
Implementation of visual management	Mechanism for interjection	Loading and unloading of material on standardized height
Integration of both hands separately within the manual process	Just insert activities for Operators (chaku chaku principle)	
Utilization of the operator on his workplace – combination of manual and automated station	Output of one process step is the input for the next process step	
One grasp for change over	Process start automated with a dedicated switch	
Standardized hand movement	Modular construction of equipment	

Tab.1: Overview about the selected methods of low cost automation (own table)

The low cost automation methods are linked to the identified and defined process steps for the worker and potential low cost automation activities. Means that the respective methods has been selected according the process steps and conceptual covering. It has been chosen not only from the technical perspective, but also from the lean perspective. Hereafter are listed the combined methods from the various field of application which has been separated and assigned to the manual handling process of the worker and to the low cost automation.

Methods for manual handling of the worker	Methods for Low Cost Automation
Implementation of visual management	Process start automated with a dedicated switch
Integration of both hands separately within the manual process	Modular construction of equipment
One grasp for change over	Output of one process step is the input for the next process step
Standardized hand movement	Mechanism for interjection
Loading and unloading of material on standardized height	
Just insert activities for Operators (chaku chaku principle)	
Utilization of the operator on his workplace – combination of manual and automated station	

Tab.2: Overview of the separated and assigned methods (own table)

4.3 Simplification to reduce the complexity

The new approach differ, compare to the general kind of approaches which are described in chapter “Low Cost Automation”. Firstly a necessary simplification of the process steps to reduce and master the complexity, needs to be performed and accordingly new defined or redefined. Also within the new approach the separation between manual activities and automation needs to be investigated. It can be stated that feeding activities are manual handlings because the development and implementation of a complex automation system is very costly therefore against the LCA philosophy. Just moving a work piece into the processing machine for the next process step has a very low grade of needed automation and complexity.

Hereafter listed the new defined process steps for feeding and loading/unloading activities for complex processing machines:

New defined process steps before machining process	New defined process steps after machining process
Receive work piece	Transfer work piece to unload position
Pick up work piece	Unload work piece from processing machine
Drop work piece to defined position	Transport / move work piece to pick up position
Transport / move work piece to loading position	Pick up machined work piece
Load work piece to processing machine	Verify work piece
Transfer work piece to processing position	Pack
	Transport to new working process

Tab.3: Overview about the new defined process steps (own table)

Focusing on separation of the named process steps between manual handling for the worker and automation activities, the following simplified structure has been selected which can also differ according the dedicated feeding and loading/unloading concept. The chosen structure gives a guide which activities are potential for implementation of low cost automation and which activities can be simple manually done by the worker.

Identified and assigned process steps for the worker	Identified assigned process steps for Low Cost Automation System
Pick up work piece (1.)	Transport / move work piece to loading position (a.)
Drop work piece to defined position (2)	Load work piece to processing machine (b.)
Pick up machined work piece (3.)	Transfer work piece to processing position (c.)
Verify work piece (4.)	Transfer work piece to unload position (d.)
Pack (5.)	Unload work piece from processing machine (e.)
	Transport / move work piece to pick up position (f.)

Tab.4: Overview about the simplified process steps (own table)

According the above listed structure it can be stated that manual activities for the operator just pick up work pieces and drop it to a defined position. The other process steps can be done by a simple automation. So to develop a low cost automation for that process area is predestined.

4.4 Overall Approach: Application of the selected methods and principles to the simplified process

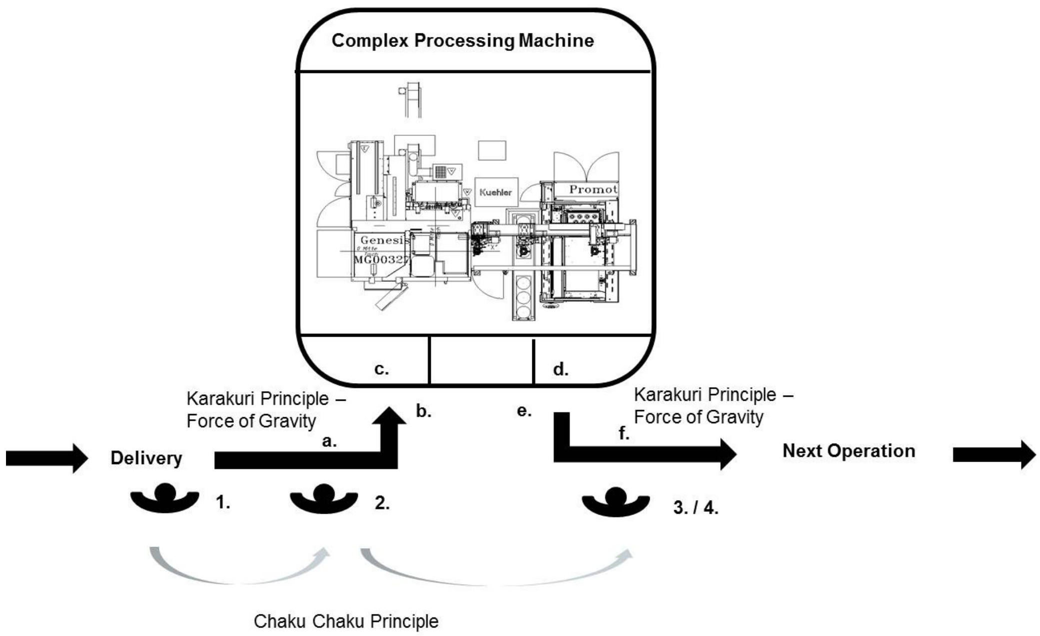

Fig.8: Schematic view of overall approach (own drawing)

The in Fig.8 schematic view shows the overall approach for a complex machine. The sequential numbers shows the simplified process steps for the worker and the characters shows the process steps for the low cost automation system. The three working position of the worker are visualized with the black element and the arrows shows the moving position and backwards. The material will be delivered by normal transport in bulk material containers. The operator picks up the work piece and put it on the feeding equipment. What is based on the Karakuri principle. So the work piece will be transported by force of gravity to the loading position. There the automatic cycle will start after a sensor has been activated that loading process, which moves the work piece to processing position.

After the processing process has been finished the work piece will be again transported by force of gravity to pick up position, where the operator can verify the processed part. For applying the force of gravity the system just needs to have a gently gradient and an underground, where it can be smooth moved by itself. The end of one process is the beginning of the next is also here applied. The standardized movement of the operator is according the Chaku Chaku principle. That kind of concept follows the principle that the operator is just doing simple manual activities and implementation of a low cost automation where the grade of automation is low. In this case the feeding and loading/unloading process.

5 Concept Development & Implementation

This concept focuses on a low cost automation for loading and unloading system of a complex cnc process machine operation. The work piece got a certain dimensions. As mentioned, the involvement of lean manufacturing aspects in context will be also an important part of the concept. But to get a complete picture the operation process before and after needs also to be taken into account. The following perspectives are in the foreground as well as the LCA and LM aspects:

- Investment saving
- Minimized manufacturing cost
- Efficiency and productivity Improvement
- Minimized lead time

5.1 Company and Work place Description

Getrag Ford Transmissions GmbH[63](GFT) is a Joint Venture(JV) between Getrag[64] and Ford Werke GmbH[65] and was founded in 2001. Core business of the Company is the transmission manufacturing with production facilities in Cologne(Germany), Bordeaux(France), Kechnec(Slovakia), Halewood(England) and Goteborg (Sweden). CTP is a manual transmission manufacturing facility based in Cologne, Niehl. Main Customers are Volvo and Ford with a yearly total volume of 450 K. The concept development concentrates on a dedicated area in the Cologne Transmissions plant (CTP). The dedicated workplace for concept development is a production area where five manufacturing processes coming together. They are separated in before and after heat treatment. The respective manufacturing part is a Ring Gear, which will be nearly described in the next chapter.

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[63] Getrag Ford Transmissions GmbH,
http://www.getrag.com/de/company/data/structure/structure.html
[64] Getrag Co. KG. merged with Magna Powertrain in 2015

5.2 Manufacturing Process and derived Requirements

5.2.1 Work Piece description

The work piece which will be manufactured is a Ring Gear with the following specifications. The dimensions are very important for the specification of the low cost automation system. It needs to proper designed to cover these dimensions. Listed below are the relevant dimensions for the work piece.

- Weight rough part: ~8 kg
- Weight finish part: ~5 kg
- Outer diameter: 279.8 mm
- Inner bore diameter: 178 mm
- Width: 34.5 mm

To give a better understanding about the form and figures from the graphical point of view, Fig.9 and Fig.10 shows a picture and the technical drawings of the Ring Gear.

Fig.9: Ring Gear (own picture)

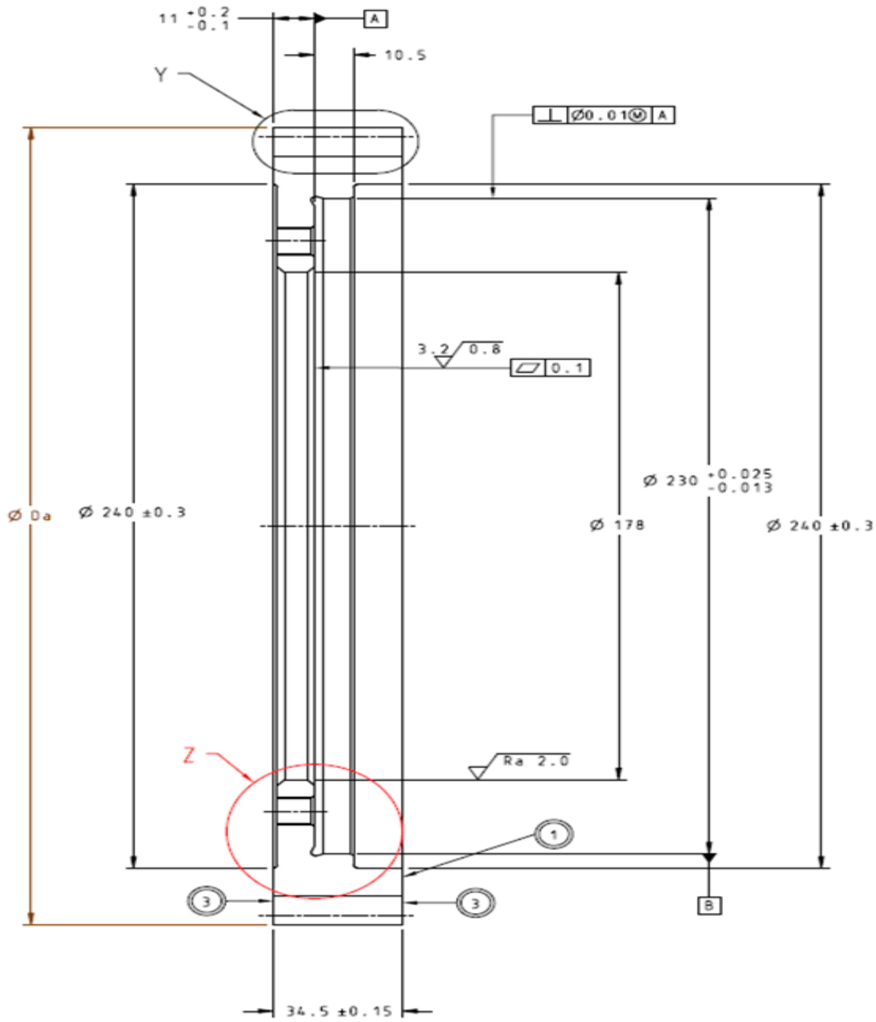

Fig. 10: Technical drawing of ring gear (Extract from CAD Drawing GFT – CTP)

5.2.2 Manufacturing Process

As already mentioned, the Ring Gear will pass through five manufacturing processes, which are according the following production chain.

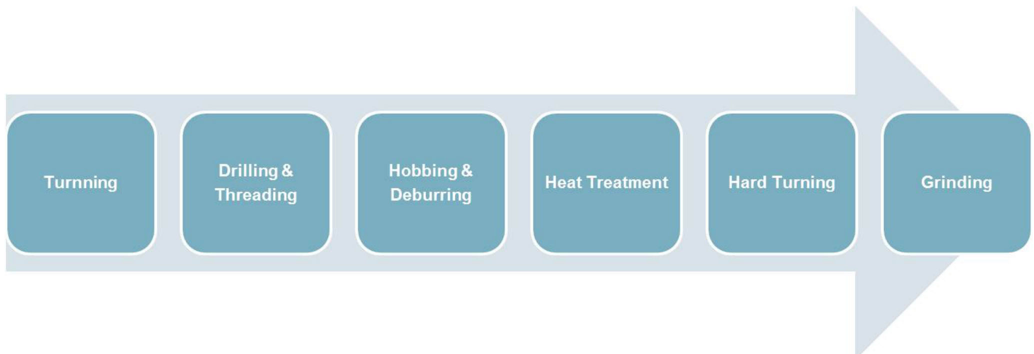

Fig.11: Conceptual production chain of a the ring gear

The production chain starts with the turning operation where the respective surfaces of the raw part will be turned with a special tool to a specified dimension. The next operation will be the drilling and threading of the work piece. As it is shown in Fig.9, twelve holes will be drilled and then threaded in fore side of the ring gear. After these operations have finished, it will move to the hobbing and deburring process. Here the teeth will be hobbed around the work piece and afterwards the deburring process will eliminate the burr which was arised during the hobbing process. The next process step is the heat treatment. During the heat treatment process the work piece will get better strength characteristics. After the Ring Gear has passed the heat treatment it will move to the hard turning process which is equal to the first operation. The last operation in the production chain is the grinding operation, where the respective functional surfaces will be grinded to a specified dimension. After the complete production chain has been passed through the finished will transport by internal logistics to the assembly. Ready for transmission assembly.

5.3 Concept Assumptions & Requirements

The following concept assumptions & requirements are the basis for the development of an appropriate low cost automation concept of complex process machines under consideration of lean management aspects for the in Fig.9 shown manufacturing processes.

5.3.1 Respected Concept Assumptions & Requirements

The listed assumptions and requirements are the basis framework for the concept development and derived from the method and principles of low cost automation in chapter 3.3. They need to be accordingly considered and integrated within the concept implementation.

- Reduction of part movement to a minimum
- As less baskets as possible
- Consideration of ergonomic issues
- Minimized amount of baskets
- Provision of flexible and simple automation
- Minimize of investment for automation
- Minimize the amount of movements for operator
- Flexible and reduced personnel deployment
- Maximum transparency and accessibility
- Operator demand max. 2
- Alignment and balancing of cycle times
- Process orientation due to modular and simple machine structure with flexible and low automation-degree
- Maintainability (simple repair and good accessibility)

Also important aspects are the quality restrictions. Influence factors which will have a negative effect on the work piece quality needs always to be taken into consideration. So the definition and alignment of dedicated quality restrictions are essential. The most commonly defects within manual handling or in simple automation systems are nicks. They are small damages on the surface, mostly on the corner which are caused by hits with other components or the like. Hereafter are listed the defined respective quality restrictions for this concept.

- No gravity conveying of machines components without pallets beyond the first operation process before heat treatment
- No accumulation and no contact of components on functional surfaces
- Avoid touching of components to each other
- Minimize manual handling and usage of Low Cost Automation wherever possible

5.4 Application of Methods for Low Cost Automation

This section is focusing on the conceptual application of the redefined process steps, combined low cost automation methods and principle for complex processing machines. And it will considerate and covers all listed assumptions and requirements.

5.4.1 Application for Manual Process of the worker

In this section it will be concentrated just on the conceptual perspective of manual handling for the worker according the defined manual process steps, which needs to be covered.

Methods for manual handling of the worker

- Integration of both hands separately within the manual process
- One grasp for change over
- Standardized hand movement
- Loading and unloading of material on standardized height
- Just insert activities for Operators (chaku chaku principle)
- Utilization of the operator on his workplace – combination of manual and automated station

5.4.2 Application for Low Cost Automation

Methods for low cost automation are selected and derived from the methods of lost cost automation in chapter 3.3.

- Process start automated with a dedicated switch
- Modular construction of equipment
- Output of one process step is the input for the next process step
- Mechanism for interjection
- Karakuri Principle – force of gravity

5.5 Application of Methods of Lean Management

According the requirements, in this section the lean methods will be appropriate considered and applied within the concept. Involvement of the elimination of the different kind of waste is another important aspect which needs also to be considered within the development. The following methods have been derived and chosen from the detailed description of lean management methods in section 3.1.3 methods of lean management.

- U-Shape structure
- Standardized work
- Visual Factory
- Kanban/Pull system
- Leveled production (Heijunka)
- Jidoka

The total arrangement of the manufacturing processes will be implemented according a u – shape structure which gives a maximum transparency and accessibility on one hand and on the other an efficient movement of the operator including a lean material flow. The manual handling of the worker will be followed according standardized process and working steps. Implementation of visual factory where ever it is reasonable is very important and will be integrated within the whole concept. The whole manufacturing process will be leaded by the pull system with its Kanban system, where the costumer tact time gives the tact for the manufacturing process. This integrates and follows also the principle of leveled production (Heijuka)

5.6 Concept Implementation

In the following chapter the developed concept implementation will be presented and explained in detail.

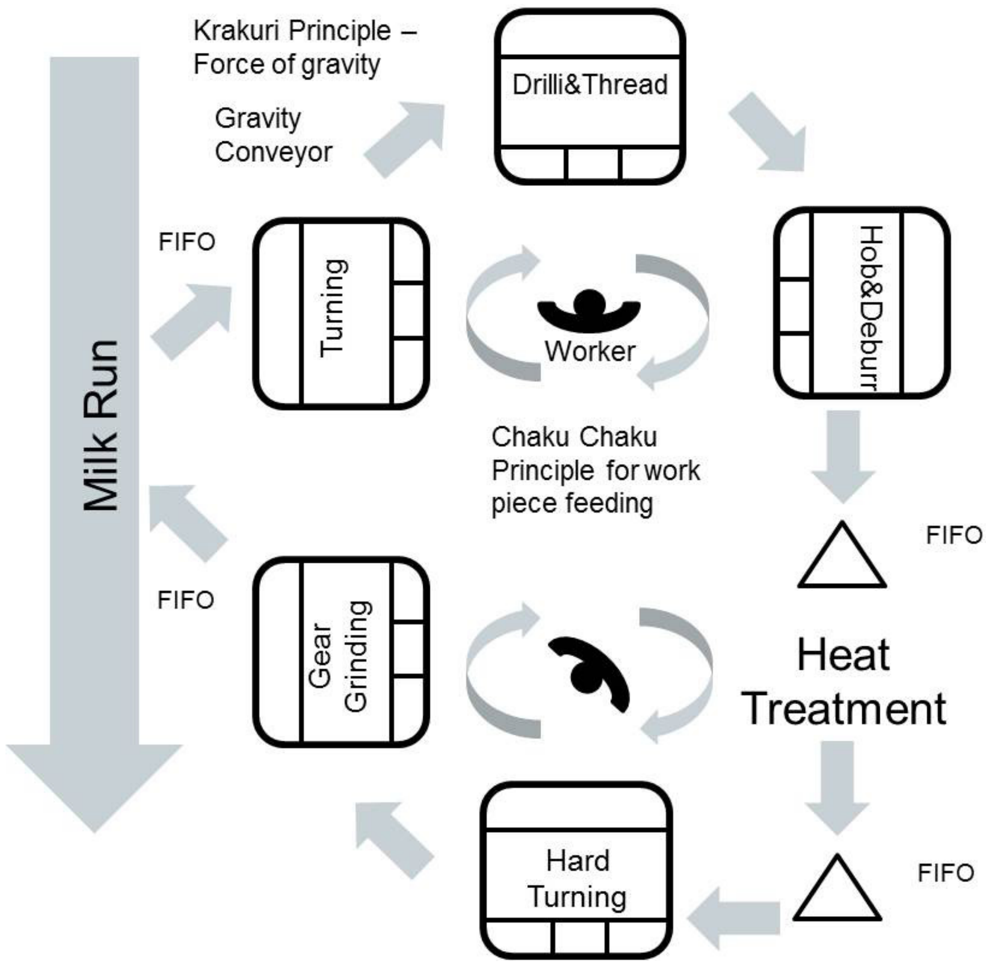

Fig.12: Schematic view of concept implementation (own drawing)

The schematic view of the concept implementation contains all necessary assumptions and requirements which are listed. Also the methods and principles of low cost automation and lean management which are shown in the previous sections have been applied.

Firstly the raw material will be delivered by a logistics milk run system in bulk material containers. The first machining process is the turning operation. The operator will follow the defined process steps, which are listed in Tab.4 and already shown and explained in the overall approach. The work piece feeding and loading/unloading equipment in the entire concept are a low cost automation system which includes the respected described methods. The operator picks the raw part from the bulk material container and drop it on the simple constructed feeding system where the part will moved by force of gravity to the loading position and the automatic loading process starts after a sensor has been activated by the work piece. It will be transported to the processing position and the machining process begins after the loading process has been finished.

The machined part will be automatically unloaded after the machining process has been finished. The work piece moves by force of gravity to the feeding system for the next operation. To avoid any defects on the gear side or any other functional surfaces of the work piece, plastic pallets will be used as transport tool which protects damaged caused by touching of parts to each other. The ring gear needs just to put on the pallet for transport. This is valid for all following processes after first turning operation until heat treatment and the last operation gear grinding, where the gears and functional surfaces could be potentially damaged.

Before the next operation starts the operator picks the finished work piece and verifies it according the quality specification. Depending on the manufacturing process operation the worker will pack the finished work piece or drop it back after verification and the work piece will be feed according the Karakuri principle to the next operation. After the hobbing and deburring operation the work piece will be picked up by the operator and dropped it on jigs which will be stored in a buffer and according the FIFO principle pulled through the heat treatment process. The buffer contains a defined amount of parts which will be defined according the value stream. After heat treatment the parts will be also stored in a buffer. From there the work piece will be transported according the FIFO system to the next manufacturing process where the dedicated operator will pick the heat treated work piece and put it on the feeding system. The process steps will repeat like already described until the complete finished work piece is ready for delivery by milk run according the FIFO principle. Compare to the raw part delivery in bulk material containers the finished parts will be finally loaded in single baskets. From the beginning all the manufacturing process will be passed through according the pull system with respective KANBAN system. The concept implementation is also able to integrate a piece flow principles where it is required.

The movements of the operator are limited according the already defined process steps and methods for the worker, and follows the chaku chaku principle. The concept proposal shows two operators, which have clear responsibilities according the schematic organization which are also shown in Fig.12.

6 Concept Validation

6.1 Methods of Validation

General it can be stated that the methods of validation are separated in two categories, quantitative and qualitative methods. In principle they differ from each other in terms of data collection method, assumption and interpretation. Selection of the proper method of validation depends always on the field of validation.

Quantitative validation method basically concentrates on the assumption of an empirical data collection and statistical evaluation. That kind of method is strict data oriented and leaves no scope for subjective evaluation. As precise are the empirical data collection as precise are the assumption which can be made. That is the reason why the quantitative validation method appropriates perfectly to countable and objective characteristics.[66]

Qualitative validation methods reference to a certain subjectivity and openness for interpretations. This kind of scope for subjective evaluation is based on human intellectual nature and relevant discussions. A favored qualitative validation method in the dedicated field of evaluation is the expert interview. An open and structured interview according defined criteria represents exact that kind subjectivity and openness for discussion and interpretations. It will be applied in a field of validation without any empirical data based and general previous knowledge, with a certain complexity and demand of subjectivity and openness for interpretation and assumptions.[67]

[66] Prein, Gerald; Kelle, Udo; Kluge, Susann (1993): Strategien zur Integra-tion quantitativer und qualitativer Auswertungsverfahren. Sonderfor-schungsbericht 186. Bremen: Universität Bremen, 28.
[67] Lamnek, Sigrid (1993): Qualitative Sozialforschung. Weinheim: PVU, 3.

Both validation methods have been accordingly evaluated whether it is the proper validation method for the concept or not. Currently there are no existing empirical data to be validated. So for the concept validation the method of expert interview has been selected. With this kind of validation method the technical and specialist expertise of the interviewer will be specifically inquired, discussed and validated by means of a validation matrix with certain criteria. Also the discussion about the opinion for the total concept from the expert point of view is a positive aspect.
The expert for the interview has been selected by certain criteria.

- Field of expert
- Practical and theoretical expertise
- Reputation and organizational position

For the selected method of validation a matrix will be created as a validation tool and basis for the expert interview which includes respective criteria and a weighting including a dedicated scoring method.

6.2 Criteria & Weighting of Validation

The criteria have been selected according the defined requirements for the concept and respective characteristics. These criteria received a certain weighting in terms of numbers from one to five, where five stands for the highest value and one for the lowest weighting. Three different partial aspects will be validated, the application of criteria for reduction of investment and increase of efficiency, integration of the defined quality restriction and involvement of lean management in context to the aim of this thesis. Depending on amount which will be the result of the total weighting leads to certain range. In the case of Tab.9 the range for result of the rating is min. 41 and max.205 points. Means the total scoring of the interviewer can just be within the mentioned range depending of the validation. The respective weighting has been selected according the principle of effectiveness, means which criteria lead to the highest effect, shown in Tab.9, the highest effect on investment reduction. The weighting of criteria was a first assumption and also part of the expert interview.

6.2.1 Criteria of validation for investment reduction and efficiency improvement (Low Cost Automation)

Based on the selected partial aspects the following criteria has been developed according the reduction of investment and improvement of efficiency. These criteria are having a direct relation to the aim of this thesis.

Validation for investment reduction and efficiency improvement (Low Cost Automation)			
very well: +++++ poor: +	**Weighting**	**Interviewer 1**	**Interviewer 2**
Validation Criteria			
Consideration of easy interaction between human and automation			
Consideration of developement and implementation by own people (in best case)			
Flexible and simple automation with low automation grade			
Process orientation due to modular and simple machine structure (compact&practicabel)			
Minimized of investment for automation			
Maintainability (simple repair and good accessibility)			
Easy to use (semi - skilled or unskilled people)			
Clear separation between manual handling and automation			
Consideration of ergonomic issues			
Result	min 0+ / max 0+	0 +	0 +

Tab.5:Validation criteria of partial aspect of investment and efficiency (own table)

6.2.2 Criteria of validation for quality restriction

The following criteria for validation has been developed according the defined and selected partial aspects which already have been described in section 5.3. Quality restriction is also linked to assignment of that thesis and in relation to the efficiency improvement, because defect parts will reduce the effectiveness of the manufacturing process.

Validation application of quality restriction			
very well: +++++ poor: +	Weighting	Interviewer 1	Interviewer 2
Validation Criterias			
No gravity conveying of machines components without any nick protection beyond the first operation process before heat treatment			
No accumulation and no contact of components on functional surfaces			
Avoid touching of components to each other			
Minimize manual handling and usage of Low Cost Automation wherever possible			
Result	min 0+ / max 0+	0 +	0 +

Tab.6:Validation criteria of partial aspect of quality restrictions (own table)

6.2.3 Criteria of validation for consideration of LM

The following criteria are based and selected under the context of lean management, which is not considered to the aim and assignment of this thesis. But in context it is an aspect which will be validated because of the influence on efficiency and productivity of manufacturing processes.

Validation application of lean management aspects			
very well: +++++ poor: + ***Validation Criteria***	**Weighting**	**Interviewer 1**	**Interviewer 2**
U-Shape Structure			
Minimize the amount of movements for operator			
Operator demand max. 2			
Flexible and reduced personnel deployment			
Minimized amount of baskets			
Reduction of part movement to a minimum			
Considartion of standardiezed work			
Consideration of visual factory			
Considartion of Pull System&One Piece flow			
Consideration of Leveled Production principle (Heijoka)			
Alignment and balancing of cycle times			
Maximum transparency and accessibility			
Result	min 0+ / max 0+	0 +	0 +

Tab.7:Validation criteria of partial aspects of Lean Management (own table)

6.3 Performing of Expert Interview

The expert interview has been performed with specialist and experts from the field of Manufacturing Engineering dedicated to concept development for new production lines. The expert for the interview has been selected by certain criteria.

- Field of expert (Low Cost Automation and Lean Management)
- Practical and theoretical expertise
- Reputation and organizational position

Guideline for the interview was the validation matrix with the respective validation criteria and weighting. The Interview was followed the defined criteria structure. The interviewer gave his estimation according the relevant scoring value. A detailed discussion about the sense of the criteria and application to the concept was also basis for the rating. For a “very well” rating five + as a character, needs to be given and for a “poor” just one + as a character, shown in Tab.5. So there is a range between very well for the best and poor for the lowest rating. The following three Tables, shown in Tab.9 to 11, show the outcome and result of the expert interview according the respective ratings for the criteria in the field of aspects. And which are focused on the consideration of the relevant criteria for the achievement of the introduced objectives for this thesis.

Validation for investment reduction and efficiency improvement (Low Cost Automation)			
very well: +++++ poor: +	Weighting	Interviewer 1	Interviewer 2
Validation Criteria			
Consideration of easy interaction between human and automation	4	++++	++++
Consideration of developement and implementation by own people (in best case)	5	+++++	++++
Flexible and simple automation with low automation grade	5	+++++	+++++
Process orientation due to modular and simple machine structure (compact&practicabel)	5	+++++	+++++
Minimized of investment for automation	5	+++++	+++++
Maintainability (simple repair and good accessibility)	4	++++	++++
Easy to use (semi - skilled or unskilled people)	4	+++++	+++++
Clear separation between manual handling and automation	5	+++++	+++++
Consideration of ergonomic issues	4	+++	+++
Result	min 41+ / max 205+	189 +	184 +

Tab.8:Validation matrix for investment reduction and efficiency improvement (own table)

Validation application of quality restriction			
very well: +++++ poor: +	Weighting	Interviewer 1	Interviewer 2
Validation Criterias			
No gravity conveying of machines components without any nick protection beyond the first operation process before heat treatment	5	+++++	+++++
No accumulation and no contact of components on functional surfaces	5	+++++	+++++
Avoid touching of components to each other	5	+++++	+++++
Minimize manual handling and usage of Low Cost Automation wherever possible	5	+++++	++++
Result	min 20+ / max 100+	100 +	95 +

Tab.9:Validation matrix for application of quality restrictions (own table)

Validation application of lean management aspects			
very well: +++++ poor: + / ***Validation Criteria***	**Weighting**	**Interviewer 1**	**Interviewer 2**
U-Shape Structure	**5**	+++++	+++++
Minimize the amount of movements for operator	**4**	++++	++++
Operator demand max. 2	**4**	+++++	+++++
Flexible and reduced personnel deployment	**4**	++++	++++
Minimized amount of baskets	**4**	+++++	+++++
Reduction of part movement to a minimum	**5**	++++	++++
Considartion of standardiezed work	**5**	+++++	++++
Consideration of visual factory	**5**	+++++	+++++
Considartion of Pull System&One Piece flow	**5**	+++++	+++++
Consideration of Leveled Production principle (Heijoka)	**5**	+++++	+++++
Alignment and balancing of cycle times	**4**	+++	+++
Maximum transparency and accessibility	**4**	++++	+++
Result	min 54+ / max 270+	245 +	236 +

Tab.10:Validation matrix for application of lean management aspects (own table)

6.4 Result of Validation

To summarize the outcome of validation it leads to the following result. General it can be said that the rating of Interviewer 1 and 2 are almost similar. The expert point of view in terms of application of criteria for investment reduction and efficiency improvement is in average rated with a scoring from Interviewer 1 with 189 points and Interviewer 2 with 184 of 205 points, which represents a validation between well and very well. The minimization of the investment and life cycle cost on one side is driven by the implementation of the following criteria, which also received 5 weighting, usage of own expertise, integration of low cost components and implementation by own people. And the Improvement of the efficiency and productivity by involvement of flexible and simple automation with low grade of automation, a clear separation between manual handling and automation and process orientation due to modular and simple machine structure on the other side.

The result of the expert interview for these high weighted criteria proofed the consideration and implementation in the developed concept, which leads clear to investment reduction and efficiency and productivity improvement. The criteria consideration of ergonomic issues received a scoring 3 because this aspect was not in detail considered. After a detailed discussion the outcome was that a separate performed ergonomically consideration makes absolutely sense caused by the amount manual handling with a weight of 8 to 5 Kg for the work piece.

For consideration and application of the Quality restriction the concept was rated with very well from Interviewer1 and 2. The solution with pallets to avoid nicks was deeply discussed and generated a great interest caused by the conceptual simple and cheap integration.

In the Context of Lean Management the interviewer rated the concept between well and very well. The implementation of a U – Shape structure within the total process line has been considerate as key criteria for a Lean concept and was the basis for discussion.

General the feedback and result of the total validation for the whole concept was a well to very well evaluation according the shown validation matrix. Feedback and next step from the interviewer side was a discussion with higher management about the concept implementation in the currently under investigation phase for a new production line.

7 Summary & Recommendation

Summarizing the conclusions which have been compiled with this Thesis, the following can be stated. Aim of this work was the investment reduction and the improvement of efficiency and productivity through the consideration and implementation of the certain criteria as derived and defined in the chapter Introduction. That aim has been achieved by the various methods of low cost automation and lean management which were separated and evaluated according their scope of application and applied under a new approach within the concept. Reduction of process complexity and high sophistication for the worker of feeding and loading/unloading activity including a clear separation between automation and manual activities of the worker was the outcome.

Various process steps in the different fields of application has been reviewed and simplified redefined for the dedicated field of application. It has been reduced to just simple movements. After an evaluation of the existing methods and principles for the dedicated area of application for the low cost automation, the Karakuri principle with the force of gravity for the feeding system has been selected. That choice brought a completely separation from the high sophisticated complex process machine a simple, efficient and cheap Low Cost Automation for the feeding, loading/unloading system. For the standardized movements the chaku chaku principle has been selected which keeps the movement of the operator to a minimum and separates also the manual activities from automation.

After completion of the developed concept the implementation into a dedicated manufacturing process chain for a certain production work piece and the concept validation were the last part of this thesis.

The concept implementation was validated by the qualitative validation methods in form of an expert interview and based on the selected criteria from derived partial aspects. Finally and summarized it can be stated according the result of validation by the experts that the developed and implemented concept is from the low cost automation point of view and lean management aspect absolutely efficient and applicable.

The next steps are the discussions and evaluation of the entire concept with the respective departments of manufacturing engineering and higher management, if it fits to the various future manufacturing concepts of the company. The priority and decision making stays to the company if the developed concept will take into account for further projects.

It is recommended to follow up on the defined approach of low cost automation for feeding and loading/unloading systems of complex process machines and the separation of manual activities of the worker and automation to keep the manual and automated process steps simple and efficient.

Also it is recommended for the next step to revive the ergonomic aspects and consideration for the manual activities of the worker. Based on the work piece dimension, described in section 5.2.1, and the amount of the various manual movements of the worker during feeding activities, further ergonomic investigations should to take into account and accordingly followed.

8 References

8.1 List of Figures

8.2 List of Tables

8.3 Bibliography

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8.4 Hyperlinks

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