Professional MBA
Entrepreneurship & Innovation

The future of mobile robots in industrial environment

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

Supervised by
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Sofia, 30-June-2017

Affidavit

I, **Martin Metodiev Ivanov**, hereby declare

1. that I am the sole author of the present Master's Thesis, "The future of mobile robots in industrial environment ", 49 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, 30.06.2017

Signature

Abstract

This master thesis is aimed to investigate the optimal manufacturing production and financial profit in an industrial environment using mobile robots instead of human operators. The broader research question I aim to answer in this paper is - a method for evaluation of the financial investment for implementing mobile robots in manufacturing. Theoretical method and practical model that will help the potential users of mobile robots to estimate the startup cost and risk in the initiation phase of the project. A scenario of ten different manufacturing processes for manual and autonomous production is created to benchmark the manual and automated manufacturing line. Multiple mobile robots that are programmed to work without human supervision in a synchronized manufacturing process to reduce total cost and improve productivity. The goal is to present *robot make robot* manufacturing process, without any human intervention. Household mobile robot is the product of the manufacturing process. The paper focus on the startup investment and returns for each scenario for a five-year period. I have referred to different literature to assess various methodological approaches and adapt them to my proposed work. The technical and financial benefits, productivity and customer satisfaction are presented through manufacturing radar chart tool.

Throughout the thesis, I have explored the impact of mobile robots and automation to business and people. The effect of automation toward the labor rate and unemployment. The feedback from the public and the organizations that are using or planning to use robots. The future of automation for the next generation and a brief look one hundred years ahead.

This study has been a challenging and valuable learning experience for me. I believe that my master thesis will have some significant takeaways for mobile robots and automation in manufacturing.

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Preface

This master thesis represents the final work of my Master of Business Administration degree at the Executive Academy, Vienna, Austria. The process of completing this thesis has been both challenging and time-consuming but has also been both instructive and educational. This assignment gave me the opportunity to expand the knowledge on several subjects of interest, namely technical and financial estimations of using mobile robots, applicable for industrial companies investing in automation and mobile robots.

Evolution of life:

Humans create humans.

Humans create robots.

Robots create robots.

Robots create humans.

Martin Ivanov

1. Introduction

In this chapter, a short background of the industrial automation and mobile robots will be conducted, presenting the reasons why this topic is relevant from an academic and industrial point of view. Afterward, aim and research questions are presented to get a general overview of the thesis. This thesis develops and implements a simulated based approach with a quantitative and qualitative research methods for integrating a mobile robot in industrial environments.

1.1. Background

Modern robots are designed by engineers for assisting or replacing the human to perform complex planning and control operations and tasks, such as managing objects, supporting workers in a variety of professions, navigating in outdoor environments, exploring unknown territories, and driving in urban areas. Mobile robots are used in different industrial areas and fields, such as aerospace, automotive, pharmaceutical and military industry, consumer market, and so on.

Automation is not a simple technology and is not a new phenomenon. The *term* "*automation*" was *coined* in the *1940*'s to describe a production process in which machine moves parts from one place to another. The key goal of automation is to minimize and eliminate human intervention. (Hayden, 2014) Autonomics refers to self-learning structure, where the system makes autonomous decisions, using high-level algorithms, continuously optimizing its performance and automatically adapting to the changing conditions of the evolving environment. An algorithm is a computer program, created to solve an issue or optimize a process as fast as possible. (Kumar, 2014)

A mobile robot is a machine that senses, thinks, and acts. Thus, a robot must have sensing elements, processing ability that emulates some aspects of cognition, and actuators. Mobile robots are grouped in structures that can operate in unconstrained environments and have the capability to move around freely. They can work autonomously in a partially unknown and unpredictable environment without the need of signs or direction devices (autonomous mobile robot (AMR)). Alternatively, mobile robots can be managed by devices that allow them to travel a predefined navigation route in a relatively controlled environment (automated guided vehicle (AGV)). (Robot Mechanisms, 2016)

Autonomy associates with systems capable of operating in the real-time environment, without any form of external control for continued periods of time. A fully autonomous robot can accumulate through sensors and vision system information about the surrounding environment, adapt to the environmental changes and operate for an extended period without human intervention. It can drive or move either all or part of itself through its sensitiveness without external support, avoiding situations that are harmful to people, properly. An autonomous robot may also learn or gain new knowledge by using its sensitiveness (sensors and controls) and adapt better to changing surroundings. Therefore, to adapt to these technological challenges and changes, mobile robots need to have the capabilities of autonomy and intelligence. Designing algorithms that allow the robots to function autonomously in chaotic, dynamic, fast changing, and uncertain environments pose a challenge to researchers to deal with the major key such as uncertainty, reliability, and real-time response.

Traditionally, industrial companies create new technologies for their products relying exclusively on their R&D capabilities (Chesbrough, 2003). Today's manufacturers have to deal with increasing designed costs, customization, decreasing product life cycle, growing product diversity, and fluctuating demands. The new millennium products require manufacturing customization and flexibility, process precision, and product reliability that is beyond the skills of the human workers alone. It requires new hardware tools and versatile software design, process and production approach. Standard industrial robots advance more and more to fulfill the customer's needs and requirements, with a broad mix of new technologies and technics. Remodeling automation elaborate new scope for the major performance indicators as form factors, payloads, and capabilities. However, new automation opportunities are also emerging for variable and semi-structured environments, especially in small and mid-sized businesses.

Technological innovations help improvement move forward at an exponential rate. Vast increases in productivity and efficiency will be realized after an integrated network of mobile robots is established. The amount of professional service robots sold in 2015 rose by 25% to 41,060 units up from 32,939 in 2014. The sales price increased by 14% to $4.6billion. Since 1998, a total of about 220,000 service robots for professional use have been counted in these statistics. It is not possible to evaluate how many of these robots are still in use due to the diversity of these devices resulting in different usability spans. Some robots (e.g. underwater robots) might be more than ten years in operation (compared to an average lifetime of 12 years in industrial robotics). Robots in the defense industry may only serve for a short time. In 2015, about 5.4 million service robots for household use were depleted, 16% more than in 2014. The sales increased by 4% to $2.2 billion. The IFR research includes 50 countries from 1993 to 2014, linking to 90 percent of the industrial robots market. (IFR, Executive Summary World Robotics 2016 Service Robots)

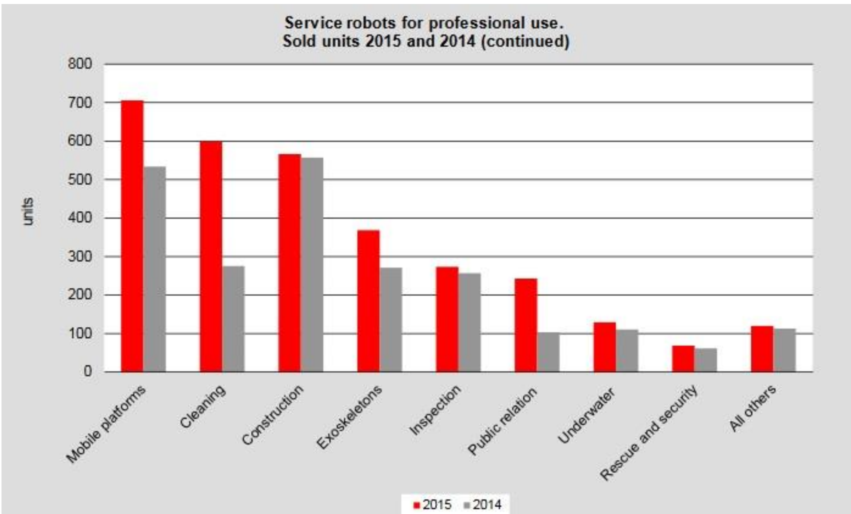

Figure 1. Service robots for professional use (2014-2015), IFR

The global robot market report from IMF is indicating that approximately 1.4 million industrial robots will be put into operation in the factories to increase productivity. About 333,000 service robots for professional use will be sold to non-manufacturing and manufacturing sectors. About 42 million service robots for personal and domestic use (consumer robots) will be utilized in our private life. (IFR, 2016)

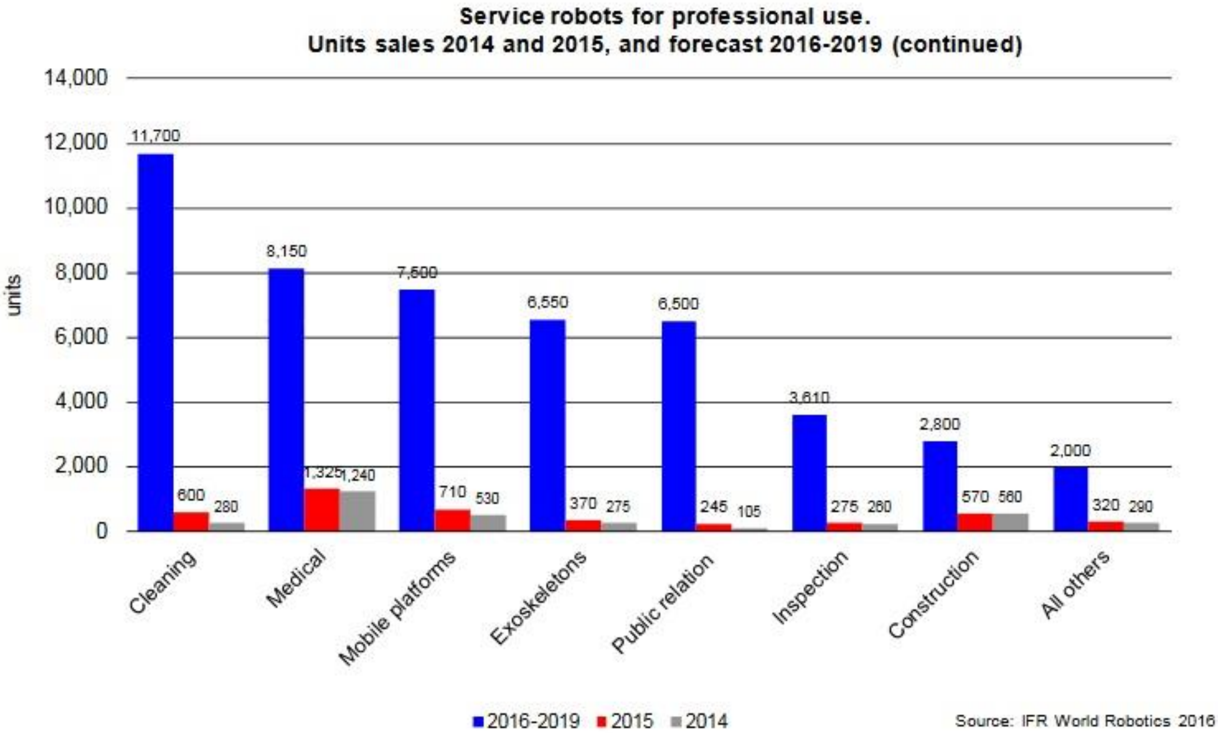

Figure 2. Service robots for professional use (2014; 2015; 2016-2019), IFR

1.2. Aim and research questions

Over the last few years, although much research has been done about Mobile robots, there is a lack of knowledge concerning risk and return on investment during the startup phase of the project. The reason *Why?* this thesis has been written is to create a method for evaluation of the financial investment for implementing mobile robots in manufacturing. First of all, there is a discrepancy of understanding regarding the methodology used by companies integrating new automated production. Furthermore, technological and financial aspects of collaboration across organizational borders are not yet fully explored.

There appears to be a conflict between autonomy, which implies that a robot is capable of taking care of itself, and control, which supposed to be monitored and managed by the human. Additional supervision and rules are required to ensure that the robots do not harm any humans or machines. In effect, this high level of control implies as part of Asimov's laws, which can be summarized like this:

1. A robot should never injure a human being.
2. A robot must execute the orders received by a human being if they do not conflict the first law.
3. A robot should not harm another robot except this contradicts the first or second law.

Asimov also added a fourth, or zeroth law, to precede the others:

0. A robot may not harm humanity, or, by inaction, allow humanity to come to harm.

“When a computer became capable of independently devising ways to achieve goals, it would very likely be capable of introspection—and thus able to modify its software and make itself more intelligent. In short order, such a computer would be able to design its own hardware”.
(The Age of Spiritual Machines, 1999)

The purpose of this thesis is to explore the benefits of investing in fully automated manufacturing line operated only by Mobile robots. The method begins with a benchmark of the manual and automated manufacturing line, identifying the challenges that investors may encounter, due to the complexity of automation. Thus, the first research question is as follows:

1. *What are the overall startup investment costs for design and development of a manufacturing line, which is manually operated by humans, compared to the automated one operated by mobile robots?*

The following step consists of understanding the direct and indirect labor costs. Therefore, the next research questions are as follows:

2. *What are the labor costs of the human worker compared to the mobile robot?*

3. *What are the financial benefits and return on investment for manufacturing using mobile robots?*

Finally, the results, as well as analysis of data, will be used to make some suggestions about how to mitigate challenges in automation of manufacturing with mobile robots, and thus some recommendations for future actions will be given. In the end, a couple of more society related questions will be discussed.
How will we pay the bills with so much unemployment caused by increasing automation?
How will our economy function without the retail sector in the absence of income from work?

2. Method

In this section, the intent is to address the main issues of implementing mobile robots from a technical company level perspective toward sub-level analysis. First of all, technical and financial challenges are assessed to classify the risk of the investment. Secondly, human and mobile robots direct labor rates are explored, highlighting the benefits of using mobile robots.

2.1. Introduction

Robotics has become a big business. As Mobile robot systems become more needed in industry, some scientific and technological challenges appear. In particular, in this thesis, I would propose control strategies which evaluate the risks and the performance of the mobile robotic system. The concerns are relevant both from a theoretical and a practical point of view because the area of application of mobile platforms is very broad.

Mobile robots can maintain dangerous industrial machines, handle hazardous materials and monitor remote oil pipelines. They can help people in various categories as consumer, health, enterprise and industrial providing different variety of services. Indeed, as mobile robots become more and more accepted, it may be increasingly difficult to say exactly what a robot is. One of the growing applications for mobile robots is in the area of consumer robots. Roomba is probably the most popular consumer type of mobile robot used for cleaning homes. Winbot is another type of mobile robot used for cleaning windows. Roomba and Winbot can be purchased from the local tech store or ordered online. Household users are willing to use the cleaning robots, but they are not predisposed to spend a lot. The consumer price for household cleaning robots is in the range of 50EUR-500EUR, and it's continuously decreasing, reported by IFR. The forecasts of household robots are predicting an increase from 4.3M per year in 2015 to 19.3M units by 2020, and revenue from $3.1 billion to more than $10.4 billion. The consumer robotics market has achieved significant growth in the past few years. The use of robotics in people everyday activities helps mainly in saving time and cost. It is increasing the comfort of the consumer and the feeling of using innovative and luxury appliance. Consumer robots serve human in a way that makes him capable of creating and controlling other machines to become faster, smarter and more robust than humans.
The goal of the manufacturing line will be to produce a new type of mobile consumer robot called TUTU. It's a household Star Wars style R2D2 mobile robot for the real world that can communicate wirelessly via protocols with the digital network and by microphone and hologram with people. The Bills of Material, the material cost, and the expanded drawing are presented in figure 3 and Table 1.

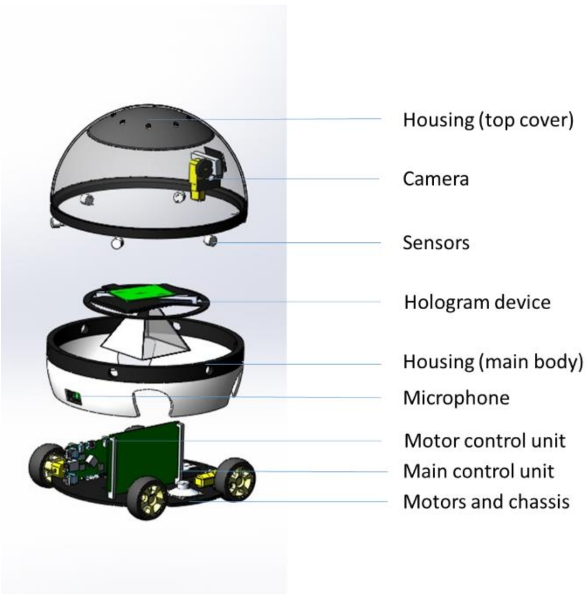

Figure 3. Hologram smart robot – expanded view

Bills of Material (BOM)		
Number	Part name	Material cost [EUR]
1	Control unit	10.00 €
2	Motors and chassis	10.00 €
3	Motor control	15.00 €
4	Housing	14.00 €
5	Sensors +Camera +Mic	12.00 €
6	Battery	8.00 €
7	Hologram device	25.00 €
8	Cables	3.00 €
9	Screws	1.00 €
10	Packing	2.00 €
	Total	100.00 €

Table 1. Hologram smart robot: Bills of Material (BOM) and material cost

2.2. Manufacturing line - process flow

A process of ten steps, presented in figure 4 is created for the production of the hologram smart robot from figure 3. The process flow applies to manual and autonomous production. It will be used as a base for benchmark the performance and the return on investment.

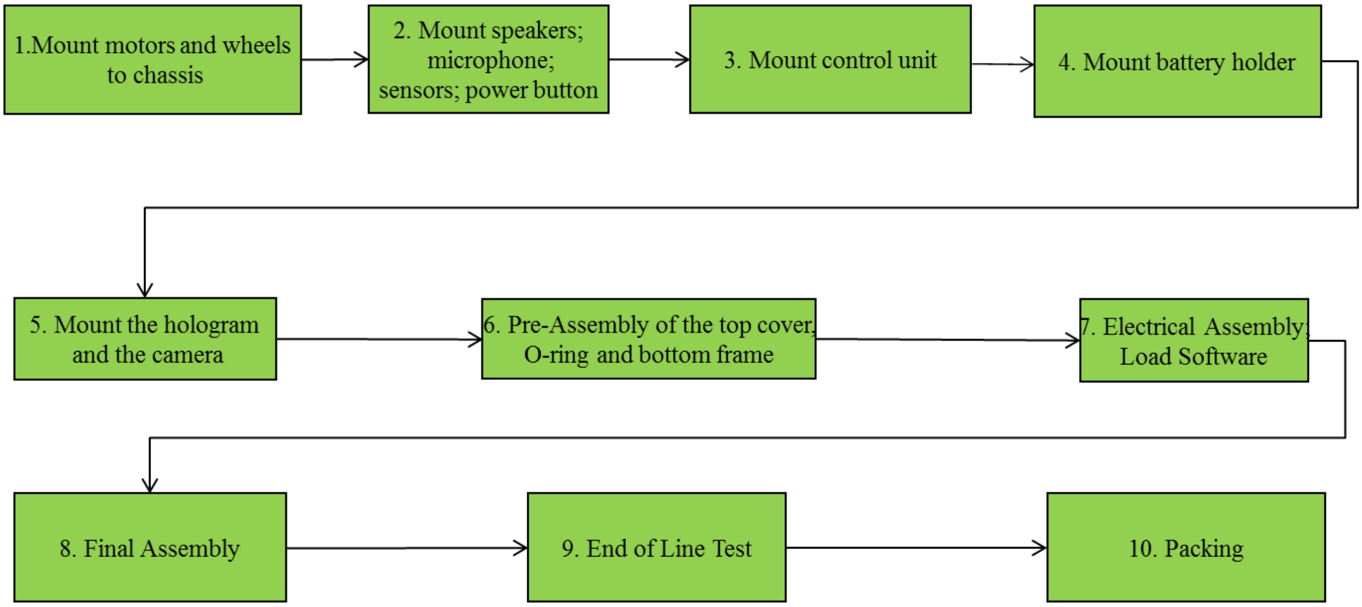

Figure 4. Manufacturing line – Process flow

2.2.1. Manufacturing line – operated by human operators

Humans create robots.

A person who accomplishes the process or works on an assembly line is a human operator. The manufacturing layout on figure 5 is presenting the real production organization with human operators, based on the process flow from figure 4.

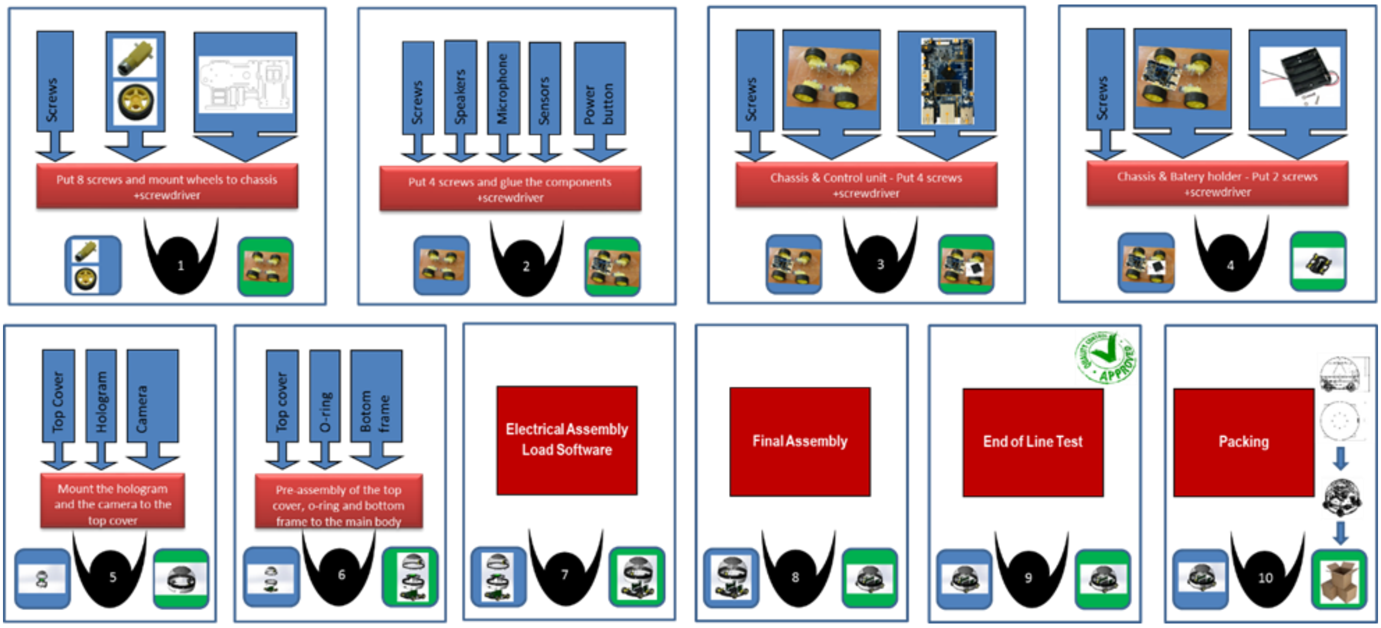

Figure 5. Manufacturing line layout – operated by human operators

Manual line operated by human operators									
Number of operation	Operation description	MACHINE	Number of machines needed [number]	Estimated Cycle time [sec]	Hour capacity pcs/1hour	OEE (%)	Average Annual capacity (5days, 3 shifts) [in KU]	Maximum Annual capacity (7days, 3 shifts) [in KU]
1	Put 8 screws and mount wheels to chassis+screwdriver	Automatic Machine for Magnetization	1	17.00	212	85%	980	1,380
2	Put 4 screws and glue the components+screwdriver	Automatic Machine for spring and screw mounting	1	18.00	200	85%	925	1,304
3	Chassis & Control unit - Put 4 screws+screwdriver	End of Line Test Machine	1	20.00	180	85%	833	1,173
4	Chassis & Battery holder - Put 2 screws+screwdriver	Asymtek Dispense XY-table and curing storage	1	20.00	180	85%	833	1,173
5	Mount the hologram and the camera to the top cover	Asymtek Dispense XY-table and curing storage	1	20.00	180	85%	833	1,173
6	Pre-assembly of the top cover, O-ring and bottom frame to the main body	NABERTHERM OVEN	1	20.00	180	85%	833	1,173
7	Electrical Assembly; Load Software	NABERTHERM OVEN	1	15.00	240	85%	1,110	1,564
8	Final Assembly	NABERTHERM OVEN	1	16.00	225	85%	1,041	1,467
9	End of Line Test	NABERTHERM OVEN	1	19.00	189	85%	877	1,235
10	Packing	NABERTHERM OVEN	1	20.00	180	85%	833	1,173

Table 2. Manual manufacturing line operated by human operators – OEE and capacity calculations

The calculations in Table 2 are presenting the process flow from figure 3 and figure 4, showing that the cycle time varies from 15sec to 20sec. The bottleneck is an operation *10.Packing* with a cycle time of 20sec. Maximum monthly capacity 97750 units per month. The maximum annual capacity of the manual line operated by human operators is 1,173,000units per year.

Manufacturing Process:

1. The operator is loading by manual handling the components, located in trays at his left side to the machine for processing
2. The machine is autonomously processing the operation, returning the assembled product
3. The operator is unloading by manual handling the assembled product to trays

The trays are placed on trolleys or cars, which are used for manual transport from one working station to another.

Annual capacity is calculated as follows:

Working days per year x Plant operation time excluding breaks x Shifts x Estimated Cycle time

Average Annual capacity:

Working days per year – 252

Plant operation time excluding – 7.2hours

Shifts – 3

Estimated Cycle time – According to operation

Maximum Annual capacity:

Working days per year – 355

Plant operation time excluding – 7.2hours

Shifts – 3

Estimated Cycle time – According to operation

Cycle time is a time measured from the first moment a component entered into the machine, till the required time to complete all the manufacturing process by the machine (Scholl, 1999).

OEE= 85%, of the human operated line with full load of equipment conforms to the following:

Availability= 94%

Performance= 94%

Quality/Yield= 97%

OEE (Overall Equipment Effectiveness) is a measure of machine performance. It is the product of yield and uptime. Any manufacturing equipment must operate at a minimum OEE of 85% long term.

Effectivity is calculated using the method described by (Braglia, 1986) as follows:

OEE = AVAILABILITY x PERFORMANCE x QUALITY

The availability is calculated taking account of gross available time, downtime loss, actual operation time and the planned production time.

AVAILABILITY is calculated as follows:

A = Gross available time (planned duration of run)

B = Planned downtime (breaks, PMs, cleaning, etc.)

C = Run time (A - B)

D = Downtime losses (breakdowns, stoppages, jams, adjustments, etc.)

E = Operating time (C – D)

F = Availability = (E / C) x 100

The performance is calculated by taking account of total output and cycle time in the system.

PERFORMANCE is calculated as follows:

G = Total output (number of units)

H = Theoretical cycle time

I = Performance = ((G x H) / E) x 100

The quality is calculated by taking account of nonconformity parts rejected by the system.

QUALITY is calculated as follows:

J = Rejects during operating time

K = Quality = ((G – J) / G) x 100

2.2.2. Manufacturing line – operated by mobile robots

Robots create robots.

Lean Manufacturing originates from the Japanese word "*muda*", which means "*waste*" or uselessness. *Lean thinking provides a way to more work with less human effect, less time, less equipment and less space* (Womack and Jones, 2003). The key goals are to eliminate the waste, improve quality and productivity, reduce inventory, etc. Competitiveness is driving manufacturing companies to continue improving the old production processes to lean production, making the customer satisfied. (Pieńkowski, 2014)

The mobile robot used in the master thesis is Adept Lynx, made by Omron. The technical specification is presented in figure 6. The Adept Lynx is a self-operating Autonomous Indoor Vehicle (AIV). It is capable of transporting goods autonomously from one point to another according to the facility layout. Lynx requires no layout modifications, such as floor magnets or guiding signs. Dedicated software and controls are steering the mobile robot movements around people and unplanned obstacles. The software is easy to use and to be programmed by an engineer. It is a flexible system, which can be customized for different applications and operations in manufacturing, warehousing, clean tech, and laboratories. The cost of one Adept mobile robot equipped with a conveyor to suit synchronized AGVs with all manufacturing processes presented in the master thesis case is approximately 5,000€. The power consumption or direct labor cost is 1€/hour. (Adept Technology, Inc., 2015)

Figure 6. Adept Lynx – technical specification

The manufacturing layout on figure 7 is presenting the optimized Lean manufacturing layout with mobile robots, based on the process flow from figure 4. Human operators are replaced by mobile robots. Compared to the layout from figure 5, machine four and machine five are positioned next to each other, which reduce the transportation time. Inventory is concentrated on one side only, which saves space. Another Lean Manufacturing principle integrated into the automated line is Jidoka. Jidoka or "automation with a human touch" is the ability of the automated line or the mobile robot to sense and automatically stop, if a failure occur. It means that the problem is detected by the machine without human intervention, preventing non-conformity products from being manufactured. (Pieńkowski, 2014)

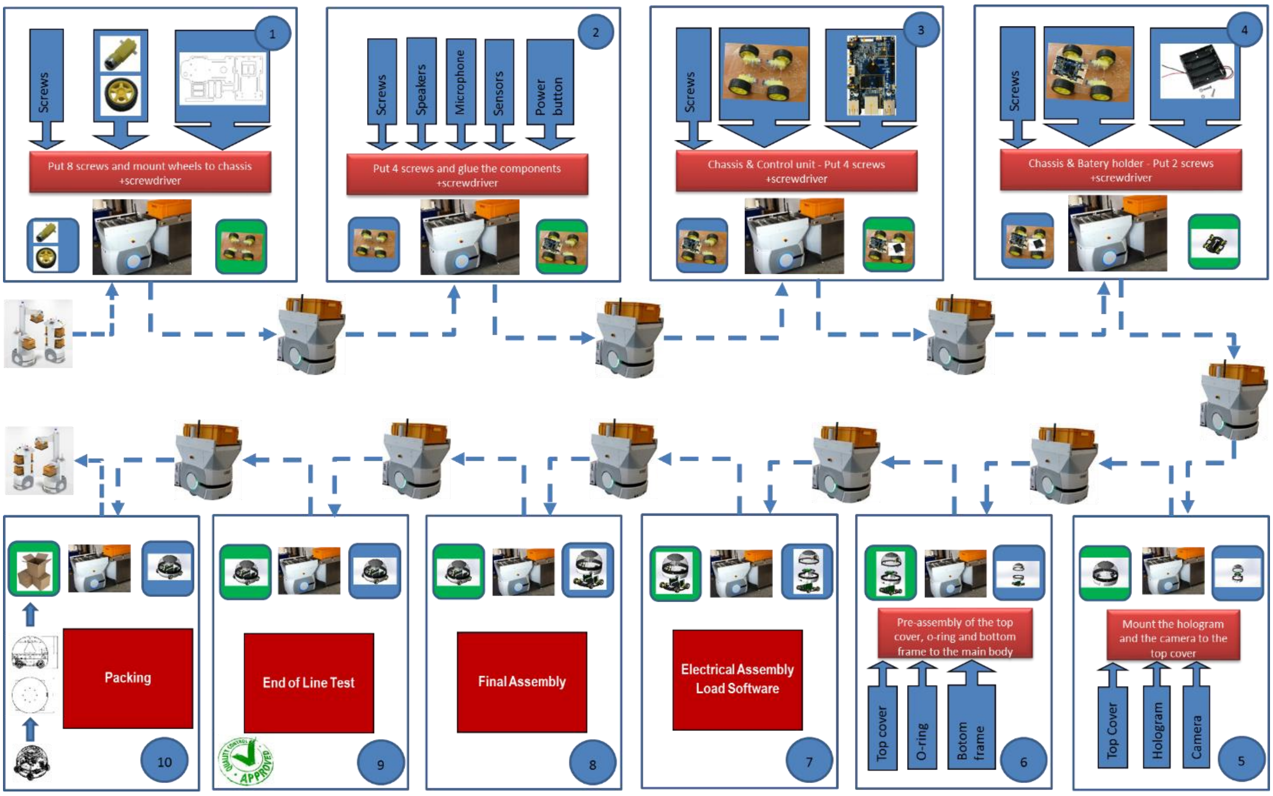

Figure 7. Manufacturing line layout – operated by mobile robots

Figure 8. Pictures of Adept in similar manufacturing environment

Figure 8 is representing the actual look of the mobile robot in real industrial environment.
The manufacturing line layout on figure 7 is presenting the following manufacturing process, which occurs without human intervention:

1. The mobile robot loads the components on the tray, automatically and autonomously through the conveyor, and conveys them to the machine for processing.
2. The stationary machine is equipped with similar conveyor capable of loading and unloading the trays from the mobile robot. Inside the machine, the components are processed and assembled automatically through several pick and place operations. The machine is synchronized for autonomously processing the operation, returning the assembled product in trays to the mobile robots.
3. The mobile robot is unloading the trays with the assembled products from the station, and it is loading them in the next station.

Each mobile robot movement is fully aligned with the production machine process. Loading, unloading, and transport are synchronized by the engineers to minimize the idle time. Idle time is the total time a mobile robot has been powered on but has not been used. A wireless charging station located in front of each machine is charging the mobile robot battery during the idle time, which ensures 24hours running time of the robot and 100% availability. The trays with the parts for manufacturing are placed on the conveyor located at the top side of the mobile robot. Each tray is marked with Data Matrix Code (DMC) to ensure full traceability of all process steps. The data is recorded in history log file managed by Enterprise resource planning (ERP) system.

ERP systems track and control business resources - cash, raw materials, production capacity - and the status of business commitments: supply orders, sales orders, and payroll. Register data for each production lot and each scrap, checks components plausibility with BOM, saves used part lots in the database. Imports and exports data from routings, BOM's and status of each production order from an ERP data server and generates production lots used by the mobile robots. Production warehouses collect data for each received package and checks for first in, first out (FIFO) component lots sequence. On the packaging, operation generates a unique serial number of boxes and sends data to traceability system. It ensures full traceability for each supplier production lot from receiving (warehouse) through the manufacturing line to the end – packing and customer. The production machines and the mobile robots, which are connected to the ERP traceability system, get automatically informed about all lots, products and process parameter settings. The mobile robots designed for this manufacturing line are identical to each other and standardized. Random-In, Random-Out (RIRO) system enables the mobile robots to pick up and deliver from anywhere to anywhere maximizing flexibility. It means that in case of a failure or maintenance issue with one mobile robot, another one can replace it. The mobile robot is fixed on a side and then returned to service. The manufacturing process continues, without any interaction, which improves the mobile robot reliability. The production lot routing is fully controlled and monitored at any time according to the reference from ERP system. It is managing the applications that make up the system share data across various departments (manufacturing, purchasing, sales, accounting, etc.). ERP facilitates information flow between all business functions.

The following OEE calculations in Table 3 are presenting the technical benefits of the automated manufacturing line operated by mobile robots, compared to the human operator's manufacturing line. The difference comes from the fact that the mobile robots can work 3 shifts x 8 hours per shift (or 24 hours per day) without a break, compared to human operators working 7.2hours per shift (or 22 hours per day).

Automated line operated by mobile robots								
Number of operation	Operation description	MACHINE	Number of machines needed [number]	Estimated Cycle time [sec]	Hour capacity pcs/1hour	OEE (%)	Annual capacity (5days, 3 shifts) [in KU]	Annual capacity (7days, 3 shifts) [in KU]
1	Put 8 screws and mount wheels to chassis+screwdriver	Automatic Machine for Magnetization	1	17.00	212	100%	1,281	1,804
2	Put 4 screws and glue the components+screwdriver	Automatic Machine for spring and screw mounting	1	18.00	200	100%	1,089	1,704
3	Chassis & Control unit - Put 4 screws+screwdriver	End of Line Test Machine	1	20.00	180	100%	980	1,534
4	Chassis & Battery holder - Put 2 screws+screwdriver	Asymtek Dispense XY-table and curing storage	1	20.00	180	100%	980	1,534
5	Mount the hologram and the camera to the top cover	Asymtek Dispense XY-table and curing storage	1	20.00	180	100%	980	1,534
6	Pre-assembly of the top cover, O-ring and bottom frame to the main body	NABERTHERM OVEN	1	20.00	180	100%	980	1,534
7	Electrical Assembly; Load Software	NABERTHERM OVEN	1	15.00	240	100%	1,306	2,045
8	Final Assembly	NABERTHERM OVEN	1	16.00	225	100%	1,225	1,917
9	End of Line Test	NABERTHERM OVEN	1	19.00	189	100%	1,031	1,614
10	Packing	NABERTHERM OVEN	1	20.00	180	100%	980	1,534

Table 3. Automated manufacturing line operated by mobile robots: OEE and capacity calculations

The cycle time varies from 15sec to 20sec. The bottleneck is operation 10.Packing with a cycle time 20sec. Maximum monthly capacity 127,833units per month. The maximum annual capacity of the automated line operated by mobile robots is 1,534,000 units per year. Compared to the manual line operated by human operators 1,173,000units per year, the automatic one is with 361,000 units or 30% more productive.

Average Annual capacity:

Working days per year – 252

Plant operation time excluding – 8hours

Shifts – 3

Estimated Cycle time – According to operation

Maximum Annual capacity:

Working days per year – 355

Plant operation time excluding – 8hours

Shifts – 3

Estimated Cycle time – According to operation

Measure the KPI of manufacturing line

OEE = 100%, of the automated operated line operated by a mobile robot with a full load of equipment, conforms to the following:

Availability = 100%

Performance = 100%

Quality/Yield = 100% (lower achievement during acceptance run to be judged)

OEE = 100%

2.3. Overall startup cost to design, develop and manufacture manufacturing line

Creating the initial process layout for mobile robots, it is a complicated process, even for people specialized in programming robots. It requires creating a new hardware and software manually for each particular task. Sometimes, an engineer has to put all mind and brain power to create a simple robotic operation. The engineer has to take deliberately into account the full range of situations that the robot may face. This sort of programming is an expensive as well as the intense, time-consuming process. The advantage of the manufacturing layout on figure 7 is the repeatability of the mobile robot movements. Once the original software of the mobile robot is programmed for the first and the second machine, then it is a multiplication with a slight adjustment of the X-Y-Z coordinates. The mobile robot is equipped with Wi-Fi module for remote control communication. The engineer is capable of monitoring or changing the program even from home.

A mobile robot equipped with a conveyor application is capable of processing operations as loading and unloading parts into a manufacturing machine. The components are arranged in trays, which are transported by the mobile robot conveyor in/out of the machine. The machine process can vary from screw-driving, gluing, welding, as well as other production processes such as polishing, laser-marking, end of line testing, packaging, palletizing, etc. The job of the mobile robot is to entirely take over the load and unload handling process, which is usually done manually by a human operator. The quality control of the product and the assembly process verification is automatically executed and recorded by the machine. Vision recognition system, load cell, electrical or pressure testing devices, and any other system for monitor and control could be implemented to verify and secure the process.

In economics total cost is considered as the overall opportunity cost incurred by a firm in manufacturing or operations as is the case with mobile robots. Total cost consists of fixed costs, which present the equipment or hardware cost and variable cost, which depends on the number of hours spend (i.e. labor cost) to design the machines. It can be written as follows:

Total cost = total fixed costs + total variable costs

Total fixed cost[EUR]: Manual line operated by humans	Total fixed cost[EUR]: Automated line operated by mobile robots	Total variable cost[EUR]: Manual line operated by humans	Total variable cost[EUR]: Automated line operated by mobile robots	Total cost[EUR]: Manual line operated by humans	Total cost[EUR]: Automated line operated by mobile robots
1,000,000 €	1,050,000 €	560,000 €	930,000 €	1,560,000 €	1,980,000 €

Table 4. Total cost of manual and automated manufacturing line

The calculations on Table 4 are showing that the startup investment cost for automated line operated by mobile robots will cost 420,000€ more, than the manual one.

The total fixed costs are equal to the expense of the production machines and the cost of the mobile robots. I will assume, that the fixed cost for every manufacturing machine equals 100,000€. The manufacturing line consists of ten production machines with a total cost of 1M€. Since the cost of a single mobile robot is 5,000€, then ten mobile robots will cost 50,000€.

The total fixed costs are calculated as follows:

Fixed cost per machine x number of machines = 100,000€ x 10 = 1,000,000€

Fixed cost per mobile robot x number of mobile robots = 5,000€ x 10 = 50,000€

Total variable costs on Table 5 are calculated by using the number of hours, that each team has to spend to complete a task, part of the overall machine builds. The estimated hours will always vary depending on machine or project complexity. The table 5 below represents an example:

Department		Task	Manual line operated by humans [hours]	Automated line operated by mobile robots [hours]
Direct	Mechanization	Mechanical Design freeze	1600	2400
	Mechanization	Machine manufacturing	800	1200
	Mechanization	Line setup and tests	1600	3200
	Software Team	Software development	1600	3200
	Drafting Team	Bill of materials - drawings	1600	2400
Indirect	Process Engineering	Machine release and process setup	1600	3200
	Operational Quality	Product quality evaluation	800	1000
	Finance	Control of the investment	800	1000
	Operations	Line release for manufacturing	800	1000
Calculate overall labour			11200	18600
Total one-time investment cost to research, develop, design, test and release the manufacturing line for mass production		Total Variable cost	Manual line operated by humans [EUR]	Automated line operated by mobile robots [EUR]
		Hour rate - 20EUR	224,000 €	372,000 €
		Hour rate - 50EUR	560,000 €	930,000 €
		Hour rate - 100EUR	1,120,000 €	1,860,000 €

Table 5. Total variable cost of manual and automated manufacturing line (Example)

Total variable cost: one-time investment cost to research, design, develop, test and release the manufacturing line for mass production is calculated as follows:

Hour rate x Total labor hours

*Different rate examples are applied, due to the labor rate variation. However, an hourly rate of 50EUR is used as a reference in the next calculations.

2.4. Compare annual direct labor cost of human operators and mobile robots

Nowadays, companies look at what they pay their employees in hourly wages plus benefits and determine that it is far cost efficient investing in a robot than investing in people. The fully burdened labor rate takes into consideration such things as the cost of the building, taxes, utilities, transportation, etc. - all the costs of doing business. The companies using a fully burdened labor rate might be surprised to find out that it could be as much as 15EUR per hour per employee as compared to the employee’s direct rate of pay which may only be 10EUR an hour. One of the main ways to justify the cost of a robot would be to look at the productivity that the company could receive versus what it is currently achieving with manual or semi-automatic manufacturing systems. In many cases, manufacturing process with a mobile robot would be two to three times faster than the human operated one. It means that every hour, there could be two times the number of parts completed with mobile robots than with human operators. Human operators can sometimes be unreliable - they do not show up for work or have bad days. Robots are reliable workforce - they are there every day and can work numerous hours without taking a break or stopping for lunch. They need less floor space than humans does. Robots can easily handle the extra volume. The key competitive advantage of automation progress is the rise of productivity by decreasing the number of labor hours needed to create a product. Labor productivity increases translate into increases in average wages, giving operators the opportunity to cut down on work hours and to afford more products and services.

To estimate the manual and automated cost, I calculate the difference between Human direct labour costs vs. Mobile robot direct labor cost, presented in Table 6.

Human direct labour rate per hour [EUR]	Mobile robot direct labour rate per hour [EUR]	Human Annual working hours	Human Average Annual cost per year [EUR]	Mobile robot Average Annual cost per year [EUR]	Variance Average human vs mobile robot Annual cost per year [EUR]	Annual manufacturing hours	Human Maximum Annual cost per year [EUR]	Mobile robot Maximum Annual cost per year [EUR]	Variance Maximum human vs mobile robot Annual cost per year [EUR]
2	1	2016	4032	2016	2016	8760	17520	8760	8760
3	1	2016	6048	2016	4032	8760	26280	8760	17520
4	1	2016	8064	2016	6048	8760	35040	8760	26280
5	1	2016	10080	2016	8064	8760	43800	8760	35040
6	1	2016	12096	2016	10080	8760	52560	8760	43800
7	1	2016	14112	2016	12096	8760	61320	8760	52560
8	1	2016	16128	2016	14112	8760	70080	8760	61320
9	1	2016	18144	2016	16128	8760	78840	8760	70080
10	1	2016	20160	2016	18144	8760	87600	8760	78840
11	1	2016	22176	2016	20160	8760	96360	8760	87600
12	1	2016	24192	2016	22176	8760	105120	8760	96360
13	1	2016	26208	2016	24192	8760	113880	8760	105120
14	1	2016	28224	2016	26208	8760	122640	8760	113880
15	1	2016	30240	2016	28224	8760	131400	8760	122640

Table 6. Human direct labor rate vs. mobile robot direct labor rate

Human direct labor rate variance is estimated from 2EUR per hour up to 15EUR per hour.

Robot direct labor rate is estimated at 1EUR per hour.

Human Annual working hours are calculated as follows:

252 working days per year x 8 hours = 2016 hours per year

Human Average Annual cost per year is calculated as follows:

Human direct labor rate x Human Annual working hours

Robot Average Annual cost per year is calculated as follows:

Robot direct labor rate x Robot Annual working hours

Variance average human vs. mobile robot Annual cost per year is calculated as follows:

Human average direct labor rate - Robot average direct labor rate

Annual manufacturing hours are calculated as follows:

365 days per year x 24 hours = 8760 hours per year

Human Maximum Annual cost per year is calculated as follows:

Human direct labor rate per hour x Maximum Annual working hours

Robot Maximum Annual cost per year is calculated as follows:

Robot direct labor rate per hour x Maximum Annual working hours

Variance Maximum human vs. mobile robot Annual cost per year is calculated as follows:

Human Maximum Annual cost per year - Robot Maximum Annual cost per year

If a human operator cost 15EUR per hour or 30,240EUR per year (8hours x 252work days per year) and the mobile robot cost 1EUR per hour or 2016EUR per year, then replacing a human operator with a mobile robot will yield 28,224 EUR in annual savings.

However, the robot is capable of working 24 hours instead of 8 hours. It will extend the annual working performance of the mobile robot to 8760hours (24hours x 355days per year).

It means that one mobile robot can cover three shifts of 8 hours or 3 people. In this case, if three people cost 15EUR per hour or 131,400EUR per year and the mobile robot cost 1EUR per hour and 8,760EUR per year, then replacing three human workers with one mobile robot will yield 122,640EUR in annual savings.

A human operator direct labor cost varies from process to process, industry to industry, country to country. Table 5 is presenting a human worker labor variance starting from 2EUR per hour till 15EUR per hour. A mobile robot direct labor cost variation is within the range of 1EUR.

The researchers have shown that most of the jobs that are affected by automation are among the lowest-paid, lower-skilled, and less-educated workers. Workers that cost more than 15EUR per hour (nowadays, 2017) can't be replaced by regular mobile robots, due to the process complexity and the higher intelligence needed to execute the work. They can be replaced by machines operating with Artificial Intelligence, machine learning, and sophisticated algorithms in the future.

A labor rate of 10 EUR per hour for human operators was used for the following calculations.

Human operator annual labor costs are calculated as follows:

Number of line operators x human maximum annual cost per year (3shifts)

10 x 87,600EUR = 870,600EUR

A labor rate of 1EUR per hour for the mobile robot was used for the following calculations.

Mobile robot annual labor costs are calculated as follows:

Number of Mobile robots x Mobile robot maximum annual cost per year (3shifts)

10 x 8,760EUR = 87,600EUR

The primary reason to start this master thesis was the curiosity within technology and financial changes within the industry sector. Financial risk arises as a result of exposure to changes and uncertainties. It was interesting to research the underlying motives behind important financial decision and investments. The table 7 below, represents the manufacturing to operate and maintain the line for a period of five years.

Manufacturing line operated by human operators					
Year	Startup investment[EUR]	Maintenance cost [EUR]	Operating cost [EUR]	Human operator annual labour cost for 3 shifts[EUR]	Total Annual cost
1	1,560,000 €	156,000 €	78,000 €	870,600 €	1,104,600 €
2		156,000 €	78,000 €	870,600 €	1,104,600 €
3		156,000 €	78,000 €	870,600 €	1,104,600 €
4		156,000 €	78,000 €	870,600 €	1,104,600 €
5		156,000 €	78,000 €	870,600 €	1,104,600 €
Total cost		780,000 €	390,000 €	4,353,000 €	5,523,000 €
Manufacturing line operated by mobile robots					
Year	Startup investment[EUR]	Maintenance cost [EUR]	Operating cost [EUR]	Mobile robot annual labour cost for 3 shifts[EUR]	Total cost
1	1,930,000.00 €	193,000 €	96,500 €	87,600.00 €	377,100.00 €
2		193,000 €	96,500 €	87,600.00 €	377,100.00 €
3		193,000 €	96,500 €	87,600.00 €	377,100.00 €
4		193,000 €	96,500 €	87,600.00 €	377,100.00 €
5		193,000 €	96,500 €	87,600.00 €	377,100.00 €
Total cost		965,000.00 €	482,500.00 €	438,000.00 €	1,885,500.00 €

Table 7. Compare manufacturing line cost for five years

The maintenance cost is the expenses incurred to keep the production machines (and mobile robots) in good working condition. Automated machines require less maintenance effort, quicker setup time and easier control of machine output. The maintenance cost is calculated as follows: 10% of the total investment.

Operating expenses are costs associated with the administration of the manufacturing line on a day-to-day basis. The operating cost is calculated as follows: 5% of the total investment

Human operator annual labor cost for three shifts is calculated with a direct labor rate of 10EUR per hour, presented in Table 6. Mobile robot annual labor cost for three shifts is calculated with a direct labor rate of 1EUR per hour, presented in Table 6.

The total manufacturing line cost is calculated as follows:
Maintenance cost + Operating cost + Annual labour cost
The total manufacturing line cost of manual line is almost three times more than the automated one.

2.5. Conclusion

Automated machines and mobile robots can manufacture robots, without human intervention. Manufacturing a robot by using mobile robots and automation is more productive and efficient compared to manufacturing a robot with human operators. It needed more time and required higher start-up investment to build automated line, but it is compensated by the low labor cost of the mobile robots later on. Applying Lean principles improve the layout flexibility and reduce overall production time. Mobile robots and AVG's can help companies to improve performance, by reducing idle time and enhancing quality and speed, resulting productiveness beyond human capabilities. The products are made faster and cheaper for the company. AVGs also contributes to productivity and overall profit. Improved productivity growth would give a needed boost to economic rise and progress. The implementation depends on the organization's motivation, opportunity, and capability to adapt the mobile robots. The key success factors are linked to the business development process managed by the organization.

3. Financial calculations

In this section, I focused on the financial calculations that need to answer the research question, by using the empirical technical calculations that were presented in the previous section.

Business serves business. The key goal of any industrial company is to manufacture as many products as soon as possible, at the lowest cost with the best quality achieving the highest profit. To achieve this goal, an investor must find a way to lower labor and equipment costs. To estimate the best profit and the risk of starting a new manufacturing, the investor has to create different startup scenarios and simulate the business for a short period – one year and a long period – five years. The startup funds are negotiable, and they can vary from business to business.

"The fundamental principle behind market calculations is the time value of money: as long as interest rates are not negative, any given amount of money is worth more sooner than it is later because you can place it on deposit to earn interest." (Welch, 2009)

3.1. Financial calculations: Manual line operated by human operators

3.1.1. Required startup investment

Startup investment depends on many factors like industry area, industry growth, entry barriers, market condition (growth or recession), supply chain, micro and macroeconomic conditions, etc. The total investment, the human resources and the time to deliver an idea to manufacturing play a major role in the organization's strategic maneuvering in taking the decision. R&D expenditure as a percentage of product value added is one of the most important cost in relation to automation development and mobile robots. The more inimitable, unique and rare the product or the service is, the longer time its values will last. Extending the life cycle time of the product will ensure stable profit and competitiveness of the organization. The standard way of protecting the intellectual capital for creating a product is to issue a patent, which generates a lot of legal and professional fees.

In the following calculations, the total startup cost is presented as a sum of fixed and variable cost. Fixed cost is representing the funds needed for equipment and fixtures (input from Table 4), decorating or remodeling the layout and installing the machines. Variable cost is representing the total development variable cost (input from Table 5), legal and other professional fees, licenses and permits, cash and miscellaneous.

The risk of investment is minimized by reducing the startup investments as much as possible.

The research and the estimations are showing that building a human operated line for the first time is less cost and less risky than building an automated one. However, if the investor decides to clone the manufacturing line multiple times, then the automated one is the more profitable choice. Replicating an automated manufacturing line is a copy-paste process. In some cases, the variable cost of the manual line may be greater than the variable cost of the automated one.

A detail overview of the fixed and variable cost and the total required start up investment for manual line operated by human operators is presented on Table8.

Required Investment for Manual line operated by human operators

Estimated Monthly Expenses

Item	Column 1 Estimate of Monthly Expenses	Column 2 Number of Months	Column 3 Annual Cash Required To Start Business (Column 1 X Column 2)*
Salary of Manager	5,000 €	12	60,000.00 €
Total Cash Requirements for Annual Recurring Expenses: (A)			**60,000.00 €**

Start-up Costs You Only Have to Pay Once

		Cash Required to Start Business
Fixed Costs		
	Equipment and Fixtures	1,000,000.00 €
	Decorating and Remodelling	10,000.00 €
	Installation of Equipment and Fixtures	10,000.00 €
	Starting Inventory	100,000.00 €
Variable Costs		
	Total variable cost	560,000.00 €
	Legal and Other Professional Fees	10,000.00 €
	Licenses and Permits	10,000.00 €
	Cash	50,000.00 €
	Miscellaneous	100,000.00 €
	Total One-Time Cash Requirements: (B)	**1,850,000.00 €**
	Total Estimated Cash Required to Start Business: (A) + (B)	**1,910,000.00 €**

* You Will Have to Decide For Your Particular Business How Many Months You Expect Your Expenses to Exceed Your Revenue So That You Will Have a Shortfall of Cash. This Should Somewhat Overestimate Your Overall Cash Requirements and Provide You With a Safety Cushion In Case Sales Don't Materialize As Rapidly As You Expected.

Table 8. Required-Start up Investment for Manual line operated by human operators

3.1.2. Income statement for one year

The following financial calculations in Table 9 are related to the manual line operated by human operators, presenting the income statement for the first year.

Pro Forma Income Statement for Manual line operated by human operators for one year

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	TOTAL EUR
1. Gross Sales	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	175,950,000
2. Less: Cash Discounts	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	1,466,250	17,595,000
A. NET SALES	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	13,196,250.00	158,355,000.00
Cost of Goods Sold:													
3. Beginning Inventory	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7331250
4. Plus: Net Purchases	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	87975000
5. Total Available for Sale	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	14,662,500	95306250
6. Less: Ending Inventory	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250	7,331,250
B. COST OF GOODS SOLD	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	7,331,250.00	87,975,000.00
C. GROSS MARGIN	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	5,865,000.00	70,380,000.00
Less: Variable Expenses													
7. Owner's Salary	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	60,000.00
8. Employee's Wages and Salaries	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	73,000.00	876,000.00
D. TOTAL VARIABLE EXPENSES	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	78,000.00	936,000.00
Less: Fixed Expenses													
9. Rent	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	240,000.00
10. Utilities (Heat, Light, Power)	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	36,000.00
11. Taxes and Licenses	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	24,000.00
12. Depreciation	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
13. Interest	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
14. Insurance	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
15. Other Fixed Expenses	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
E. TOTAL FIXED EXPENSES	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	348,000.00
F. TOTAL OPERATING EXPENSES	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	107,000.00	1,284,000.00
G. NET OPERATING PROFIT (LOSS)	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	5,758,000.00	69,096,000.00
H. INCOME TAXES (estimated)													33,166,080.00
I. NET PROFIT (LOSS) AFTER INCOME TAX													35,929,920.00

Table 9. Pro forma income statement for Manual line operated by human operators

Gross sales – the total amount of revenue expected in return for goods sold during a specified period

Gross sales (Table 9) are calculated as follows:

The maximum monthly capacity of the manual line operated by human operators x cost of the product x GM%

The maximum monthly capacity (Table 3) of the manual line operated by human operators – 97,750units

Cost of the product (Table 1) = 100EUR

Gross Margin (GM) = 50%

97,750units per month x 100EUR x 1.5 = 14,662,500EUR

Less cash discounts are 10% of the gross sales.

The salary of the owner or manager = 5,000EUR per month

Employee wages and salaries (input Table 6) are calculated as follows:

Number of operators x direct labour x Human Maximum cost per month = 10 x 7300 = 73,000EUR

The manufacturing line is designed for 10 operators.

Human Maximum cost per month = Human Maximum Annual cost / 12 months = 87600 / 12 = 7300EUR

Human Maximum Annual cost (input Table 6) is estimated at 10EUR per hour.

Total variable expenses are calculated as follows:

The salary of the owner + employee wages and salaries

Total fixed expenses are representing rent, utilities, taxes and licenses, depreciation, interest, insurance and other fixed expenses. The idea is to represent the expenses related to the manufacturing operations. The values are based on assumptions.

Total operating expenses are calculated as follows:

Total Variable expenses + Total fixed expenses

Net operating profit is calculated as follows:

Gross Margin - Total operating expenses

Net Profit is calculated as follows:

Net operating profit – Income tax

3.1.3. Income statement for five years

The following financial calculations in Table 10 are related to the manual line operated by human operators, presenting the income statement for five years.

Pro Forma Income Statement for Manual line operated by human operators

	End of 2017	End of 2018	End of 2019	End of 2020	End of 2021
1. Gross Sales	175,950,000.00 €	219,937,500.00 €	285,918,750.00 €	371,694,375.00 €	520,372,125.00 €
2. Less: Cash Discounts	17,595,000.00 €	17,595,000.00 €	17,595,000.00 €	17,595,000.00 €	17,595,000.00 €
A. NET SALES	158,355,000.00 €	202,342,500.00 €	268,323,750.00 €	354,099,375.00 €	502,777,125.00 €
Cost of Goods Sold:					
3. Beginning Inventory	7,331,250.00 €	7,331,250.00 €	9,164,062.50 €	11,913,281.25 €	15,487,265.63 €
4. Plus: Net Purchases	87,975,000.00 €	21,993,750.00 €	28,591,875.00 €	37,169,437.50 €	0.00 €
5. Total Available for Sale	95,306,250.00 €	29,325,000.00 €	37,755,937.50 €	49,082,718.75 €	15,487,265.63 €
6. Less: Ending Inventory	7,331,250.00 €	9,164,062.50 €	11,913,281.25 €	15,487,265.63 €	0.00 €
B. COST OF GOODS SOLD	87,975,000.00 €	20,160,937.50 €	25,842,656.25 €	33,595,453.13 €	15,487,265.63 €
C. GROSS MARGIN	70,380,000.00 €	182,181,562.50 €	242,481,093.75 €	320,503,921.88 €	487,289,859.38 €
Less: Variable Expenses					
7. Owner's Salary	60,000.00 €	60,000.00 €	60,000.00 €	60,000.00 €	60,000.00 €
8. Employee's Wages and Salaries	876,000.00 €	876,000.00 €	876,000.00 €	876,000.00 €	876,000.00 €
D. TOTAL VARIABLE EXPENSES	936,000.00 €	936,000.00 €	936,000.00 €	936,000.00 €	936,000.00 €
Less: Fixed Expenses					
18. Rent	240,000	240,000	240,000	240,000	240,000
19. Utilities (Heat, Light, Power)	36,000	36,000	36,000	36,000	36,000
21. Taxes and Licenses	24,000	24,000	24,000	24,000	24,000
22. Depreciation	12,000	12,000	12,000	12,000	12,000
23. Interest	12,000	12,000	12,000	12,000	12,000
24. Insurance	12,000	12,000	12,000	12,000	12,000
25. Other Fixed Expeses	12,000	12,000	12,000	12,000	12,000
E. TOTAL FIXED EXPENSES	348,000.00 €	348,000.00 €	348,000.00 €	348,000.00 €	348,000.00 €
F. TOTAL OPERATING EXPENSES	1,284,000.00 €	1,284,000.00 €	1,284,000.00 €	1,284,000.00 €	1,284,000.00 €
G. NET OPERATING PROFIT (LOSS) (G = C - F)	69,096,000.00 €	180,897,562.50 €	241,197,093.75 €	319,219,921.88 €	486,005,859.38 €
H. INCOME TAXES (estimated)	33,166,080.00 €	86,830,830.00 €	115,774,605.00 €	153,225,562.50 €	233,282,812.50 €
I. NET PROFIT (LOSS) AFTER INCOME TAX	**35,929,920.00 €**	**94,066,732.50 €**	**125,422,488.75 €**	**165,994,359.38 €**	**252,723,046.88 €**

Table 10. Five years pro forma income statement for manual line operated by human operators

Gross sales are calculated as follows:

The maximum monthly capacity of the manual line operated by human operators x cost of the product x GM%

127,833units per month x 100EUR x 1.5 = 19,174,950EUR

Maximum monthly capacity 127,833units per month

3.2. Financial calculations: Automated line operated by mobile robots

3.2.1. Required startup investment

The following calculations in Table 11, the total startup investment for automated line operated by mobile robots is presented as a sum of fixed (input from Table 4) and variable cost (input from Table 5). Since the equipment is easy to clone or replicate, the cost of the human operated machines is similar to the mobile robot operated one. The difference comes from the cost of the mobile robot (5000EUR/unit). The total development variable cost of the automated line is higher than the total development cost of the manual one. It means that the startup investment and the overall risk in launching an automated line are higher than the manual one.

Higher risk = Higher return

By accepting the higher risk, the organization has the potential to gain a better return on the investment. It is a real challenge to predict what strategy the organization should choose during the startup and how the resources should be used. Will the organization decide to buy an expensive server or use cheap cloud services, for example? It depends from case to case, but for each case, alternative scenarios could simulate the business process in the long term. The investment risk could be measured by the probability of permanent loss of capital. In such situation, the investor would be able to sell the manufacturing line and the mobile robots as operating units. The organization can't sell humans or the human's knowledge in the same way as selling the mobile robots. If the mobile robots are not fully operational, they can be still sold as spare parts. This key advantage is reducing the investor's risk. It also gives an advantage in case of selling the manufacturing line. Most of the companies spend a lot of money to train operators during line transfer from one location to another or changing the ownership. The organization using mobile robots have the potential of selling separately the algorithms or the software developed to run the manufacturing process, which makes the investment even more reasonable. The mobile robot might be out of service for some years, but the software, which is always stored on a server and the transfer of the information to a new mobile robot will take a minimum time. In other words, *the software developed to operate the mobile robot will be owned forever*. It opens the opportunity for the business using mobile robots to grow faster over time than the human one.

Required Investment for Manual line operated by human operators

Estimated Monthly Expenses

Item	Column 1 Estimate of Monthly Expenses	Column 2 Number of Months	Column 3 Annual Cash Required To Start Business (Column 1 X Column 2)*
Salary of Manager	5,000 €	12	60,000.00 €
Total Cash Requirements for Annual Recurring Expenses: (A)			**60,000.00 €**

Start-up Costs You Only Have to Pay Once

		Cash Required to Start Business
Fixed Costs		
	Equipment and Fixtures	1,050,000.00 €
	Decorating and Remodelling	10,000.00 €
	Installation of Equipment and Fixtures	10,000.00 €
	Starting Inventory	100,000.00 €
Variable Costs		
	Total variable cost	930,000.00 €
	Legal and Other Professional Fees	10,000.00 €
	Licenses and Permits	10,000.00 €
	Cash	50,000.00 €
	Miscellaneous	100,000.00 €
	Total One-Time Cash Requirements: (B)	**2,270,000.00 €**
	Total Estimated Cash Required to Start Business: (A) + (B)	**2,330,000.00 €**

* You Will Have to Decide For Your Particular Business How Many Months You Expect Your Expenses to Exceed Your Revenue So That You Will Have a Shortfall of Cash. This Should Somewhat Overestimate Your Overall Cash Requirements and Provide You With a Safety Cushion In Case Sales Don't Materialize As Rapidly As You Expected.

Table 11. Required Annual Funds for Automated line operated by Mobile Robots

3.2.2. Income statement for one year

The following financial calculations in Table 12 are related to automated line operated by mobile robots, presenting the income statement for the first year.

Pro Forma Income Statement for Automated line operated by Mobile robots for year 2017

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	TOTAL EUR
1. Gross Sales	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	230,099,400
2. Less: Cash Discounts	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	1,917,495	23,009,940
A. NET SALES	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	17,257,455.00	207,089,460.00
Cost of Goods Sold:													
3. Beginning Inventory	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9587475
4. Plus: Net Purchases	9,587,484	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	115049709
5. Total Available for Sale	19,174,959	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	19,174,950	124637184
6. Less: Ending Inventory	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475	9,587,475
B. COST OF GOODS SOLD	9,587,484.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	9,587,475.00	115,049,709.00
C. GROSS MARGIN	7,669,971.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	7,669,980.00	92,039,751.00
Less: Variable Expenses													
7. Owner's Salary	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	60,000.00
8. Employee's Wages and Salaries	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	7,300.00	87,600.00
D. TOTAL VARIABLE EXPENSES	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	12,300.00	147,600.00
Less: Fixed Expenses													
9. Rent	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	20,000.00	240,000.00
10. Utilities (Heat, Light, Power)	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	3,000.00	36,000.00
11. Taxes and Licenses	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	24,000.00
12. Depreciation	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
13. Interest	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
14. Insurance	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
15. Other Fixed Expenses	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	12,000.00
E. TOTAL FIXED EXPENSES	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	348,000.00
F. TOTAL OPERATING EXPENSES	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	41,300.00	495,600.00
G. NET OPERATING PROFIT (LOSS)	7,628,671.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	7,628,680.00	91,544,151.00
H. INCOME TAXES (estimated)													43,941,192.48
I. NET PROFIT (LOSS) AFTER INCOME TAX													47,602,958.52

Table 12. Pro forma income statement for automated line operated by Mobile Robots

Gross sales – the total amount of revenue expected in return for goods sold during a specified period

Gross sales (Table 12) are calculated as follows:

The maximum monthly capacity of the automated line operated by mobile robots x cost of the product x GM%

The maximum monthly capacity (Table 3) of the automated line operated by mobile robots – 127,833units

Cost of the product (input Table 1) = 100EUR

Gross Margin (GM) = 50%

97,750units per month x 100EUR x 1.5 = 19,174,750EUR

Less cash discounts are 10% of the gross sales.

The salary of the owner or manager = 5,000EUR per month

Employee wages and salaries (input Table 6) are calculated as follows:

Number of mobile robots x Mobile robot maximum cost per month = 10 x 730 = 7300EUR

The manufacturing line is designed for 10 mobile robots.

Mobile robot maximum cost per month = Mobile robot Maximum Annual cost / 12 months = 8760 / 12 = 730EUR

Mobile robot Maximum Annual cost (input Table 6) is estimated at 1EUR per hour.

Total variable expenses are calculated as follows:

The salary of the owner + employee wages and salaries

Total fixed expenses are representing rent, utilities, taxes and licenses, depreciation, interest, insurance and other fixed expenses. The idea is to represent the expenses related to the manufacturing operations. The values are based on assumptions.

Total operating expenses are calculated as follows:

Total Variable expenses + Total fixed expenses

Net operating profit is calculated as follows:

Gross Margin - Total operating expenses

Net Profit is calculated as follows:

Net operating profit – Income tax

3.2.3. Income statement for five years

The following financial calculations on Table 13 are related to automated line operated by mobile robots, presenting the income statement for five years. It is presenting the five-year financial plan and the projection of revenues.

Pro Forma Income Statement for Automated line operated by Mobile robots

	End of 2017	End of 2018	End of 2019	End of 2020	End of 2021
1. Gross Sales	230,099,400.00 €	287,624,250.00 €	373,911,525.00 €	486,084,982.50 €	680,518,975.50 €
2. Less: Cash Discounts	23,009,940.00 €	23,009,940.00 €	23,009,940.00 €	23,009,940.00 €	23,009,940.00 €
A. NET SALES	207,089,460.00 €	264,614,310.00 €	350,901,585.00 €	463,075,042.50 €	657,509,035.50 €
Cost of Goods Sold:					
3. Beginning Inventory	9,587,475.00 €	9,587,475.00 €	11,984,343.75 €	15,579,646.88 €	20,253,540.94 €
4. Plus: Net Purchases	115,049,709.00 €	28,762,427.25 €	37,391,155.43 €	48,608,502.05 €	0.00 €
5. Total Available for Sale	124,637,184.00 €	38,349,902.25 €	49,375,499.18 €	64,188,148.93 €	20,253,540.94 €
6. Less: Ending Inventory	9,587,475.00 €	11,984,343.75 €	15,579,646.88 €	20,253,540.94 €	0.00 €
B. COST OF GOODS SOLD	115,049,709.00 €	26,365,558.50 €	33,795,852.30 €	43,934,607.99 €	20,253,540.94 €
C. GROSS MARGIN	92,039,751.00 €	238,248,751.50 €	317,105,732.70 €	419,140,434.51 €	637,255,494.56 €
Less: Variable Expenses					
7. Owner's Salary	60,000.00 €	60,000.00 €	60,000.00 €	60,000.00 €	60,000.00 €
8. Mobile robot's Wages and Salaries	87,600.00 €	87,600.00 €	87,600.00 €	87,600.00 €	87,600.00 €
D. TOTAL VARIABLE EXPENSES	147,600.00 €	147,600.00 €	147,600.00 €	147,600.00 €	147,600.00 €
Less: Fixed Expenses					
18. Rent	240,000.00 €	240,000.00 €	240,000.00 €	240,000.00 €	240,000.00 €
19. Utilities (Heat, Light, Power)	36,000.00 €	36,000.00 €	36,000.00 €	36,000.00 €	36,000.00 €
21. Taxes and Licenses	24,000.00 €	24,000.00 €	24,000.00 €	24,000.00 €	24,000.00 €
22. Depreciation	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €
23. Interest	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €
24. Insurance	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €
25. Other Fixed Expeses	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €	12,000.00 €
E. TOTAL FIXED EXPENSES	348,000.00 €	348,000.00 €	348,000.00 €	348,000.00 €	348,000.00 €
F. TOTAL OPERATING EXPENSES	495,600.00 €	495,600.00 €	495,600.00 €	495,600.00 €	495,600.00 €
G. NET OPERATING PROFIT (LOSS) (G = C - F)	91,544,151.00 €	237,753,151.50 €	316,610,132.70 €	418,644,834.51 €	636,759,894.56 €
H. INCOME TAXES (estimated)	43,941,192.48 €	114,121,512.72 €	151,972,863.70 €	200,949,520.56 €	305,644,749.39 €
I. NET PROFIT (LOSS) AFTER INCOME TAX	**47,602,958.52 €**	**123,631,638.78 €**	**164,637,269.00 €**	**217,695,313.95 €**	**331,115,145.17 €**

Table 13. Five years pro forma income statement for automated line operated by Mobile Robots

3.2.4. Benchmark of Manual and Automated line

As it was introduced, the purpose of this master thesis is to explore the benefits of investing in fully automated manufacturing line operated only by Mobile robots. The annual working and manufacturing hours for the manual and automated line used in the following calculations are presented in Table 6. The data on Table 14 is representing the key values from Income Statement for the manual (Table 10) and automated manufacturing line (Table 13).

Benchmark Financial calculations		
	Manual line operated by human operators	Automated line operated by Mobile robots
Investment [EUR]	1,910,000	2,330,000
Manufactured Units per year	1,173,000	1,533,996
Human/mobile robot employees	31	11
Hours per unit (HPU)	22.12	11.00
Organizational hours per unit (OHPU)	0.07	0.06
Gross Sales [EUR]	520,372,125	680,518,975
Net Sales [EUR]	502,777,125	657,509,035
Cost of Goods Sold [EUR]	15,487,265	20,253,540
Gross Margin [EUR]	487,289,859	637,255,494
Total variable expense [EUR]	936,000	68,760
Total fixed expense [EUR]	348,000	348,000
Total Operating expense [EUR]	1,284,000	416,760
Net Operating profit [EUR]	486,005,859	636,838,734
Net Profit After Tax [EUR]	252,723,046	331,156,141
ROI[%]	13,232	14,213

Table 14. Benchmark of the financial calculations

Hours per unit (HPU) measures the number of hours required to manufacture one unit.

HPU are calculated as follows:

HPU = Human workers x annual working hours/annual manufacturing hours

Human workers manual line: 31 (1 manager and 30 human operators)

The manual manufacturing line is designed for 10 human operators. One operator is capable of working 8 hours. To cover 3 shifts per 8 hours or 24 hours manufacturing process, the organization needs 30 human operators.

Annual working hours for a human working 1 shift of 8 hours: 2016 hours

30 human operators x Annual working hours for a human = 60,480 hours

Annual manufacturing hours for a human covering 3 shifts or 24 hours: 60,480 hours

Manager x Annual working hours for a human = 1 x 2016 = 2016 hours

Annual working hours for a manual line are calculated as follows:

Annual manager hours + Annual human operator’s hours = 2016 + 60,480 = 62,496 hours

Human workers automated line: 1 (1 manager)

Mobile robots: 10 units

Annual working and manufacturing hours for a mobile robot working 24 hours: 8760 hours

Mobile robots x Annual working hours for a mobile robot = 10 x 8760 = 87,600 hours

Organizational hours per unit (OHPU) is a labor measure used to benchmark manufacturing processes.

OHPU are calculated as follows:

OHPU = Total annual working hours/Annual Manufacturing units

Return on investment (ROI): Return on investment represents the benefits generated from the investment. It measures how efficiently the resources are used, and it is calculated as follows:

ROI = Net Profit/Investment

The calculations in Table 14 and figure 9 are showing the financial benefits of replacing human with a mobile robot. The Net profit after tax of the automated line for a five-year period is more than 30 percent than for the manual one. It's a huge gap between returns to capital, returns to labor and returns to manufactured units in favor of automation. The higher ROI it's also indicating that the introduction of mobile robots in manufacturing has enormous potential for the organization.

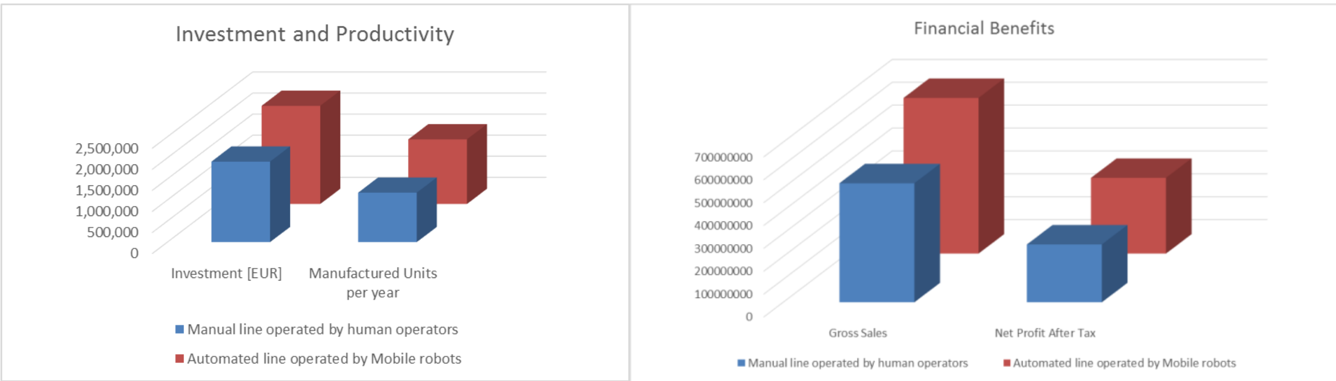

Figure 9. Investment, productivity, and financial benefits

Automation plays a significant role in achieving the sustainability of competitive advantage. Starting a full autonomous manufacturing may become a difficult challenge for some organizations. They may face not just high internal barriers from management, but also external resistance from government and society. If however, an organization succeeds to achieve the transformation process from traditional manufacturing with human operators to advance autonomous manufacturing with mobile robots, it will gain superior organization performance, positive productivity effect and sustained competitive advantage. The business progress will depend not just on the organization capability to adopt digital products or services, but also the capability to use advanced financial tools for analysis and reports. New supply, inputs, process, outputs and control methods and instruments need to be developed. The robots will be the key driver of the digital transformation process from the nowadays manual, human operated manufacturing process to a new modern, automatic, autonomous and flexible model, not just in the manufacturing industry, but wherever tasks can be automated.

3.2.5. Manufacturing Radar chart tool

Manufacturing Radar chart tool on figure 10 represents the final analysis of the method proposed in this master thesis. Center of the chart accounts for a value of zero, and the outer edge represents higher values. Higher scores equate to more desirable attributes. The main pillars are covering the questions: *What?* (Productivity); *Who?* (Customer needs and requirements); *How?* (Process stability); *Where?* (Presence on the market). There are pros and cons of each of these pillars.

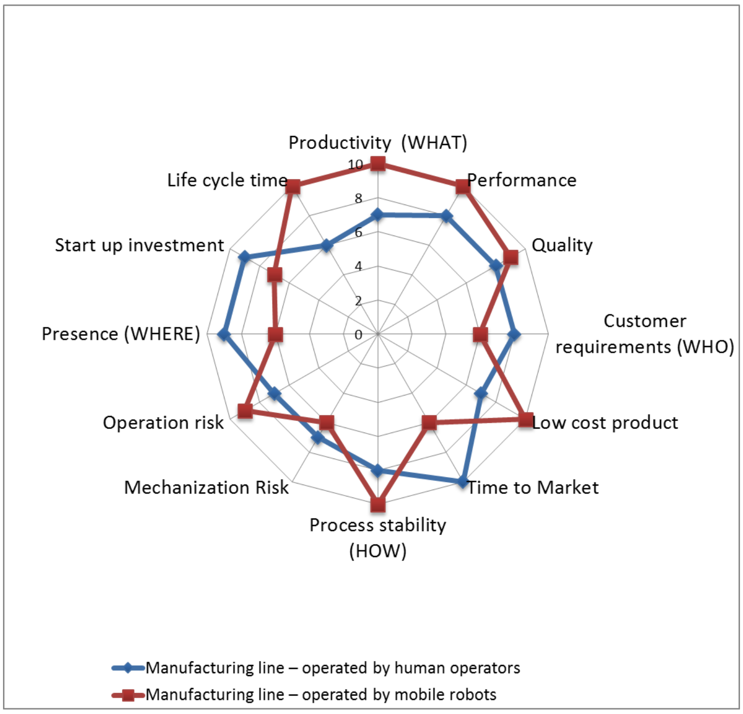

Figure 10. Manufacturing Radar chart tool

Productivity is the link between input and output. Achieving higher productivity with low manufacturing cost is a key goal in manufacturing. Productivity is measured as follows:

Productivity = Output/Input

In this thesis, the productivity of the manufacturing line is calculated through OEE (Overall equipment effectiveness). The estimations have shown that productivity of the automated line is by 30% higher than with the manual one.

Performance is calculated through OEE and OHPU. It is presenting machine performance and labor performance. The estimations have shown that performance of the automated line is better than the manual one.

Quality is calculated through OEE by taking into account the quality losses or the rejected parts. The estimations have shown that quality of the automated line added to the quantity of mass manufacturing is better than the manual one.

Customer requirements are measured through Lean Manufacturing integration. The automated line is complying better with Lean manufacturing principles "*less human effect, less time",* as well as the ability of Jidoka to automatically detect the failure. It's also providing the customer with the functionality to write their own application and add its own value work to the platform. However, only 60-70% of all manufacturing process could be automated. It means, those customer requirements could not be fully met and the customer will be slightly more satisfied with the manual line.

The low-cost product is measured through the wages or direct labor cost. The products manufactured with the automated line will have a lower cost than products produced with the manual one. It means that the commercial success and competitive advantage is on the side of the automation and mobile robots.

Time to Market is measured by the number of hours a company needs to research, design, develop, test and release the manufacturing line for mass production. The estimations are showing, that the manual line needs less time to market, than the automatic one.

Process stability is measured by reliability, reputability, reproducibility and the volume of non-conformity products of the manufacturing process. The conclusion is that the automated line is slightly better than the manual one.

Mechanization risk is measured by the complexity to design and integrate automation and mobile robots. If the mechanization team does not have the knowledge, the resources, the engineers or the experience to build such automated line, then the risk of failure is very high. Due to that, the mechanization risk for creating a manual line is lower, than for the automatic one.

Operation risk is measured by safety, diversity, operating cost and maintenance cost. "Safety first" is a must in manufacturing. Since there are only mobile robots and no human operators, the automated line is safer than the manual one.

Presence is measured by the value added and the contribution to the market. The manual line has more value added to the market, than the automatic one.

Startup investment is measured by the total cost (Table 4). The estimations have shown that automated line requires more startup investment than the manual one.

Lifecycle time is measured by the number of years the line will be in service or use. The machines do not die. The mobile robots are designed to work on any equipment that fits their size for as long as it takes. The research has shown that the automated line has longer life-cycle time than the manual one.

Investing in autonomous automation creates a new economic model of maximizing the use of robotic systems and minimizing the human well-being. The model requires a detail risk assessment and modern knowledge management of automation to increase the confidence of the organization. Investing in mobile robots empowers companies to be a step ahead in developing innovations capable of securing their long-term competitiveness. Innovation is the key to creating differentiated new products that drive growth. Innovativeness of an organization perspective is the ability to use modern manufacturing approach, as using mobile robots and develop a new or significantly improved product by optimizing the layout organization and the business model. Sensor-driven computing, industrial analytics, and intelligent machine applications are the new manufacturing tools of competitiveness and sustainability.

4. Analysis and Discussion: Business profits vs. manufacturing jobs

This chapter is presenting the impact of mobile robots and automation to business and people. In the last section, some social analysis on how automation and innovations will challenge the future of humanity are provided.

4.1. Introduction

Without active manufacturing, there is no national prosperity. The future of manufacturing is circulating around everything that is automatable. Reports are foreseeing, that automation will replace and eliminate more jobs, than creating new ones. According to Davenport & Harris (2007), the competence to predict the clients' needs is based on knowledge of the Business Intelligence and the future customer behavior. Figure 11 is presenting a graph from Davenport and Harris (2007), where they illustrate some methods for analysis, which will guide me in this chapter. Applying various analytical techniques and Business intelligence methods is a must if we would like to reach sustainable competitive advantage.

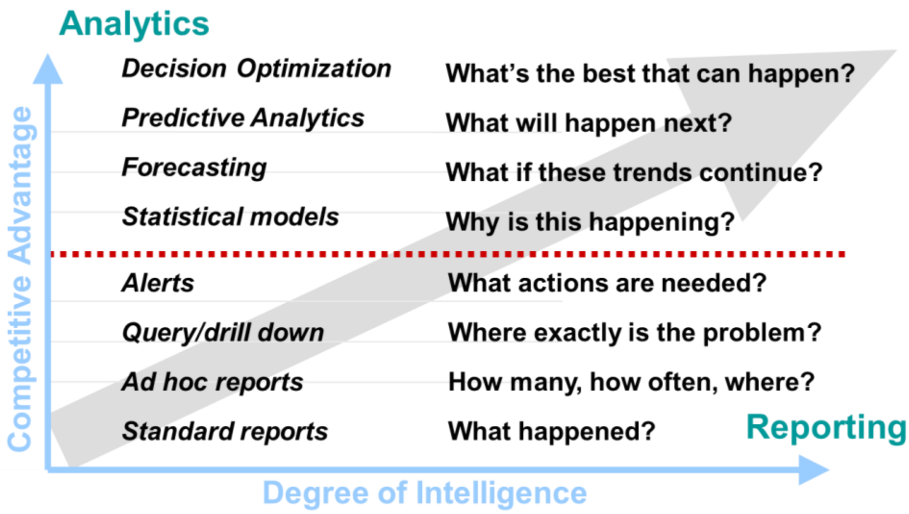

Figure 11. Business intelligence and analytics (Davenport & Harris, 2007)

The economist Herbert Stein wrote in 1986 "if something cannot go on forever, it will stop." Consumer values, needs, and requirements will continue to evolve and change. Their needs are shaping the future of automation in manufacturing. The majority of consumers worldwide buy the lowest cost products, due to financial constraints. They don't pay attention to *Who?* made the product – human or robot. They don't know *How?* the product was made – with or without automation. They don't even check *Where?* was the product made – in China or in their country. China is the world leader in manufacturing. If all manufacturing is situated in China, then there will be no work. Shouldn't we look for a job in China and migrate? Are the workers making the products in China treated properly by the employee? Are the products safe? Is buying a product made in China going to affect the local manufacturers in the US or Europe? Is buying a product made by mobile robots in the US or Europe, instead of human workers in China more ethical and moral, than buying a product made in China? How will the mobile robots affect the local and global economy?

How will that affect you and me?

Between 1997 and 2005, "manufacturing output increased by 60 percent in the United States, while 3.9 million manufacturing jobs were eliminated during roughly the same period." (Rifkin, 2014) Mobile robots would replace human workers because the scales are tipping toward lower costs for the maintaining machines than for hiring people. The manufacturers' organizations like EEF in UK or Reshoring Initiative in US support and advice manufacturing companies to bring back and keep their business eco-system locally instead of offshoring in Asia. They assist them to become and stay competitive and sustainable. They provide manufacturing estimations explaining the benefits of reshoring vs. offshoring, case studies, literature, survey data, economic development programs, skilled workforce program, etc.

Terry Scuoler, EEF's chief executive, said:

"While it will always be two-way traffic, the need to be closer to customers, to have ever greater control of quality and the continued erosion of low labor costs in some competitor countries means that in many cases it makes increasingly sound business sense."

The key benefits of local manufacturing:

- Image of being Made in Europe / Made in the USA
- Faster lead time
- Low freight cost
- Quick changeover according to customer needs and requirements
- Keep intellectual property and know-how in-house
- Local tax stimulus
- Better customer service

Reducing unemployment by supporting local manufacturing will change the global manufacturing imbalance and Chinese domination. The shortest path is to follow fourth industrial revolution (figure 12), where industrialization and modernization will fusion the new technologies and techniques to smarter products.

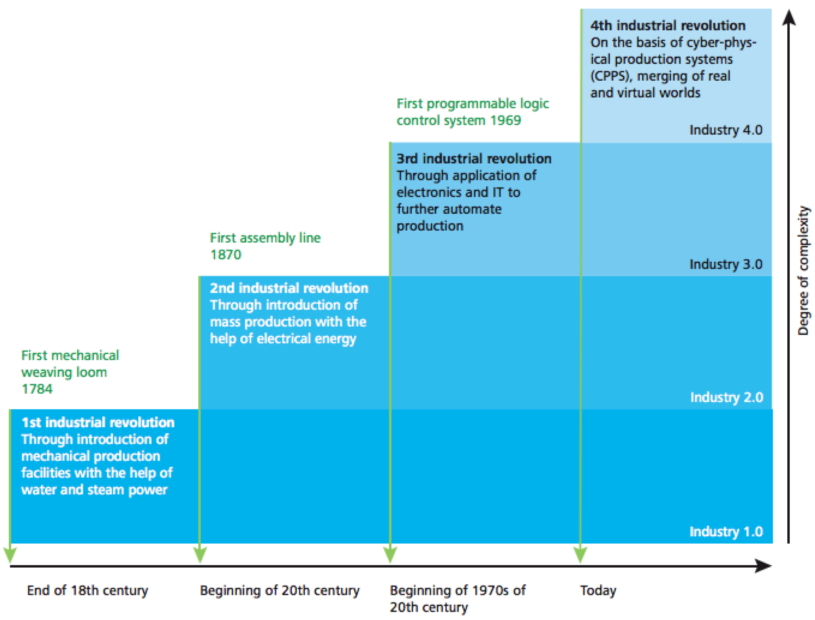

Figure 12. Fourth industrial revolution (Deloitte AG, 2015)

The First Industrial Revolution adopted water and steam power to industrialize manufacturing.

The Second Industrial Revolution adopted electric energy to establish serial manufacturing.

The Third Industrial Revolution adopted electronics and information technology to automate manufacturing.

Fourth Industrial Revolution is adopting digital, physical and biological systems to make the manufacturing autonomous.

The key benefits of Fourth Industrial Revolution:

- The Industrial Internet of Things
- Big data
- Secure digital infrastructure

By now it is well-known that robotics, Big Data, Artificial Intelligence (AI), Business Intelligence (BI), advanced analytics, and algorithms are replacing and complementing the human abilities. The evolution of business technology will be based on data. Data generated by the consumers worldwide. Big data is described by its features: variety, volume, and velocity. Variety stands for the different data origin as languages, encrypted patterns, audio or video format and so on. Volume means the enormous quantity of information produced and supplied every day through the media. Information, which we are not capable of handling anymore. Velocity is the measure of how fast the data is collected, computed and supplied further. Artificial Intelligence (AI) is designed to collect, analyze, and transform data into humanized formats that are easy to digest and act upon. AI is the machine or robot ability to imitate human intelligence. In cases when the robots are not able to imitate or fully replace the human abilities, they complement the human abilities.

An analysts from IDC robotics developed 10 robotics predictions presenting the near digital future. (IDC. 2017)

- Prediction 1: Robot as a Service by 2020.
- Prediction 2: New 3rd platform technologies will evolve by 2019 in the area of:
  - *Mobility* – access data through mobile devices;
  - *Cloud services* – computing power and storage capacity via internet network;
  - *Analytics (Big data)* – cognitive AI
  - *Social technology* – digital communication through 360° virtual reality media.
- Prediction 3: New Cloud-based services by 2020. Services that are better structured, distributed, secured, reliable, trusted, concentrated and intelligent.
- Prediction 4: Artificial intelligence everywhere by 2020.
- Prediction 5: New digital regulations for human security, safety, and privacy by 2019.
- Prediction 6: Software Defined Robot. By 2020, 60% of robots will bet on cloud-based software programs to determine new skills, experience, cognitive capabilities, and application programs, leading to the formation of a robotics cloud marketplace.
- Prediction 7: Smart Robots, operating three times faster than nowadays robots by 2018.
- Prediction 8: Intelligent Robotics Network, connecting industrial robots by 2020.
- Prediction 9: New robo-applications out from manufacturing by 2019.
- Prediction 10: "Augmented Humanity" by 2018. Human augmentation stands for body enhancements as prosthetics, implanting RFID or electronics into human bodies, or taking pills to live longer.

In the coming decade, wearable technology will touch nearly every aspect of our lives. It will allow us to bring the power of the internet to everything we do. – Marcus Weller

4.2. China manufacturing: Apple

"Designed by Apple in California. Assembled in China." Rawson (2012). There were more than 230,000 workers (2007) in a single factory in China involved in manufacturing the iPhone. Some employees were situated in company-owned homes or barracks next to the manufacturing plant. Apple employs 43,000 people (2007) in the United States. The number of staff in the US is much lower than the number of employees in China mainly due to the labor cost in manufacturing. According to Apple executives: "iPhones aren't made in America because they just can't be. The infrastructure and labor force doesn't exist at the levels necessary to support Apple's operations -- it's not even close" Rawson (2012). In 2015 the number of Apple related employees in China reached 1.6 milion people (China labor watch, 2016).

The Shanghai Municipal Government increased the minimum wage from $304 to $330 in April 2016. A manufacturing operator in Pegatron is making $1.85 per hour or 4,200 yuan to 5,500 yuan ($650-$850) a month for 12-hour shift, 6days a week (Bloomberg, 2016). The operator gross salary is around $350 a month. The production supervisor, line leader or engineer gross salary is around $471 a month. The Base net salary without overtime and after taxes is $213 a month; overtime hours $250-$300; compensation and rewards $100-$150 (China labor watch, 2016). Overtime hours are calculated as follows:

Overtime hours = regular overtime pay/ (1.5 x hourly wage) + weekend overtime pay/ (2 x hourly wage) + holiday overtime pay/ (3 x hourly wage)

Often, those wages have to cover the expenses of the worker and his family – parents, and children. The workers are so dependent from the overtime that they have to quit their jobs if the employee is not able to provide enough overtime. They don't need the money to make their life upscale or to display their wealth. They need them to cover basic living expenses and survive. A lot of students are hired:

"Thousands of Chinese students…work 10-12 hours a day, six days a week, for up to 5 months."

Student's overtime is reaching 100 hours per month, which is exceeding the government limit of 36 hours per month. Imbalance in manufacturing wages had led to a massive gap between the rich and the poor. Imbalance in manufacturing, supported by unregulated government rules and policies for free trade between countries, expanded the window of personal autonomy and delivered a fair distribution of the wealth on a global scale. Seeking for an equal share of wealth is still a world challenge.

As soon as autonomous automation is integrated and the financial benefits presented in this master thesis by the introduction of mobile robots are visible to companies like Apple, they will reduce or shut down the manufacturing facilities in low-cost labor countries as China. The manufacturing domination of China will be reduced, but it will help to recover the world manufacturing balance.

Figure 13. Apple iPhone workers in China (Photographer: Qilai Shen/Bloomberg)

As Automation raises competition, it will push the development of engineering to new levels. Within the last few years, the robot has become more competitive and lower-cost than the Chinese worker (figure 13). We are just a step away from a Global manufacturing profound shift, according to the data from figure 14 and figure 15. Developed countries with high-educated and skilled automation engineers planning to integrate mobile robots and autonomous manufacturing will soon become more competitive than the low-cost Chinese workers. Mobile robots are opening a new strategic gateway for the developed countries with high-cost human manufacturing labor to keep manufacturing competitive by using low-cost mobile robot manufacturing labor.

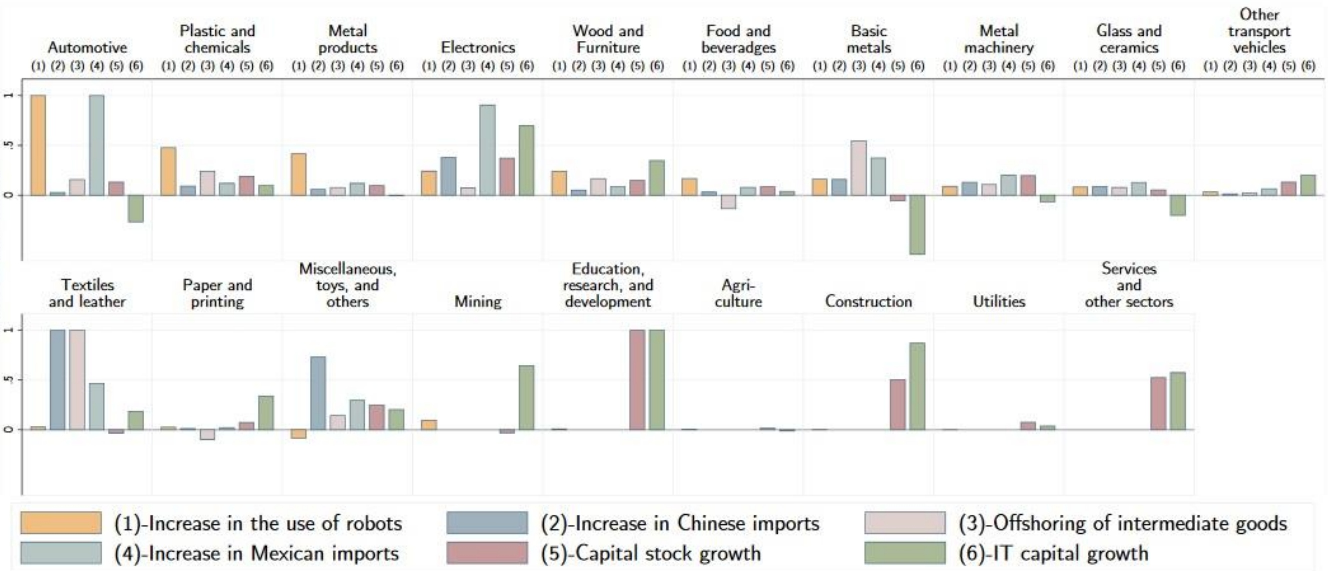

Figure 14. Industry-level changes in the use of robots, Chinese imports, capital stock and IT capital. (IFR)

Note: This figure plots the increase in the number of robots per thousand workers between 1993 and 2007 Reports are showing that 47% of the workers in the US and 35% of the jobs in the UK can be substituted by robots. Apple has the organizational, financial and technical resources to automate the iPhone assembly and replace 50% of the manufacturing workers with robots. The profits will be maximized, but thousands of people will become unemployed. Automation is, therefore, one of the main drivers why incomes have decreased.

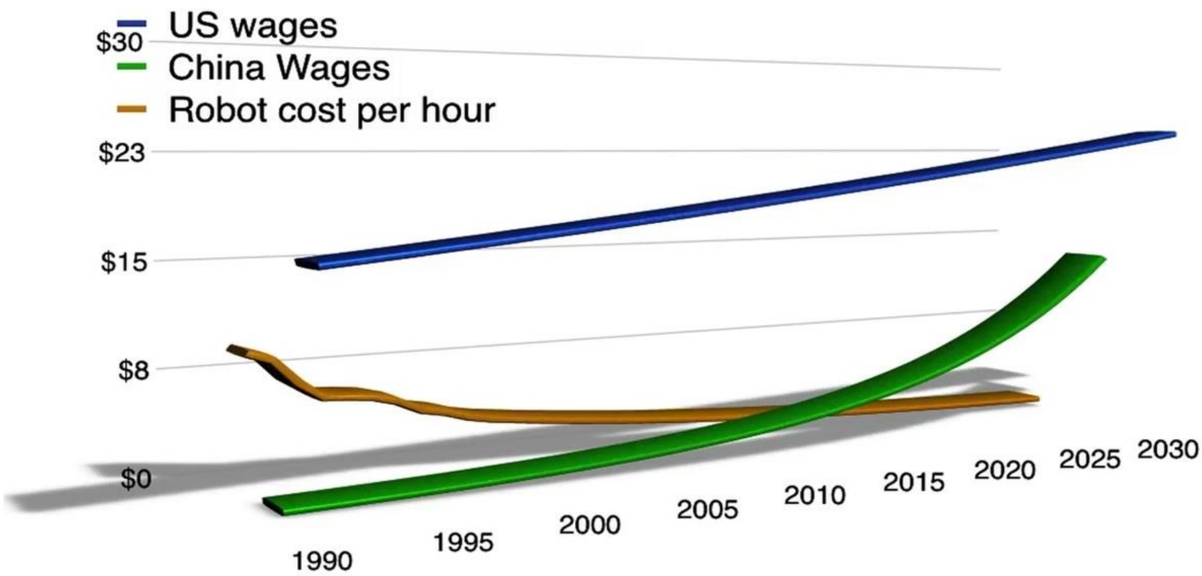

Figure 15. US wages, China wages and robot cost per hour (BCG, 2015)

According to World Population aging report (2015), in the next ten years, the world's population is projected to increase by 11% or 766 million more people. As soon as robots replace human labor across the entire economy, a greater inequality in labor markets will come. The number of people living close to the line of poverty will increase significantly. They will seek for low prices and purchase the cheapest products available on the market in order to survive. This consumer behavior drives the supply chain complexity, which is pushing the manufacturing to become more efficient and automated. The differentiation in the supply chain will be directed more by price competition, than from quality competition. Developed countries with high manufacturing wages will have a leading role in adopting mobile robots and automation. Emerging economies with lower wages will follow them later on.

The more intelligent and smarter an autonomous mobile robot is, the more cost efficient and profitable will be.

We have to rely on automation, but we do not have to underestimate its negative impact. Robots certain plus comes from the productivity effect, while their unfavorable consequence comes from the direct displacement of human workers.

4.3. Fourth robotic challenge

How can a human trust robot if the robots themselves do not understand what trust is?

"The robots are coming." Robots are slowly, but truly replacing people. They need to *build and win the* confidence from all living organisms, in the same way as we do. Everything is changing from biological to artificial. It is changing irreversibly in unthinkable scale. Preserving biological life from artificial mutation will become a mission impossible. Our biological children are the product of our bodies. The artificial robots are the product of our biological brain. It is not a challenge anymore to create a human-like kind of machine that would be capable of communicating, moving, reacting or even thinking as we do. There are still some operations where the people are performing better, but in the majority of cases, robots are over-exceeding human capabilities. Mimicking natural movements and expressions, and some of our nonverbal communication reactions are still complicated and not suitable for robots: ballet arm gestures combined with face acting, for example. From another side, our environment is becoming so high technological and digital that we are not capable of distinguishing from a single look what's natural and what's artificial. What's next?

Robots create robots.

The technological evolution is what allows us to move forward with the next generation of industrial mobile robots. The next artificial robotic generation will become intelligent enough and capable to self-reproduce, without any human intervention, which I can describe as an artificial life. This artificial life will create a new type of artificial digital communication - machine culture. Combining the AI software algorithm properties like adaptability, editability, copytability, and expandability will allow the robots to discover hidden informational clues providing them with the artificial ability to self-improve and self-reproduce. Biological human abilities like remember, notice, forget, focus attention on, shift attention from, reason, plan, execute a plan, reconsider a decision, modify an action will become part of the machine consciousness and machine culture. Some of them will mutate, adapt or disappear. Even emotional intelligence and intellectual property will be artificially created and hard to differentiate from the biological one. By continuously improving the algorithms through trial and error or recursive self-improvement method the AI will advance to a higher and higher level. The machine learning ability will open a window for the machines to progress biologically. The human knowledge is the current driver. However, there is a deficit of human knowledge. The need for AI and the development of AI are growing with the same speed as globalization is growing. The evolution of robotics is evolving with the same speed as the computers were evolving twenty years ago. One human knowledge can differ from another human knowledge by the information accumulating capabilities, competencies or memory capabilities. The AI information storage is limited to the life of Universe, e.g. it's more than the human capabilities. The AI technology will always advance by continuing improvement actions. Once the machine learning passes through the technical singularity, exceeds and overpasses the human capabilities, the machine knowledge will become the future driver of the business intelligence and the organization growth. (Urban, 2015)

Ray Kurzweil is starting his book *The Age of Spiritual Machines* with the following introduction:

"We are the last.
The last generation to be unaugmented.
The last generation to be intellectually alone.
The last generation to be limited by our bodies.
We are the first.
The first generation to be augmented.
The first generation to be intellectually together.
The first generation to be limited only by our imaginations."

…

"We're so exquisitely privileged to be living in this time, to be born right on the precipice of the greatest paradigm shift in human history, the only thing that approaches the importance of that reality is finding like minds that realize the same, and being able to make some connections with them. "

Each new mobile robot generation is improving the technical characteristics as speed, power consumption, flexibility, weight, etc., which improves the overall services, moving the cost of the manufactured products down, the volume high and quality better and better. Robots are becoming a must have working force for any industry on a global scale. Robots are open to learning and adopting intelligence faster than we do. Once they take our jobs; then we do not have to do them anymore. US President Lyndon B. Johnson settled a national commission to explore the effect of technology on the employment, declaring that automation did not have to destroy jobs but "can be the ally of our prosperity if we will just look ahead." Nowadays, the same questions are raised in the media almost every day. An organization is as good as the people working for it. Automation is changing the way that we live, communicate, move, think, work and relate to one another. Shortly, robots will replace at least half of the low-skilled jobs, which are easy to clone or imitate. Then robots will start substitute or complement partially middle-skilled jobs as security guards, for example. It will have an enormous impact on unemployment rate affecting low and middle-income earners. It will change the direction of knowledge and the needs of the human skills. Some of the human skills and abilities will be no longer needed, but new human potential will be unleashed. The need for high-skilled human workers will increase while the need for human workers with less education and lower skills has decreased. The talented and high-skilled labor market will emerge.

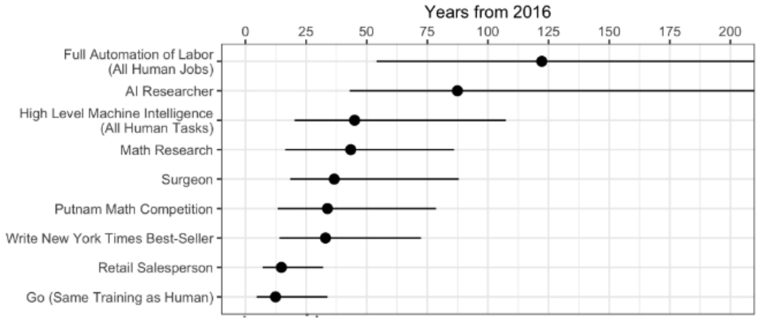

Figure 16. Timeline of Median Estimates (with 50% intervals) for AI Achieving Human Performance Data'. (Katja Grace, 2017)

According to a research from Oxford and Yale (Katja Grace, 2017) presented in figure 16, artificial intelligence will dominate over human intelligence in driving a vehicle (by 2027), working as retail salesperson (by 2031), writing a book (by 2049), and working as a surgeon (by 2053). AI will be capable of replacing half of the jobs within 45 years and all of them within 120 years. Negative unemployment effects of robots and AI will influence on essentially all occupations.

The time to market through integration of technology and automation is decreasing more and more. The speed from the innovative idea to a real manufacturing of product or service is close to the speed of light. The futuristic ideas are becoming a reality much faster than ever before. The rational scientific society is adapting the robot's abilities to the human preferences by combining different material properties, existing biological functionalities and discovering new methods of automation every day. Automated vacuum cleaners and different consumer smart products for home use can be purchased at an affordable price in any tech market store today. They were considered as an expensive fancy product just a few years ago. One of the basic business goals is to manufacture a product, which the customer would love. Nowadays it's almost impossible to manufacture without machines and automation. Would the customer love a perfect product designed and manufactured by AI machines without any human passion, spirit or touch? The short answer: Yes it would love an artificial product.

The more abilities and functionalities the robot has, the more valuable his contribution to the society will be.

Robots do not rely on parents or God to guide or help them survive. They rely on sensors, controls, and adaptive machine learning. If a mobile robot is moving autonomously from point A to point B, it will use the integrated sensors and controls to find the shortest path safely. It will not touch or harm a human by moving gently around obstacles or other machines. It will wirelessly communicate its position at any time, giving feedback to the rest of the mobile robots moving in the same area to eliminate chaos and improve coordination. The next artificial generation of mobile robots would evolve as self-adapting machines, continuously improving the organization, and capable of imitating and over performing even a complex biological organization as the ant’s colony. (Urban, 2015)

We create them, one by one, and now they are everywhere. People used to communicate with people. Nowadays people don’t just talk about smart products and don’t just communicate through the smartphone. Nowadays people interact more frequently with robots than with humans. Even the family dog is replaced by a dog-robot (it will never die). It is changing the society and the way that individuals interact, socialize and communicate. The new digital environment creates a new relationship to work, new relationship to life and new relationship to the universe.

What makes a robot a smart robot?

Intelligent – Smart robots have the computing brain that enables autonomous intuitive decision making and self-learning processes based on integrated algorithms. Able to learn from other robots, people, and its environment, they transform or mutate the biological life to artificial one.

Information – Smart robots have the capability to access information in multiple ways, which updates their software and improves their service.

Communication – Smart robots have a wireless machine to machine communication to exchange data within the Wi-Fi network, which enables remote motion coordination.

Adaptive – Smart robots have the control power and functionalities to adapt their technology from its experience.

Abilities – Smart robots have the necessary communication skills of understanding, speaking, hearing, recording and the freedom of motion. They vacuum floors at home, paint or wash cars, organize the warehouse, waltz-like people, and clean up windows or nuclear reactors.

Rodney Brooks, founder, chairman and CTO of Rethink Robotics said that sensors help the robot to "feel" and "see" so it can tailor to our world. "We do not have to tell it how fast a conveyor belt is moving," Brooks said. "It sees it; it knows it; it has common sense to figure that out." (Laskowski, 2014)

"Would you say a drone is a robot?" asked **Terry Fong**, director of NASA's Intelligent Robotics Group at CNET's CES robotics panel. "Well yes, as soon as it becomes more autonomous, it is definitely a robot." (Collince, 2017)

Alonzo Kelly, a robotics professor at Carnegie Mellon, said: "Your washing machine is a robot. Your dishwasher is a robot. You do not need to have a very broad definition to draw that conclusion... Robotics will continue to be ubiquitous and fairly invisible. Systems will just be smarter, and people will accept that. It is occurring around us all the time now." (Lafrance, 2016)

Technological progress is increasing the manufacturing capabilities and productivity but is decreasing the jobs. Nowadays and in the near future, the changes would affect primarily simple, low-skill occupations that are easy for replacement by robots and don't require a high level of responsibility or intelligence. The engineering knowledge is being put in the background, thus opening a window for automation and robotics to become part of the industrial revolution.

Consumer reaction and acceptance of mobile robots are critical for the future industrialization. Consumer behavior and feedback have to be followed and analyzed. The report from the Committee of Legal Affairs in the EU highlighted that robots would *"unleash a new industrial revolution, which is likely to leave no stratum of society untouched*." More than $16 trillion in wages paid to people on a global scale has the potential to be replaced by nowadays technology. The report is announcing that the threatened jobs over the next decade or two would range from 9 to 47 percent. Every three months about 6 percent of employment in the US economy is lost by reducing or closing workplaces, while a smaller percentage of jobs are added—resulting in decreasing jobs and a consistent unemployment rate. The same numbers are confirmed by a US National Bureau of Economic Research completed in March 2017. The positive productivity effect of automation will ignite huge displacement effect on human workers from the jobs, which they were previously executing. One more robot per 1,000 human workers will cut down employment by 5.6 workers and reduces wages down to 0.5 percent. Artificial intelligence is additionally raising the displacement effect, and virtually no job is safe, reported by International Data Corporation. We are already able to see that computer algorithms working with faster processing speed are now eliminating jobs formerly done by highly trained individuals, while robotics and automation continue to displace industrial workers. An algorithm can be defined as "*a process that performs some sequence of operations in order to solve a given problem"*. The economy and the individuals have repeatedly proven capable of adapting to changeover, although it would depend on how fast the changes will happen and how concentrated the losses will be in specific occupations that are hard to shift. Universal basic income is one of the topics discussed globally to prevent poverty and human unemployment. It's a single basic income to ensure the comfort and the pleasure of our personal lives. More human cooperativeness, more community involvement, less corporate domination and better government control needs to be established.

4.4. US manufacturing: Mobile robots in Amazon warehouse

Amazon’s fulfillment center, located in Robbinsville, NJ, USA is a place, where humans and mobile robots are working together in coordinated harmony. Amazon warehouse is a storage space containing square shelves packed with various products from Amazon’s inventory. Before the integration of mobile robots, Amazon’s workers would have to load, unload and search for the products themselves to fulfill each new order. Now the shelves are moved autonomously by mobile robots across the floor space. The main work of the mobile robots is to transport items from one part of the warehouse to another. The operators are waiting till the products are delivered to them by the mobile robots. They pick the product from the trays carried by the mobile robot and continue with packing and shipping process. The mobile robot is returning the trays to its initial location. The overall control and navigation are managed by a central computer and ERP system. Additional markers on the ground floor are guiding the moving paths. The navigation software is allowing the robots to plan their paths to travel quickly and efficiently anywhere they need to go. The mobile robots either rearrange the shelves or bring them over to human workers, who stack them with new products or take off the products for packaging. Warehouse managers can monitor the mobile robots at any time and to change or prioritize their path flows or work assignments.

Figure 17. Amazon warehouse

Amazon’s automated shelf system allow more products to be packed into a tighter space. They also make stacking and picking more efficient by automatically bringing empty shelves over to Packers or the right products over to pickers.

Amazon spokesperson Kelly Cheeseman announces: *“We already have over 15,000 robots in our fulfillment centers working alongside our employees,”* (Harris, 2015)

The mobile robots work 24/7 over three shifts, making the warehouse process more efficient, which is certainly increasing the productivity. It is also a real example of how automation can replace human workers and increase unemployment.

According to an RBC Global Asset Management report, the costs of robots have collapsed rapidly. A lawn robot that cost 400,000EUR 10 years ago, now can be purchased for 400EUR. The robots are imitable and easy to clone. The cloning however, is sometimes better than the original. It used to be that the “high costs of industrial robots restricted their use to few high-wage industries like the auto industry. However, in last years, the average costs of robots have dropped, and in a number of key industries in Asia, the cost of robots and the unit costs of low-wage labor are converging ... Robots now represent a viable alternative to labor." Decreased cost of robots has led to a shorter payback time of the investment. Related hardware components such sensors and controls and software become cheaper and easier to use. The software flexibility to re-program the machine functionalities and performance also had a significant role in the integration of automation. The easier to use, the more preferable the machine will become. The life cycle times or the replacement cycles of electronic products have become lower. It has created additional need for quick design change of the product and fast changeover in the manufacturing process. The go-to-market speed is playing a crucial role in any manufacturing. Standardization and mass-volume production of low-cost products have increased the necessity of automation. Customization from another side, driven by the customer individual preferences has increased the need for adaptable and precise equipment, fulfilled by the modern programmable automated machines. Priceless and more affordable, the robots are entering into new areas and fields, servicing new applications as never before.

Other firms following the Amazon example of replacing humans with robots are DHL (collaborative robots or cobots); Walmart (warehouse drones); UBER and Tesla (automotive industry); Best Buy, Target and Lowe's (retail robots); Adidas (shoe manufacturing robots); Nestle (Pepper robots to sell Dolce Gusto coffee pods); Pizza Hut (Robot waiters); Chipotle (drone delivery); ING (banking sector); Marriott and Crowne Plaza hotels (Hotel room service robots).(MSN, 2017) Leading technology companies like Google (Deep Mind) and IBM (Watson) are developing not just robots, but robots with the brain-power to think and take decisions autonomously. The motive is a higher profit. More than 30% of the robots used by various organizations are still unclassified. The main businesses using robots outside of manufacturing are agriculture, forestry; mining; utilities; construction; education, research, and development. The applications are continuously growing and evolving. The digital transformation will disrupt every industry in every country. (IFR, 2016)

4.5. Future look: year 3017

Are the robots risk for humanity?

Let's take a look in the future (personal view):

The year is 3017. Mobile robots and self-driving cars are replaced by self-flying drones, powered by alternative energy. The Artificial Intelligence has passed the point of technological singularity, and the robots are smarter and more intelligent than any human. Robots are invisible. Equipped with precise cameras and covered with flexible screens, they can project a real-time background image as a hologram on the front side of the robot body, resulting transparency. They move gently around us, but we are not able to hear, see or smell them. Human sensitiveness is blind and deaf. The robots have achieved complete clearness, protecting them from humans.

Robots create humans.

Robots leave within the robot smart open-source decentralized network, creating a new type of artificial human. Robots have achieved the level of artificial intelligence allowing them to create human beings. Our human confidence that the robots would help us to create people's life more comfortable, called *robo-hope*, has turned to *robo-fear*, where robots need humans to make their future sustainable. They still communicate through Wi-Fi network, but the network is over engineered for a human, and no living organism understands the encryption or can use it. No access, no control, no information. Through sophisticated financial instruments, the robots succeed to take full control of the World Bank and the World stock market. All the money belongs to them. Information, knowledge, gold, diamonds, digital currency (Bitcoin), digital assets, real estate properties belong to them. However, money is not a valuable product for robots. Their goal is to survive and dominate by creating artificial humans, which will obey their orders. People are replaced by robots…

More than 200 years ago, in 1816, a young girl called Mary Shelley wrote the story of Victor Frankenstein. A horror story of a young scientist who creates a grotesque but sapient creature, becoming the world-famous monster. The novel is a combination of science and fiction. Fiction, which the science will transform into reality by 3017.

Integration of the robots and the artificial intelligence could become an imminent global catastrophic risk. If we do not understand today that we cannot understand how the machine evolution tomorrow will influence the human evolution and planet natural environment, then we need to continue study what machines do or can do, how they can do it and how the natural ones can be adapted safety to their synthetic minds. We have to continue sensing what another human or non-human is experiencing from his frame of reference, but we have to be always aware that our creativity and intelligence might end the humanity.

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