Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Planning a Production Space and Micro Logistics in an Industry 4.0 Factory

Master's Final Degree Project

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Kaunas University of Technology

Faculty of Mechanical Engineering and Design

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Industrial Engineering and Management (6211EX018)

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Kaunas, 2020

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Planning a Production Space and Micro Logistics in an Industry 4.0 Factory

Declaration of Academic Integrity

I confirm that the final project of mine, Marija Seniūnaitė, on the topic „Planning a Production Space and Micro Logistics in an Industry 4.0 Factory“ is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

(name and surname filled in by hand) (signature)

Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Task of the Master's final degree project

Given to the student – Marija Seniūnaitė

1. Title of the project –

Planning a Production Space and Micro Logistics in an Industry 4.0 Factory

(In English)

Gamybos erdvės ir mikrologistikos planavimas pramonės 4.0 gamykloje

(In Lithuanian)

2. Aim and tasks of the project –

Aim –
To create a model for production space and micro logistics, under the principles of industry 4.0 factory, that could apply to Company X.
Tasks –
1. To prepare space planning for a company X producing automotive components.
2. To prepare micro logistics concept for manufacturing processes.
3. To create the layout of the factory

3. Initial data of the project –

Not applicable.

4. Main requirements and conditions –

While planning Company's X production space, the minimal requirements of a single production line space usage shall be followed. Therefore, for a standard SMT line, the minimal area required – 120m². A standard fully automated BE line area requires at least 100m². Industry 4.0 micro logistics concept aims to reduce employee number, while using automated systems.

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Summary

Today, manufacturing industry cope with new challenges that rapid growth and implementation of digital technologies brings, alongside the benefits it creates. The term Industry 4.0 is used to describe the recent transformation of the manufacturing industry, towards automated technologies and other innovative usage of digital tools. This research focuses on the production space planning and micro logistics in modern, Industry 4.0 factory, as these particular aspects are key, in order to design effective production layout. In this research the example model of production layout of Company X is presented, while adhering and following the Industry 4.0 trend.

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Kaunas, 2020. 56. p.

Santrauka

Šiandien, kuomet informacinių technologijų populiarumas ir naudojimas gamybos pramonėje auga, šių technologijų kuriami pranašumai, su savimi atneša ir naujus iššūkius. Terminas Pramonė 4.0 tapo naudojamas apibūdinti gamybos pramonės transformaciją, kuomet gamyboje pradedami naudoti inovatyvūs informaciniai ir automatizavimo įrankiai. Šis tyrimas koncentruotas į gamybos erdvės ir mikro logistikos planavimą Pramonės 4.0 gamykloje, kadangi šie aspektai turi didelę įtaką siekiant sukurti efektyvų gamybos sustatymą. Šiame tyrime taip pat pateikiamas pavyzdinis modelis Pramonės 4.0 gamybos erdvės sustatymo plano, kuris atliktas besilaikant naujausių Pramonė 4.0 tendencijų.

Table of contents

List of figures

List of tables

Introduction

Global industry leaders are considering large green field investments to continue their growth as business. Few years ago, the countries around the world were competing to be home for Tesla's second "Gigafactory"[1], while locally in Lithuania, few of the biggest green field investments in countries history were made in 2019 when, Hella, Hollister and Continental decided to open up factories in Kaunas[2]. The term Industry 4.0 is considered as the new trend in manufacturing world, when some refer to it even as the fourth industrial revolution. Automatization, development of digital and communication technologies has seen rapid growth of popularity in the recent decade and the manufacturing industry took advantages of the newest inventions. Implementation of the newest technologies, that represents the concept of Industry 4.0 trend, requires thorough research and planning ahead. This research presents the calculations and decisions that has to be made, in terms of manufacturing space planning and the micro logistics, while creating a model for manufacturing company.

Aim of the project:

To create a model for production space and micro logistics, under the principles of Industry 4.0 factory, that could apply to Company X.

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1. Literature Review of Space Planning and Micro Logistics in Industry 4.0 factory

1.1. Industry 4.0

Modern economies seek to maximize the profit from manufacturing, therefore, the implementation of latest technologies plays a big role in the process. This trend, which is focused to increase the efficiency and productivity in industrial manufacturing is commonly known as "Industry 4.0". With the implementation of internet technologies, which aims to improve the communication and management of systems involved in the manufacturing processes, modern Industry 4.0 factory can be developed. The concept of Industry 4.0 factory and connections between technologies is presented in the Figure 1.

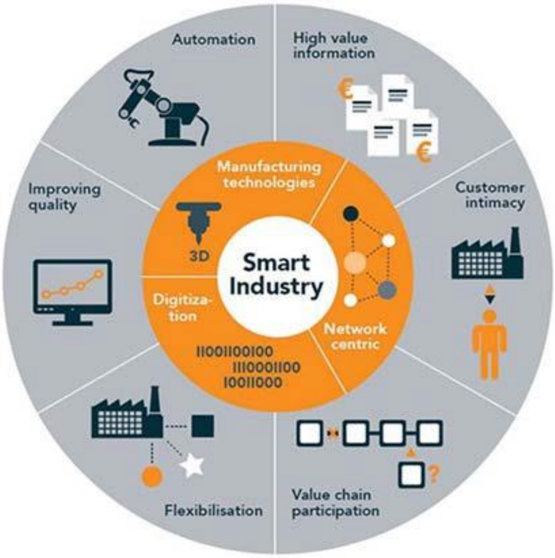


Figure 1. Industry 4.0 Concept [3]

As the interest for the concept of Industry 4.0 factory grows, analysis of collected experience and implementation of various tools and strategies to achieve better results are highly valuable due to its potential impact to improve the quality of life for people around the globe [4].

When implementing elements of Industry 4.0, it is noticeable that such a change is rather an everlasting process, than one day project. The main characteristic of the smart factory is the integration of cyber-physical-systems. This type of systems works in fully digital environment, while using IoT (Internet of things) tools, to control and optimize the flow of materials and goods produced in the factory. Real time management of such process, leaves open the possibilities to be flexible and adapt to changes in demand. [5].

Javaid et al. (2020) in his research, presents one of the most recent examples of how the tools of Industry 4.0 can be used to impact the quality of life in the society, where the COVID-19 crisis is selected as research object. AI (Artificial Intelligence), 3D Printing, 3D Scanning, IoT (Internet of Things) and other innovative tools, can all be used to fight the pandemic in many ways – from monitoring the information that is provided for the society in terms of recommendations and regulations, to ensuring quarantine breaches are monitored. Big data analysis can provide real-time data and new findings for scientists, doctors and epidemiologists, to help finding cure or new ways of fighting the outbreak [6].

1.1.1. The Fourth Industrial Revolution

Currently, the world is on the edge of a new industrial revolution. Digital technologies are used to fully operate modern factories, from concept or idea of the product, its evolution path, to the customer related processes of service, maintaining and recovering.

Industry 4.0 is expected to transform not only the industrial sector, but also the society. While on paper, Industry 4.0 concept should bring higher efficiency, quality and overall improvement of the production, there is still some room for discussion, as it can bring challenges, which could not be easily overcome [7].

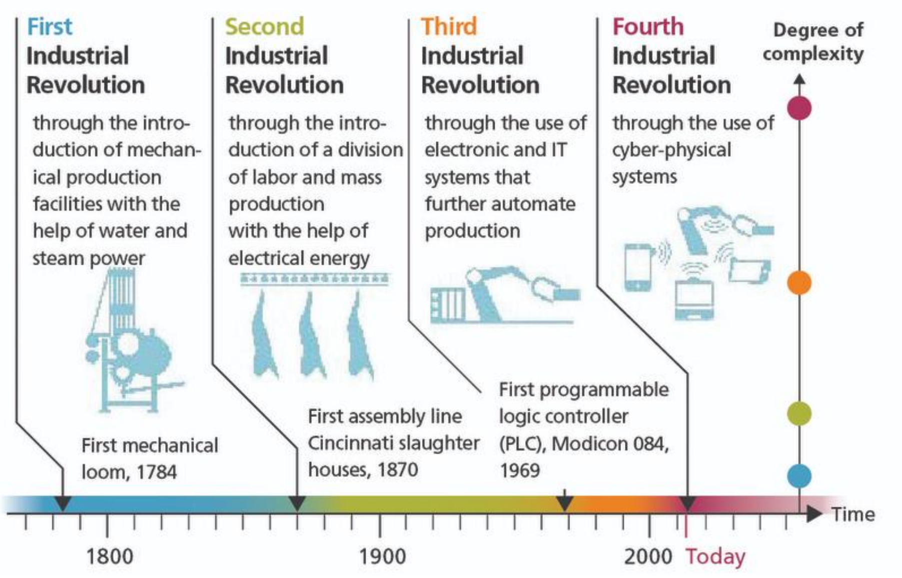


Figure 2. Industrial revolution [1].

Industry 4.0, as a term, was first mentioned at the Hannover Fair in 2011, and since then, the academic world, political leaders and business owners are deeply involved in this subject. Kagermann et al. (2013) considers Industry 4.0 as the current trend toward automation and data exchange in manufacturing technologies.

The term “Industry 4.0” originated from Germany, where government had a project to promote high-tech manufacturing possibilities. Lee J. (2013) in his article considering Industry 4.0 as the next phase in the digitization of the manufacturing sector, and mentions four main points, with the most impact:

- The tremendous rise in data, computational power, and connectivity;
- The possibilities of analytics and the capabilities businesses can use the information;
- New forms of user interfaces with the machines – from touch control, to augmented reality system;
- Possibilities to give digital information a physical form, for example 3-D printing or making advanced robotics perform actions desired.

Figure 3. Digital compass [8].

All the digital technologies mentioned in the figure above have been in development for years, and some of the technologies still need time to be fully developed, but many of them are at such a point, where the possibilities and expectations weights out the required costs of implementation. There are surveys done, which state that todays' companies are not always aware of the latest technologies. McKinsey did a survey with 300 manufacturing leaders in January 2015, and only 48% of manufacturers consider that their companies are ready for Industry 4.0. 78% percent of suppliers answered that they were prepared for the implementation of 4.0 industry equipment in the companies [8].

Industry 4.0 takes manufacturing automation to higher level and introduces new technologies for production. Most advanced machines will operate independently or with a small coordination from operator, to make production as effective and efficient. Machine collects the data, analyzes it, and prepares reports on the performance and possible improvements.

1.1.2. Micro Perspective of Industry 4.0

In Figure 4, the micro view of smart factory is presented, which covers the processes of modern business.

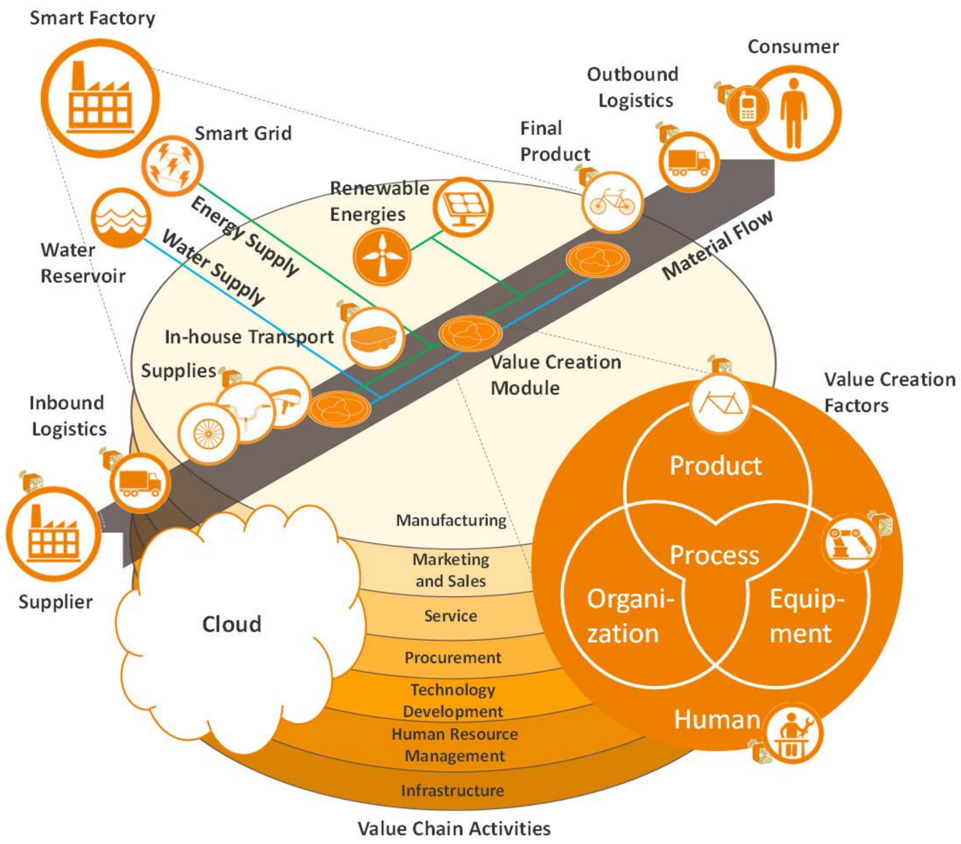


Figure 4. Micro perspective of Industry 4.0 [9].

Smart factories using renewable energy and becoming self-sufficient regarding supplies are creating higher value. There are few main factors that can be considered the biggest value creators:

Equipment – Since the modern equipment is highly automated and robots are part of it, it must be able to adapt to changes, therefore, the more versatile the equipment is, the more value it creates. It also should be noted that robots will be working alongside humans on the same tasks in the future.

Human – Because of the intense automatization in the manufacturing field, humans are facing a risk where robots can replace their jobs, and the qualification of a modern manufacturing worker will increase highly, as the unqualified work force will be replaced by robots.

Organization – Decision making takes a lot of expensive time, therefore, all the processes can't be controlled from centralized institution. All the decisions in smart factories should be made by the employees that are responsible for the process, or the artificial intelligence that is able to analyze the data it collected.

Process – Modern processes, such as 3-D printing will be used more often, since it is becoming less expensive to use. This type of manufacturing can be more customized and focused to the customers' requirements. The product can be more complex, various shapes and sizes, therefore, the value of the product increases highly.

Product – Individual requirements of the customer will define the batch size, that the products will be produced in [9].

1.1.3. System architecture and operational mechanism

Modern manufacturing factories are now usually referred as smart factories, since the communication between different departments and processes in the production are carried out using digital technologies. In the Figure 5, smart factory systems' architecture and the mechanism of how it operates are shown. There are four layers – Supervisory control terminals, Cloud, Industrial network and Physical resources. At the physical resource level, the intense communication between machines, products and conveyors happen, and all the data goes through Industrial network to the Cloud, where all the information is analyzed, and distributed to the supervisory control units, which directs the information to people. Also, Figure 5 shows that the smart factory can be viewed as a dual closed-loop system. First loop consist of physical resources and cloud and second loop consists supervisory control terminals and cloud.

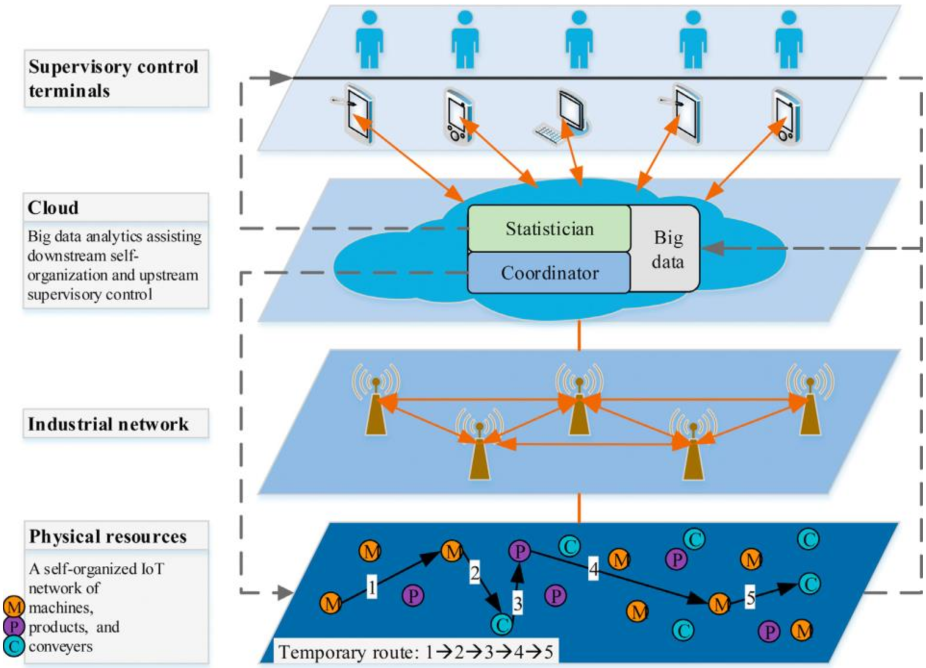


Figure 5. Framework of the smart factory of industry 4.0 [10].

The application of automation and information systems such as enterprise resource planning (ERP) and manufacturing execution system (MES), significantly improves factory productivity [10]. Manufacturing execution system (MES) – is a system used in manufacturing, to follow and document the transition of raw materials to finished products. MES can provide data that could be used in manufacturing optimization projects, to increase the efficiency of the plant. MES works in real time to enable the control of multiple elements of the production process. MES helps company not only to track movement of material, but also to control and track machine work.

1.1.4. CPS 5C Level Architecture

Cyber-Physical Systems (CPS) is defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities [3].

CPS has two main sections. First – real-time data gathering from physical processes through highly advanced connectivity. The second one – all the analyses and management of the big data collected. Figure 6 presents 5C architecture that defines the flow of the processes and explains the CPS concept.

5C consist of:

- Connection
- Conversion
- Cyber
- Cognition
- Configure

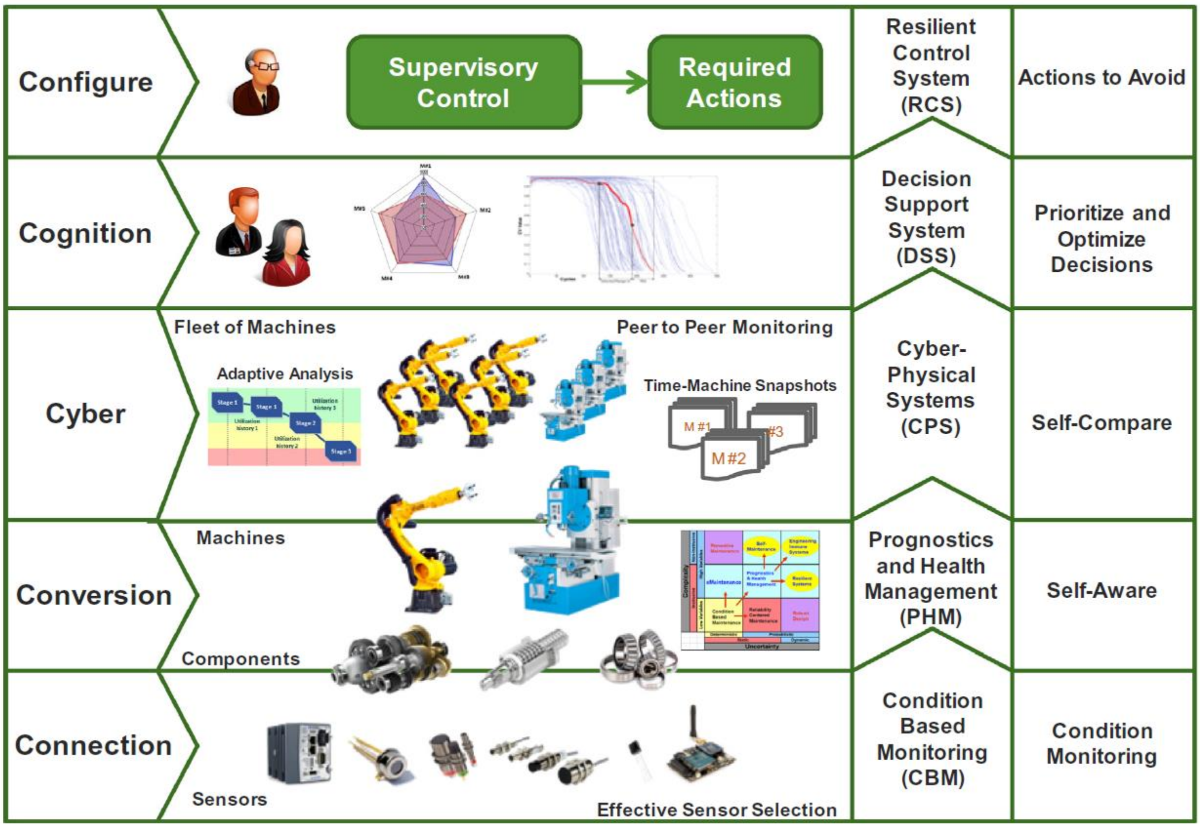


Figure 6. Applications and techniques associated with each level of the 5C architecture [3].

Figure 7 presents information flow example how implementation of 5C CPS architecture could work in the company that have numerous amounts of machine tools.

This way of knowledge control not only guarantees near zero downtime production, but also provides production organizing and inventory management plans for factory management.

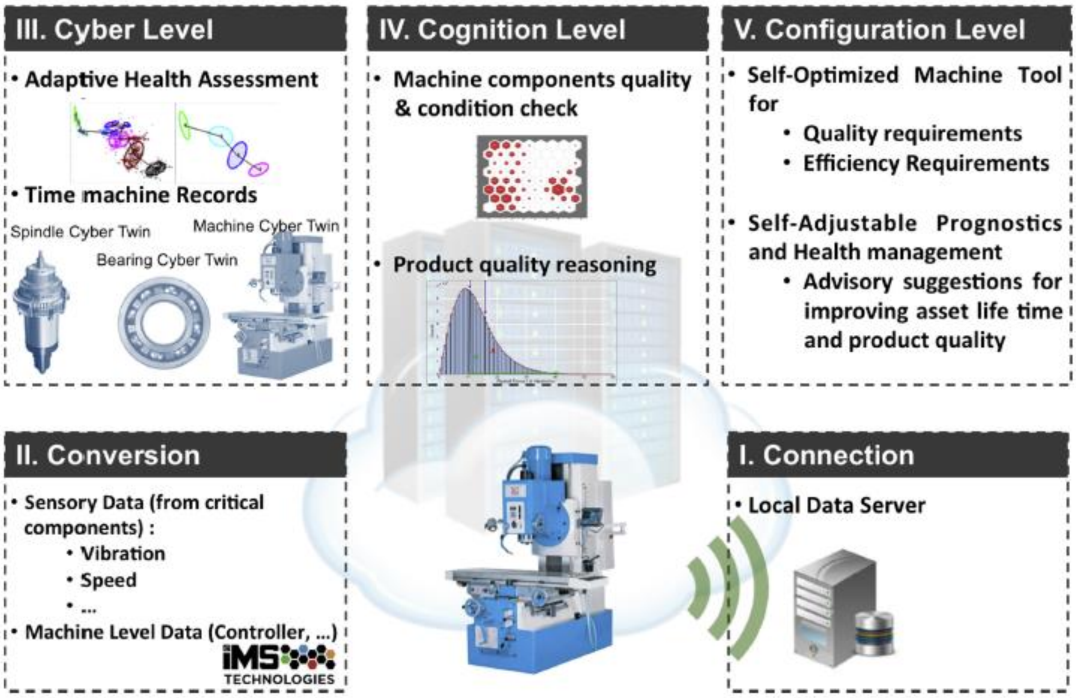


Figure 7. The flow of data and information based on 5C CPS architecture [3].

1.1.5. Production Space Planning

Due to constantly changing parameters in the logistic processes, manufacturing industry has to cope with new challenges, and rapidly adapt to changing customers' demands. One of the ways to successfully overcome these challenges, is to strategically plan the space in factory, which would be used for production, material handling and warehousing. Traditional industries are shifting from the ordinary mass production, to more customized mass production. With this kind of change, challenges and problems of material handling processes rise and overall productivity is usually reduced, unless the implementation of such a shift is well organized and carefully fulfilled [11].

Layout of the facility and production is often modelled using 2D CAD technologies and its' tools. The data for modeling is usually gathered from existing blueprints or previous layout models, which can be misleading and have many errors when comparing to the real-life situation in the facilities, due to any undocumented changes or errors in the blueprints that have never been fixed. Any mistakes in the stage of modelling may result in costly changes later, for the machinery or facility. As one of the innovative tools for this process, 3D imaging technologies can be used [12]. Lindskog et al. (2016) in his research presents terrestrial 3D laser scanner solution, for layout planning. The laser scans the surface of the facility and provides accurate measurements and in depth look of how the machinery could be installed. The Figure 8 represents the view angle of such a laser.

Figure 8. 3D laser scanner [12].

Ojaghi (2015) states that one of the biggest factors that influences costs is poor production layout, and in his research for specific case facility planning, several methods of production space planning were mentioned, e.g. Systematic Layout Planning (SLP), Pairwise Exchange Method (PEM), Graph Based Theory (GBT), etc.

Havard (2019) suggested to use simulation tools for layout planning and to study the production flow. One of the most intriguing and new ways of layout planning, is to use the latest VR (Virtual reality) solutions, to follow the production flow in virtual reality environment, determine bottlenecks and other obstacles that might occur in the production. VR is not limited to a human point of view, therefore several approaches can be done: First person perspective places user in the experiment of the simulation of real environment he would encounter in the facility, therefore, it is the most noticeable and used perspective; Top view perspective lets the user follow production flow from "bird eye" view; Global view is used to control the VR experience and give information for the VR users. During testing of this innovative solution two of four groups found a better solution for their layout [13].

It is well known, that machine layout has one of the biggest impact for the manufacturing capabilities, and any flaws in the layout results in decrease of productivity. Reconfigurable manufacturing system (RMS) could be an answer to most of the challenges faced. RMS is a logical development of the two manufacturing systems already used in the industries: Dedicated manufacturing system (DMS) and Flexible manufacturing system (FMS) [14]. While building RMS, the same constrains of layout planning has to be evaluated, as using the most simple layout planning techniques, e.g. size and number of machines, area for them and around them, movement routes. It is also worth mentioning that the RMS is built for product family and its evolution. Mehami (2018) when talking about RMS, highlights its main feature as flexibility to be reconfigured in a short period of time and applied for different product manufacturing, while keeping the production line costs inexpensive.

1.1.6. Micro logistics and Its Management

Several key elements of logistics, including warehousing, handling, transportation, distribution, and information services, have been forced to change by technological developments to increase efficiency. [15] One of the main goals of successful logistics, is to effectively use the current capacity, implementing new technologies, which would help with mobility, communication and information flow in the facility. Since in the modern Industry 4.0 factories the capacity is increasing, space planning for the production, warehousing and overall material handling routes becomes one of the main strategic points. Kirch et al. (2017) suggested a new term - Smart Logistics Zone, describing the processes of production and logistics in Industry 4.0 factory. Various production and logistics processes is monitored with the help of information and communication technologies. Implementation of these Smart Logistics solutions and Information Management ensures interaction and information sharing between order processing, inventory control, production units, warehouse operations, and accounting, thereby reducing costs and increasing value-added services [15]

Micro logistics is a key part of success for manufacturing companies, therefore the management of logistics processes is considered main point, that covers various operations. Logistic management consists of strategy formulation, planning, command and control of minimizing the flow processes and storage of raw materials, inventory, work in progress, finished goods and relevant information - from the point of acquisition to the point of consumption - in order to adjust to customers' needs and their satisfaction. [7] Since today the world is dependent on the information flow, the most efficient and effective management is achieved through fast and smooth communication, and sharing of knowledge in the most effective way. When managing logistics the most efficient way of moving the goods has to be in tact with dynamic production plans, which are affected by rapidly changing market demands. In order to have great synergy between these processes, autonomous solutions are implemented in many Industry 4.0 companies.
The application of autonomous control in production and logistics can be realized by recent information and communication technologies such as radio frequency identification (RFID), wireless communication networks etc. [16][36]. Through these communication channels, the intelligent machines has the ability to make decisions and ensure the continuous production flow.

As one of the most popular solutions for material handling in the production, Automated Guided Vehicles (AGV) are used. AGV's tackles the challenges of production flexibility and efficiency, but the implementation is highly technical, time consuming and has very little room for any error. In todays' Industry 4.0 factories, multiple AGV's can be used, therefore the paths it takes, has to be without any obstacles, and with such a number of possibilities to move around as there are options to reach any given point in the production space. Task of designing of roadmaps for the AGV's could be very time consuming and very precise, therefore some new solutions of this process is being invented. Beinschob et al. (2017) presented a new approach for the roadmap designing task, which with a help of advanced laser scanner technologies, creates a semantic map of the environment that contains both geometric and topological information regarding all the elements in the environment. The information is then used for automatically designing of the AGV roadmap [17]. AGV systems is required to have the ability to adapt to changing layout of the facility and successfully operate in highly dynamic environment [18].

2. Introduction of Company X and Its’ Product Range

The purpose of the final thesis is to analyze requirements and ideas of space planning and micro logistics in Industry 4.0 factory and apply solutions while creating company X. To fulfill these requirements, company that will be analyzed is selected.

When selecting company, the following requirements were taken into consideration: high accuracy, precision, speed and most importantly competitiveness among all other companies.

The chosen company will produce electronical components for cars. The automotive industry sets a high standard for their suppliers. There are many companies that are producing similar parts, therefore the competition between suppliers is huge [20]. List of companies that is producing electrical components for automotive industry:

- Tesla,
- Continental,
- Land Rover,
- Harman Automotive,
- Alpine,
- Bosch,
- Cadillac,
- LG,
- BMW,
- Hella,
- Other…

All these companies have years of experience and “know how” producing product with the best quality and price. The main purpose of these companies is to fulfil all requirements and make cost-effective tactical and strategic decisions. Because of that it is important to choose strategically good location for production, to build or to buy production area that will fulfil all space and construction requirements [15].

Company X will be producing electrical components that will be used in cars. List of products that will be produced in the company:

- Engine ECU
- Restraint control ECU
- TPMS ECU
- Parking aid module
- Instrument cluster
- Body ECU
- Driver seat control
- Data link
- Driver door control
- Keyless entry ECU
- Telematics box

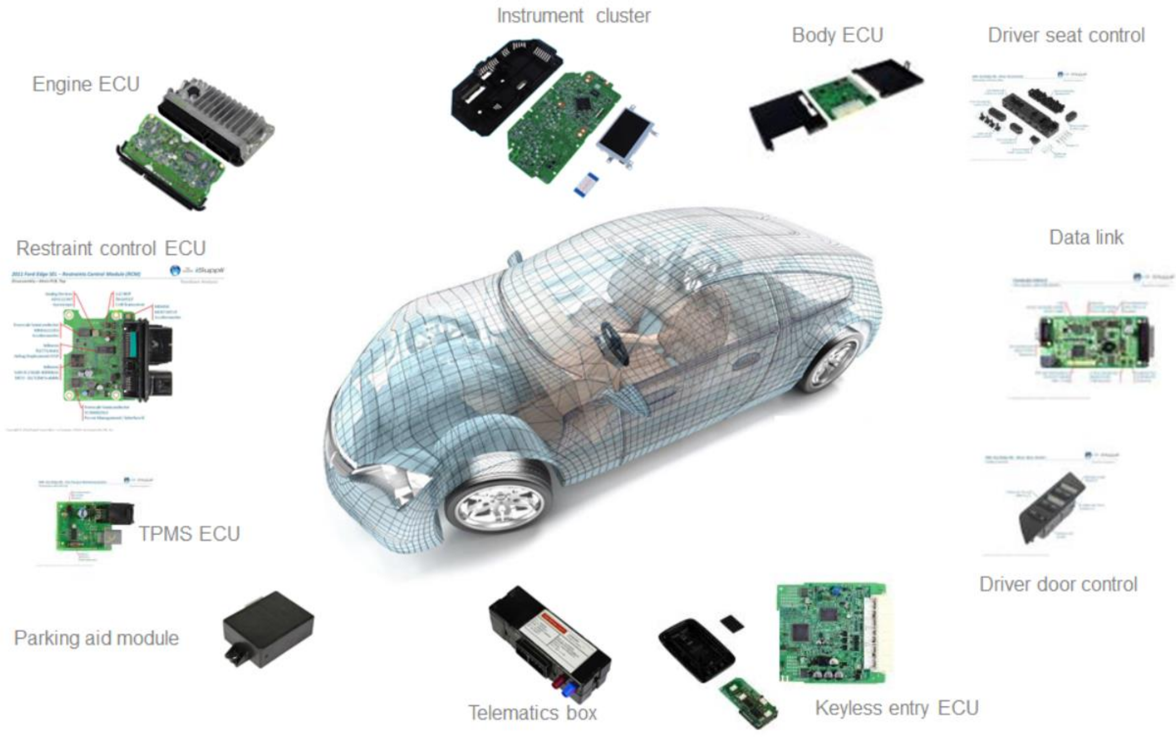


Figure 9. Car components that will be produced in company X [21].

Products are considered as high complexity units. To produce these kind of products, a lot of knowledge and experience is required.

Table 1 presents the Company's X product range, which consists of 11 different products, with approved concept and finished development stage. The company must have the availability in their production lines to fully meet the demand of yearly volumes provided by the customer, while guaranteeing to fulfill the requirements for at least 6 upcoming years, having in mind, that new products implementation is also a key part of successful business growth.

Table 1.Yearly production volumes of company X

		Yearly production volumes					
	Product	2021	2022	2023	2024	2025	2026
1	Engine ECU	50 000	130 000	350 000	755 000	400 000	150 000
2	Resistrain control ECU	0	13 000	25 000	500 000	42 000	39 000
3	TPMS ECU	10 000	40 000	70 000	120 000	259 000	450 000
4	Parking aid module	0	0	150 000	700 000	1 300 000	1 600 000
5	Instrument cluster	100 000	1 100 000	2 300 000	4 800 000	2 900 000	1 200 000
6	Body ECU	10 000	67 000	190 000	400 000	300 000	150 000
7	Driver seat control	0	900 000	1 500 000	3 300 000	4 020 000	5 700 000
8	Data link	0	0	500 000	900 000	1 280 000	2 690 000
9	Driver door control	0	0	35 000	173 000	440 000	910 000
10	Keyless entry ECU	50 000	150 000	400 000	800 000	600 000	600 000
11	Telematics box	0	30 000	150 000	500 000	900 000	600 000
	Total production yearly volumes	220 000	2 430 000	5 670 000	12 948 000	12 441 000	14 089 000

Company X will be producing electrical components that will require 4 main categories of components:

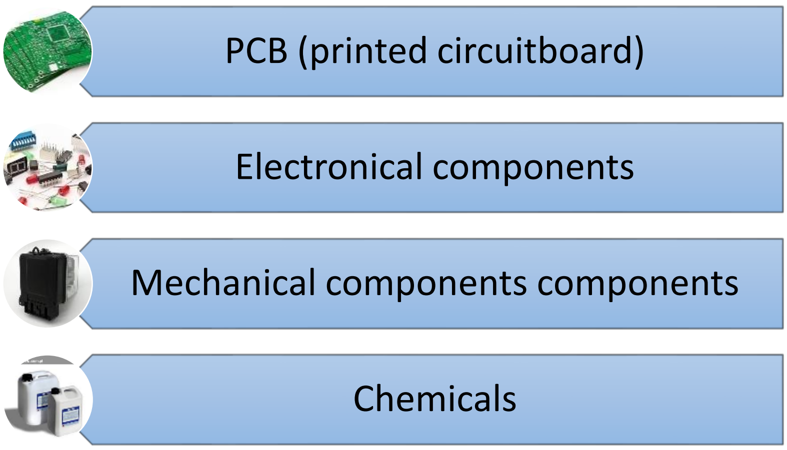


Figure 10. Components that will be used by company X

All these components will be delivered by suppliers and the purpose of the company will be to connect all components into one finished product.

In order to get closer to zero downtime production goal, the company is required to have different spaces, that will be used for different processes. The production area will be separated into 3 main smaller areas: warehouse, repacking area and shopfloor. Each of it is divided to few smaller spaces: warehouse is split in 3 sections, Repacking area has 3 separate rooms and the shopfloor will have 2 main areas. In this project office area, lockers, analysis rooms, maintenance and test engineering rooms are not considered, because these areas does not have any impact to our production space planning and micro logistics.

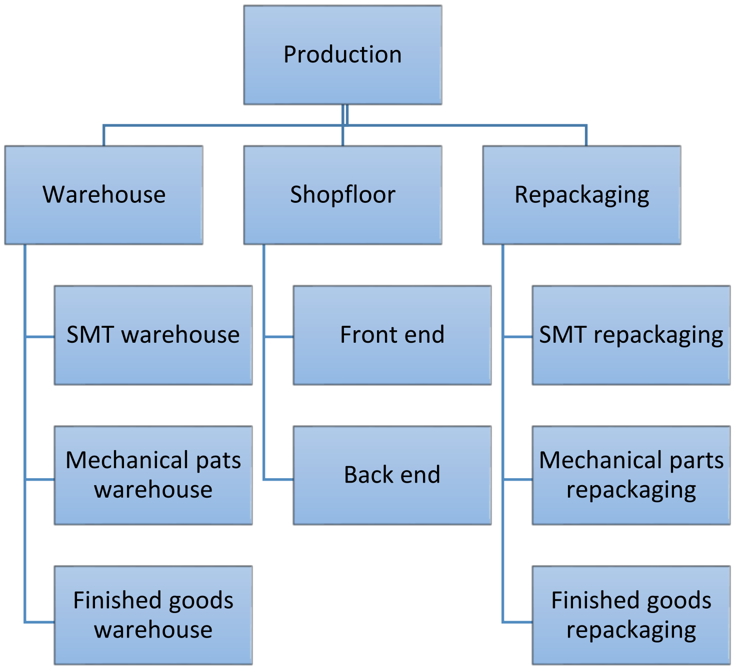


Figure 11. Company X production structure

3. Space Planning and Micro Logistics

3.1. Space Planning

First step of space planning requires to know what kind of products and in what quantities company will produce in the near future, in this case - 6 years. With this information company can do predictions what kind of space is required for production area. Table 1 shows the volume of 11 products that company will produce in 6 years. Not all products will be produced in first year 2021. It is important to notice that all products have their life cycle which can be from 5 years to 10, and more years. At first year Company X will have 5 products that will have to be produced with total volume of 220 thousand parts. At year 2026 company X will be producing 11 different products with total volume of 14,089 million parts. Also, in the table 1, production peek yearly volumes were marked, and according to these numbers calculations will be done. Line capacity must meet peek year volumes, because lack of capacity might lead to not fulfilling the production orders from customers, which may result in fines.

Next step is to calculate takt time that will be required for every line. Takt time – is available time of production divided by customer demand.

Company X available time:

- 335 workdays per year
- 22 hours per day
- 3600 seconds per hour

$$\text{Takt time} = \frac{\text{Available time}}{\text{Customer Demand}} = \frac{335*22*3600}{755000} = 35s \quad (1)$$

Before calculating required cycle time of the lines, we have to decide required OEE that the company will have to achieve. OEE (Overall Equipment Effectiveness) – identifies the percentage of manufacturing time that is productive. When OEE is 100% that means company are manufacturing only Good quality Parts, as fast as it is possible, with no Stop Time. In real life it is almost not possible because of faulty items, utilities break downs, unplanned breakdowns. In company X the planned OEE will be calculated - 80%.

$$\text{Required cycle time} = \text{Takt time*OEE} = 35*80\% = 28s \quad (2)$$

Table 2.Takt time and required cycle time of company X

	Product	Peak production volumes	Takt time	Required cycle time
1	Engine ECU	755 000	35	28
2	Resistrain control ECU	500 000	53	42
3	TPMS ECU	450 000	59	47
4	Parking aid module	1 600 000	17	13
5	Instrument cluster	4 800 000	6	4
6	Body ECU	400 000	66	53
7	Driver seat control	5 700 000	5	4
8	Data link	2 690 000	10	8
9	Driver door control	910 000	29	23
10	Keyless entry ECU	800 000	33	27
11	Telematics box	900 000	29	24

The table 2 suggests that the total count of production lines would be 11, but since there are cycle times that are too short to produce these kind of products, it is required to have 2 separate lines instead of 1, which would result in the total number of production lines to be 14. Products that would have 2 identical lines are Parking aid module, Instrument cluster and Driver seat control.

After the calculations, variation of the cycle time is defined, which in this case variates from 8 seconds to 54 seconds. Due to big variation of cycle times, production lines needs to be separated to 3 different groups:

– High runners (cycle time < 10 seconds)
– Mid runners (10 seconds < cycle time < 30 seconds)
– Low runners (cycle time >30 seconds)

Table 3. Line grouping according cycle time

High runners	Mid runners	Low runners
• Instrument cluster 1	• Parking aid module 1	• Resistrain control ECU
• Instrument cluster 2	• Parking aid module 2	• TPMS ECU
• Driver seat control 1	• Engine ECU	• Body ECU
• Driver seat control 2	• Driver door control	
• Data link	• Keyless entry ECU	
	• Telematics box	

Production lines can be separated in two categories – SMT Lines and Back End lines. Every single product is produced using both of these lines.

Front-end lines – these lines are standard construction lines that are responsible for laser marking and placement of an electrical components on a PCB board.

Back-end lines – these lines are responsible for depaneling of PCB board in to separate products, laser marking all components for tracking, and assembling all required mechanical parts in to one finished good. Also, this line includes packing in final packaging concept or internal packaging concept.

Back-end lines could be split in to 3 main groups:

– Automated line
– Semi-automated line
– Manual line

Automated line – these lines are fully automated. One line operator could manage to operate even more than one automated line, since only few operations needs to be done – material loading and unloading, starting up the line and periodically checking the parameters. This line consists of automated conveyor system, cobots, robots and machines with sensors. This line could be built in U-shape and I-shape. In this specific factory, I shape line will be used to have easier control of material flow.

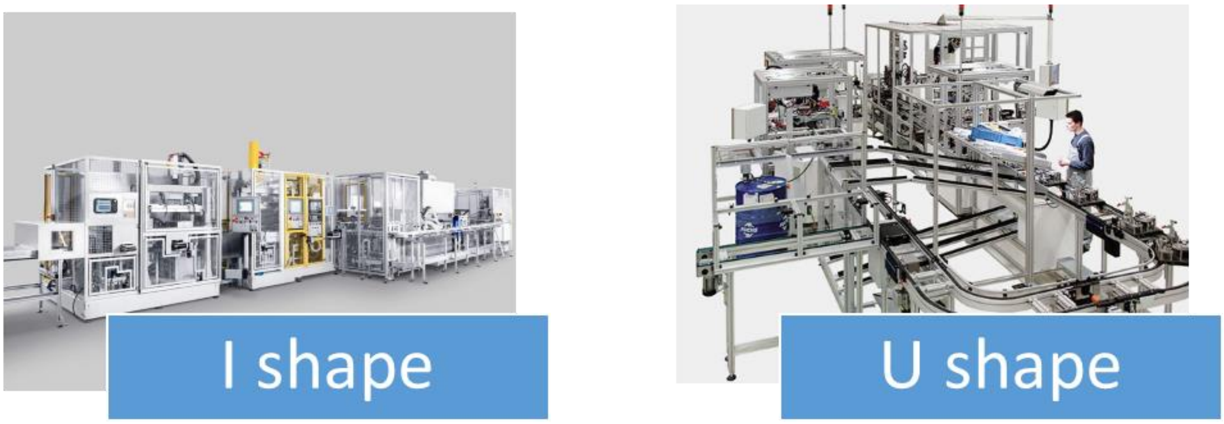


Figure 12. Fully automated line shapes [22][23].

Semi-automated line - these lines are not fully automated, for smooth production it requires at least one worker inside the line and one for material loading and unloading. This line could also consist of automated conveyor system, cobots, robots and machines with many different sensors. But the main difference from fully automated line is that some of the robots are replaced with humans. This change can create more flexible line, save money, which should be invested into equipment, and most of the time might reach higher OEE. Best shape for this line is U shape. Using U shape, company can save on people walking time, because walking distances will be reduced comparing with I shape lines.

Manual line – these lines consists of separate machines that are not connected with conveyors. For transportation of production there is no cobots or robots used. All work is done by machine or line operators. These lines are flexible and cheap with equipment price. But also, it has many disadvantages, like – big cycle time, many operators required, could appear more defects.

It is important to check line loading yearly, since after this calculation, company can calculate required number of operators and material handlers. Also, this calculation helps to notice if the line is capable of producing required amount of products. This calculation must be done every time when suppliers are updating production volumes. If the loading is more than 100% company has to start thinking about installing new machines or even building a second line.

Firstly the calculations of Back End production line loading is performed. Cycle times of the production lines are taken from the table 2, while the OEE value is determined to be 80%. The OEE rate is selected having in mind that OEE will increase during the production years. Output per day values are calculated using the formula below:

$$\frac{\text{Output}}{\text{Day}} = \left(\frac{\text{Working hours per day} * 3600\text{s}}{\text{Cycle time}}\right) * \text{OEE} = \left(\frac{22 * 3600\text{s}}{28}\right) * 0{,}8 = 2254$$

(3)

To calculate Loading of the BE lines, previously calculated values and yearly production volumes are used:

$$\text{Line loading} = \frac{\text{Volume} * \text{Cycle time}}{(\text{OEE} * \text{Working Days per year} * \text{Working hours per day} * 3600\text{s})} * 100\%$$

(4)

$$\text{Line loading} = \frac{50\,000 * 28}{(80 * 335 * 22 * 3600\text{s})} * 100\% = 7\%$$

(5)

Table 4. Loading of the BE lines in 6 years

Project	C/T (Sec)	OEE %	Output/ shift	Output/ Day	2021	2022	2023	2024	2025	2026
Engine ECU	28	80	1127	2254	7%	17%	46%	100%	53%	20%
Resistrain control ECU	42	80	746	1493	0%	3%	5%	100%	8%	8%
TPMS ECU	47	80	672	1343	2%	9%	16%	27%	58%	100%
Parking aid module 1	27	80	1194	2388	0%	0%	9%	44%	81%	100%
Parking aid module 2	27	80	1194	2388	0%	0%	9%	44%	81%	100%
Instrument cluster 1	9	80	3582	7164	2%	23%	48%	100%	60%	25%
Instrument cluster 2	9	80	3582	7164	2%	23%	48%	100%	60%	25%
Body ECU	53	80	597	1194	3%	17%	48%	100%	75%	38%
Driver seat control 1	8	80	3960	7920	0%	17%	28%	62%	76%	100%
Driver seat control 2	8	80	3960	7920	0%	17%	28%	62%	76%	100%
Data link	8	80	4015	8030	0%	0%	19%	33%	48%	100%
Driver door control	23	80	1358	2716	0%	0%	4%	19%	48%	100%
Keyless entry ECU	27	80	1194	2388	6%	19%	50%	100%	75%	75%
Telematics box	24	80	1343	2687	0%	3%	17%	56%	100%	67%

When loading of Back End lines is calculated it is required to calculate the loading of SMT lines to get the total count of lines required in the production. SMT lines are not dedicated to a specific product and are able to produce all the products in Company's range. Cycle time for SMT line will be used 8 seconds. Loading of SMT lines is calculated using the same formula as before.

$$\text{Line loading} = \frac{50\,000 * 8}{(80 * 335 * 22 * 3600\text{s})} * 100\% = 1{,}84\%$$

(6)

Table 5. Loading of the SMT lines in 6 years

Project	C/T (Sec)	OEE %	Output/ shift	Output/ Day	2021	2022	2023	2024	2025	2026
Engine ECU	8	80	3960	7920	1,88%	4,90%	13,19%	28,46%	15,08%	5,65%
Resistrain control ECU	8	80	3960	7920	0,00%	0,49%	0,94%	18,85%	1,58%	1,47%
TPMS ECU	8	80	3960	7920	0,38%	1,51%	2,64%	4,52%	9,76%	16,96%
Parking aid module 1	8	80	3960	7920	0,00%	0,00%	5,65%	26,38%	49,00%	60,30%
Parking aid module 2	8	80	3960	7920	0,00%	0,00%	5,65%	26,38%	49,00%	60,30%
Instrument cluster 1	8	80	3960	7920	1,88%	20,73%	43,34%	90,46%	54,65%	22,61%
Instrument cluster 2	8	80	3960	7920	1,88%	20,73%	43,34%	90,46%	54,65%	22,61%
Body ECU	8	80	3960	7920	0,38%	2,53%	7,16%	15,08%	11,31%	5,65%
Driver seat control 1	8	80	3960	7920	0,00%	16,96%	28,27%	62,19%	75,76%	107,42%
Driver seat control 2	8	80	3960	7920	0,00%	16,96%	28,27%	62,19%	75,76%	107,42%
Data link	8	80	3960	7920	0,00%	0,00%	18,85%	33,92%	48,24%	101,39%
Driver door control	8	80	3960	7920	0,00%	0,00%	1,32%	6,52%	16,58%	34,30%
Keyless entry ECU	8	80	3960	7920	1,88%	5,65%	15,08%	30,15%	22,61%	22,61%
Telematics box	8	80	3960	7920	0,00%	1,13%	5,65%	18,85%	33,92%	22,61%

At year 2021 the total loading of SMT lines will be 8,29%, which means that for the first year, it is enough to have 1 SMT line. In 2026, when the peak volume is reached, total loading of the SMT lines will be 602,19%, which results in demand of 7 SMT lines.

In conclusion, the Company X will have 14 Back End production lines, which could be divided in 3 types: High runners, Mid runners and Low runners. In addition, 7 SMT lines are going to be used in the production as well.

3.2. Micro Logistics

In this project we will be considering micro logistics only for shopfloor material transportation. There will be 3 types of transportation methods used to transport material to the line and to transport finished goods to the warehouse – AGV (Automated Guided Vehicle), conveyor system, manual transportation. All materials and finished goods will be transported in only 2 types of containers – KLT box and PCB Magazine. Here we will also have 3 types of material handling in the line – cobots, conveyor system, manual handling of the parts.

3.2.1. Micro Logistics Containers

There is huge variety of different types of containers that could be used in production. In our electronic parts production, all products will be grouped in to 2 subgroups:

1. PCB products and semi-finished PCB parts
2. Raw materials and finished goods

First group of products will be contained in PCB magazine. Requirements for this container: smooth and quick width adjustment without using tools, ESD Safe plastic card guides with 50 slots, Heat-resistant card guides for board temperatures up to 135 °C.

Table 6. Specification (mm) - Nikko Rack ESD PCB magazine [24]

Model No.	Max. Tolerant Temperature for Cardguide	Outer Dimensions	Adjustable Width	Base Material	Ref.Position	Pitch P	PCB Slots	Weight (kg)	Size
		L			W				
SR25	165℃	355	320	563	50～250	Plastic	34	34	10

Figure 13. Nikko Rack ESD PCB magazine [24]

Second group products are required to stack into box type container. For this storage type we will use standard ESD KLT boxes. ESD KLT container is perfectly adapted to automated production processes and is suitable for use at various stages of production. Sensitive electronic components can be stored and transported without any problems thanks to the electrically conductive plastic. Outer dimensions L*W*H: 60*40*15 cm, inner dimensions L*W*usable H: 54,4*36,4*10,95 cm [24].

3.2.2. An Automated Guided Vehicle

The cost of transportation and delivery of goods to the required production line can be up to one thirds of the total cost for production when human labor is used. To avoid these expenses AGV could be used.

An automated guided vehicle (AGV) is a portable robot that follows along marked long lines or wires on the floor, or uses radio waves, vision cameras, magnets, or lasers for navigation. Application of the automatic guided vehicle broadened during the late 20th century [25].

For this project an Automated Guided Vehicle that navigates by its own, without human intervention, will be used. It’s driverless vehicle. There is different AGV navigation technologies, these technologies define the way that robot knows where to drive.

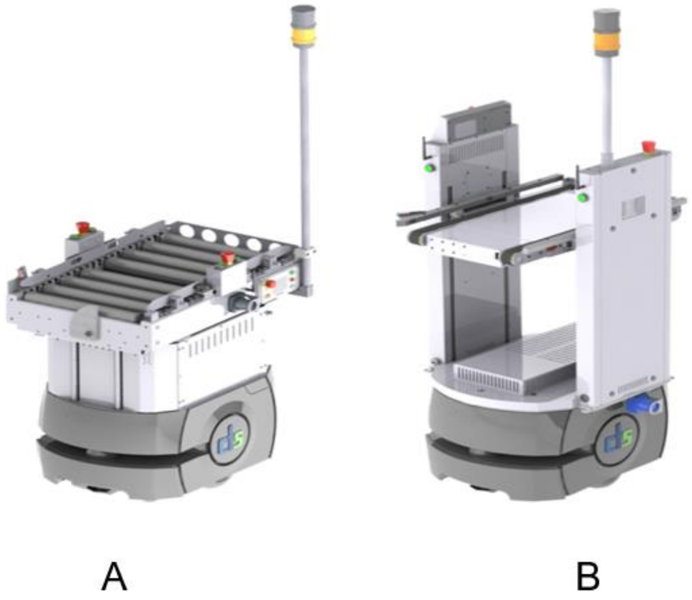


Figure 14. AGV types: A – Magazine transportation, B – KLT box transportation [26]

Advantages of using an Automated Guided Vehicle:

- Reduced labor costs
- Increased safety
- Increased productivity and accuracy
- Modularity

Disadvantages of using an Automated Guided Vehicle:

- Potentially high initial investments
- Maintenance costs
- Not Suitable for Non-repetitive Tasks

For a production material flow AGV will be used for magazines and KLT boxes transportation. For these transportation options, 3 types of AGV will be used. First material subgroup (PCB products and semi-finished products) will be transported with an AGV that is designed to transport magazines. For a transportation of KLT boxes, 2 types of AGV robots will be used. First one will be with one level integrated conveyor that is designed to transport KLT boxes. This AGV will transport PCB raw material and PCB components to the front-end lines. Second type of AGV will be with lifting option. This type of AGV will be able to transport up to 4 KLT boxes.

3.2.3. Conveyor System

Conveyor system will be used only for transportation in the back-end production area. This type of transportation requires big investments and planning before starting construction of a factory. First thing that is required to have, is second floor of a production. This whole area will be designed for the conveyors that will transport all the materials to required area. Whole system consists of 2 main parts: elevator system and conveyor system.

Elevator system - The Qimarox Prorunner Mk1 is a vertical elevator, which is flexible and very versatile. Unlike traditional chain lifts, this lift uses belts, which does not require such a strict maintenance, for example lubrication or retightening. In and out feeds can be either from side or from the front. The lift platform is fitted with high quality grip top belt [27]. For our production it is important to have special cleanliness requirements, because of that, this elevator will be required to be mounted in the shaft.

Figure 15. Qimarox® Platform Elevators [27]

Conveyor system is a complex mechanism with sensors and scanners that transports boxes in to required place. In the first-floor area we will have 2 levels of conveyors. 1st level for empty boxes, 2nd level for incoming materials or finished goods. Next to conveyor there will be scanner and monitor (this system will help to track material flow). In the second floor we will have conveyor net that will be connected to warehouse.

Belt conveyor lines can be created wider, longer and with the proper selection of belt. Straight, curved and gradients can be combined to user-defined sizes. For customers, this means not only there is high flexibility but also large energy-saving potential [28].

Advantages:

- Very low maintenance
- Tailor-made solutions to the best price/performance ratio
- Quick application and return on investment
- Large savings with additions or extensions

Figure 16. Example of Modular Belt Conveyor [28]

4. Layout Planning

Factory has its layout scheme, that can show all the internal parts, that combined makes the factory as a whole. Determining different areas in the factory is an important task for the production optimization. Creating such schematic with determined areas for people, flow of the raw materials and produced goods is a key part of company's success [29]. Plant layout could improve resource utilization and could provide means for application of lean methodology tools like: seven wastes, 5S, Just In Time (JIT), Kanban and other. These tools will help not only to reduce cost but also benefit company by improving quality of the product.

4.1. Standard Production Layout

A comprehensive process analysis is the first step to achieve an optimal Cost/Benefit Ratio along entire production layout and process. Every unused square meter requires big variety of expenses like – ventilation, heating, light, cleaning services and material (building expenses).

It is important to have internal standard how to create, operate and improve production layout. This standard should have minimal distances between production lines, width of material route, width of pedestrian route, colors that will be used in the layout and other.

Advantages of standard production layout design:

- Removal of obstacles in production
- Economies in material handling
- Lesser manufacturing time
- Lesser work in progress
- Proper use of floor space
- Economy in inspection
- Lesser manufacturing cost
- Lesser labor costs
- Introduction of effective production control

Disadvantages of standard production layout design:

- Lesser flexibility
- Large investment
- Higher overhead charges
- Interruption due to breakdown:
- Difficulties in expanding production

Standard production layout design optimizes the use of the production floor space, while removing obstacles in the production process, which can create bottleneck situations. Having in mind that the materials used in the production in handled in one continuous way, avoiding backward motions, production time is reduced by significant measures. To keep the production running smoothly, most crucial points in various processes must be located and kept in check, while running inspection of the production processes. Due to simple processes of operation in the production and clever use of automated solutions, less qualification is needed to successfully operate the machinery, therefore the labour costs are reduced. While it sounds that the standard design layout may be the way to go, the challenges and required investments in this type of layout could create some doubt and even suggest reconsidering other options. When work is organized and carried in specific sequence, it reduces the flexibility of the production. Making adjustments to production might be too difficult, or high cost. There is also a high chance that duplicate machinery is going to be needed, to fulfill the continuous flow idea. While having few of the same machines, the optimization of its capacity is lost, while the investments multiplies. Production stops or interruptions has to be evaluated too, since if even one process in the line breakdowns, all the production flow is stopped, which may create few unexpected issues, such irregular material supply, bad planning of the production and so on [29].

4.1.1. Standard Layout Colors

Colors in the drawings could help to understand information faster and more easily.

Table 7. Layout color marking

Description	Area marking color
Main and subsidiary routes	
Designed space for materials, storage area for good products, essential product items	
Analysis area, area for faulty parts/rejects, discrepant material	
Equipment, machines	

4.1.2. Standard Distances in the Layout

– Passage width for people between production plants minimum 0.8m
– Passage width for material transport (max. width of trolley + 0.2m)
– Movement area at the workplace at least 1.5m²
– Maintenance access must be ensured (control cabinets, media)

4.1.3. Standard Material Transportation and Pedestrian Route

One of the most important topics in creating a workplace that employees can feel safe is to follow all safety requirements. One of these requirements is to have save path to the fire exit. Path that leads to the fire exit minimal width has to be 1m.

Company that has automated micro logistics concept has to follow additional requirements for automated guided vehicles. Bottle neck for an AGV is 80cm, for easily and not interrupted transportation of materials one-way optimal transportation path has to be 120cm. When AGV is transporting material though the same path that employee could walk minimum width of this path has to be 190cm. For a two-way AGV path combined with pedestrian path minimum width is 270cm. Also it is important to mention that if company has more than 200 employees minimum pedestrian path has to be 120cm [37].

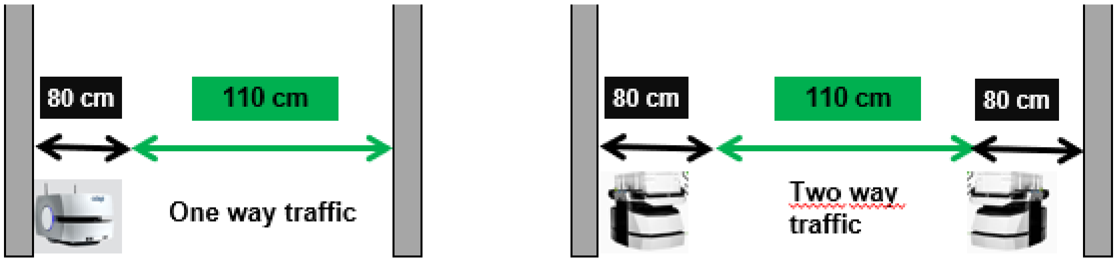


Figure 17. Minimum driveways with frequent employee traffic

4.2. Standard Production Line Process Layout

Every production company is required to have equipment. Correct placement of required equipment could help to improve production flow, reduce employee number and production lead time. Before creation of a process layout it is important to decide which rules will be applied in your layout. There are few standard rules that has to be considered in the creation of U-cell and I-shape line.

Advantages of standardized Process Layout:

- Maximum utilization of machines
- Greater flexibility:
- Scope for expansion
- Specialisation
- Effective utilisation of workers
- More effective supervision
- Lesser work stoppages

Disadvantages of standardized Process Layout:

- Coverage of more floor area
- Higher cost of material handling
- Higher labour costs
- Difficulties in layout planning

Standard production line process layout provides the opportunity to optimize and utilize the usage of the machines, to reach the maximum potential. Any required changes in the machines and operations can be made without costly changes, since the machines are arranged around their processes. Another significant advantage of the standard process layout is the ability to easily implement new machines, since the expansion is taken into consideration before. Since the machines are more specialized and defined about their production operations, workers are also appointed to different kind of works, defined by the departments. Also, such critical point as production stoppage is also reduced, since the production flow does not stop after a single break in the production. Standard production layout method usually requires more space than product layout method, due to this reason, the material handling costs are also increased since the product is moved around different departments. Since the workplace is more specialized, labour costs are also increasing, due to specific specialized workers demand. Layout planning of this method is also considered a challenge, due to its large variety of products and bigger area [29].

4.2.1. Distance Inside of U-cell.

It is important that distance inside U-cell is not to large and not too small to avoid unnecessary movement or defects and health (work ergonomics) issues. If inside distance is to large operator has too much unnecessary movements, which increases production cycle time. If inside distance is to small operator could bump into equipment and hurt himself or damage product.

Recommended distance inside U-cell for one operator is from 0,8m to 1,2m and for two operators that is working back to back, starts from 1,2m to 1,5m.

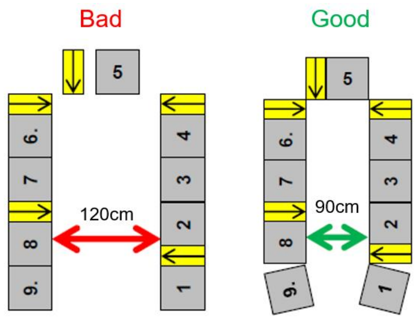


Figure 18. Distance inside of U-cell

4.2.2. Equipment Positioned in Sequence of Production Flow

In the line layout, all the machines should be arranged in the same sequence as the according processes in the production flow. Start and end of the processes has to be next to each other. Arrangement on the machines according to the process creates the most efficient way of movement for the operator, and reduces or eliminates any kind of movement that does not create value.

4.2.3. Counter-clockwise Operator Path

Most of operation steps that operator is doing during production is load and unload of the product, because of that, workplace has to be designed to make employees work as easy as possible. We know that most of the people are right-handed, therefore going counterclockwise would result in less motion, less turning of body and more work is done with dominant hand (better precision of movement), less operator time.

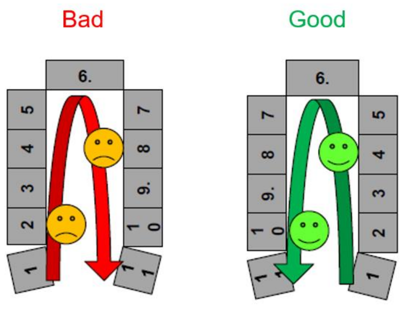


Figure 19. Clockwise and counter clockwise operator path

4.2.4. All Process Integrated in the Line.

All processes required to produce one product has to be in one production line, no isolated processes (except shared equipment). All processes integrated in one line (U-cell) reduce number of operators, do not require additional buffer areas (before and after isolated process), easier to control FIFO, shorter distances, do not require additional transportation between stations, shorter cycle time, less space required.

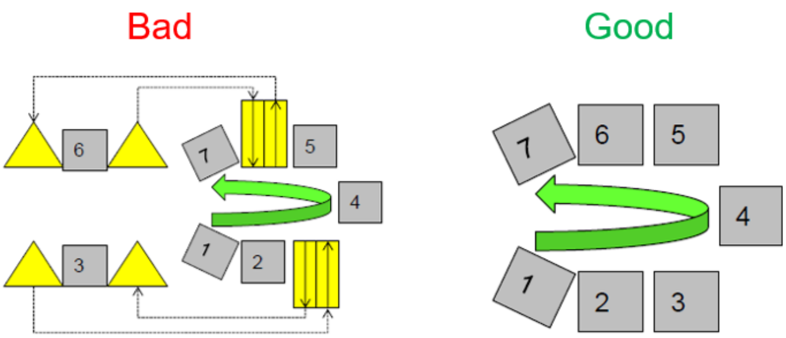


Figure 20. Example of interrupted process flow and integrated in one line process

4.2.5. Layout of the Deepest Equipment in the U-cell

Every production line consists of different sizes of equipment, machines, material supply racks. To save space we have to allocate the deepest equipment/machine in the front head of the U-cell, but process flow should be not interrupted.

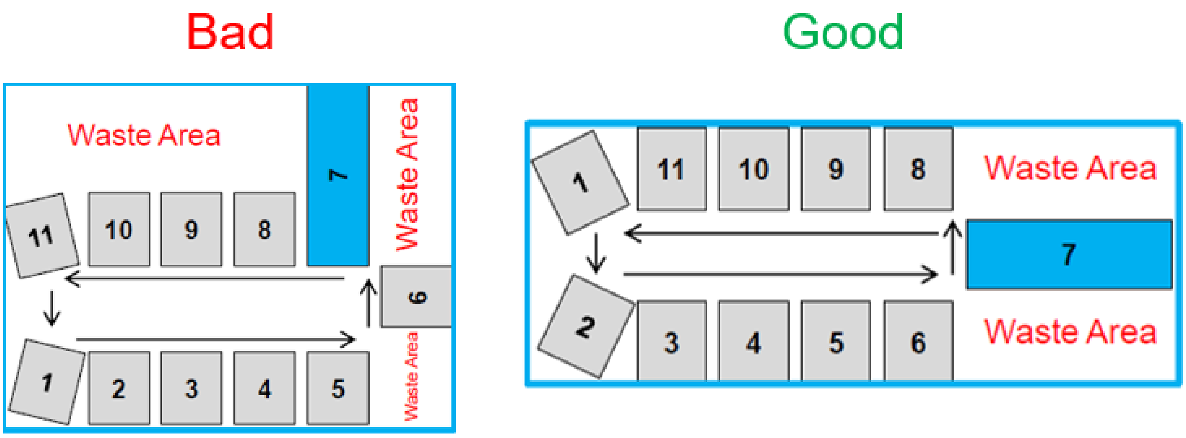


Figure 21. Deepest equipment position in U-cell

4.2.6. Eliminate Empty Spaces

Empty spaces increase the non-valuable space (area). This unused space will accumulate dust and it will lead for more cleaning and could cause quality problems. Gaps between machines prolong the production cycle time.

4.2.7. Smooth Product Handling Between Stations

Work piece has to be handled between stations loading points that maintain the same level of height and depth. There should be no rotation during the handling. Avoid waste of motion – Up-and-down and Front-to-Back transfer of the work piece.

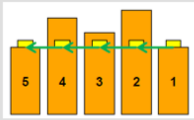
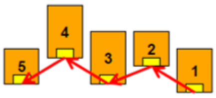
	Bad	Good
Horizontal handling – Front View		
Vertical handling – Top View		
Rotation handling – Front View		

Figure 22. Example of smooth product handling between stations

4.3. Production Process Flow

Company X is producing electronical automotive parts. To produce this type of product whole production will be divided in to two segments:

- SMT area (Front end)
- Final assembly (Back end)

Surface mount technology (SMT) area – this technology is not a technology of tomorrow, but a technology of today which could produce state-of-the-art miniaturized electronical products. Although SMT is a mature technology, it is developing and improving every day [30]. Manufacturing of electronical components using surface mounting technology (SMT) means that all electronical components are assembled with automated machines that is placing all components on the surface of the printed circuit board (PCB). Electronic components assembly is not only placing components and soldering to the PCB but also the following production steps:

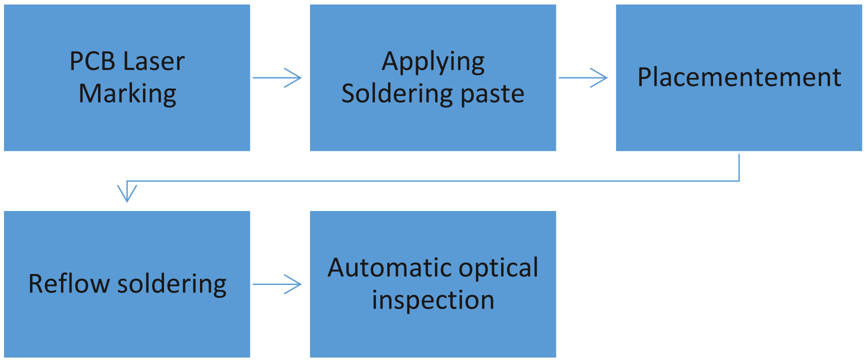


Figure 23. SMT Process flow

Back end (final assembly) – this process consists of many different steps to create functioning product. Back end lines are more complex than SMT lines, because SMT process is standard and standard lines could be used to create different products with only changing of electronical components. Every back end line is individual and is created according product that will be produced in the line. These lines could consist of many different processes and every process has few variations how it could be done. Example of Process flow:

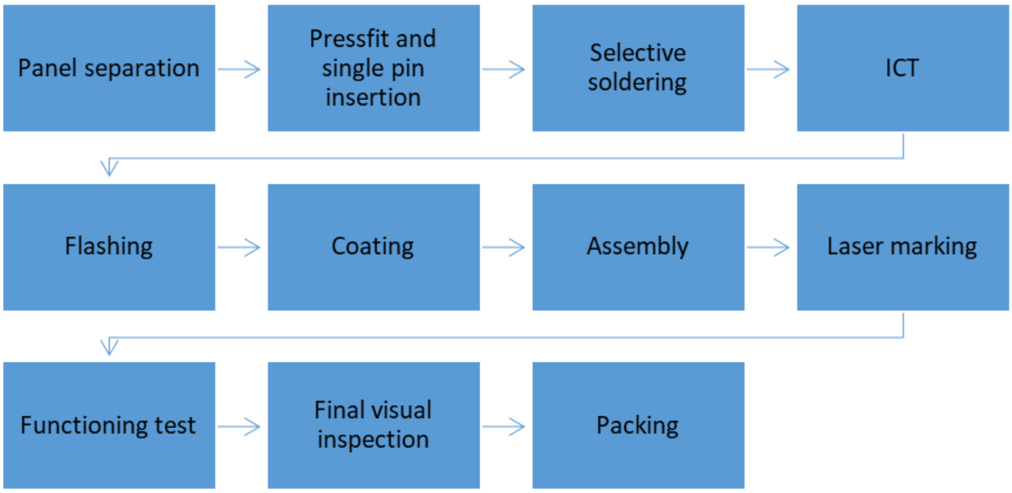


Figure 24. Back end Process flow

4.4. Company X Layout Planning

First step in creating a production layout for a new company is to calculate what number of production lines will have to fit in to the production layout. This calculation was done in chapter 2 – Space Planning. After summarizing the calculations, type of lines required can be defined, which would be: 5 fully automated lines, 6 semi-automated lines and 3 manual lines. In total 14 back end lines plus 7 SMT lines.

Next step is to calculate space required to different types of lines. In this step we will predict that every type of line will require average amount of square meters:

- 1 SMT line – 120 m2
- 1 BE fully-automated line – 130m2
- 1 BE semi-automated line – 45m2
- 1 BE manual line – 25m2

Using average square meters that is required for every type of line we can calculate required value-added space for company X. To get this space we need to sum up 11 SMT lines, 7 BE fully-automated lines, 4 BE semi-automated lines, 3 manual lines and total number will be area required for production in year 2020 – 2026.

$$\text{SMT Lines} * \text{area} + \text{Fully autoamted lines} * \text{area} + \text{Semi automated lines} * \text{area} + \text{Manual lines} * \text{area} = \text{Required area for Production lines} \tag{7}$$

$$7 * 120 + 5 * 130 + 6 * 45 + 3 * 25 = 1835 \text{ m2} \tag{8}$$

After calculation of value-added space, the calculations of non-value-added space – material transportation routes and pedestrian routs, can be determined. For this part it is important to decide what material transportation ways will be used. Company X will have 3 transportation types- AGV transportation, conveyor transportation and manual transportation. Because of 3 transportation solutions and pedestrian routes, roughly 30% of total production area has to be dedicated to internal transportation roads.

Last part that has to be considered, is value-added area for future projects. This part of a factory will be additional 20% of value-added space. In this calculation was decided to choose 20% because of a product lifecycle time, when new projects will be placed in the production area some of the old products life cycle will be already finished, in this way old lines will be replaced or modified to produce new products. After summing up all these values the theoretical area that is needed for a shopfloor is determined.

4.4.1. Production Flow of Company X

When the calculations of the required production area is complete, production flow has to be defined. Production flow has to have logical sequence, to make the production as effective as possible, starting from transportation of raw material from the warehouse, to finished goods transportation to the warehouse.

Company X production flow:

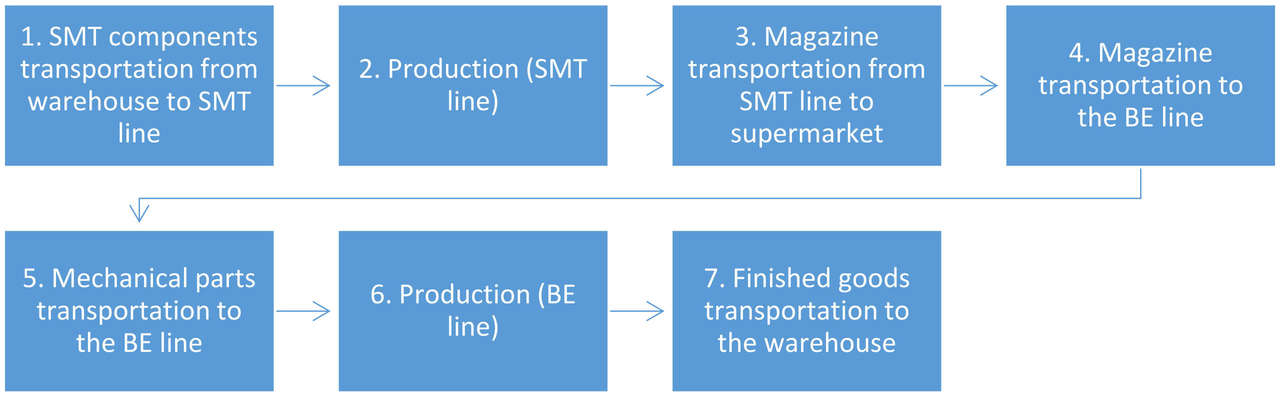


Figure 25. Company X production flow.

Using calculated production space and production process flow draft version of the shopfloor layout is prepared. Green arrows leads through the path of production flow, which starts at the warehouse, goes through the SMT lines, Supermarket, Back end lines, and finishes its cycle at warehouse.

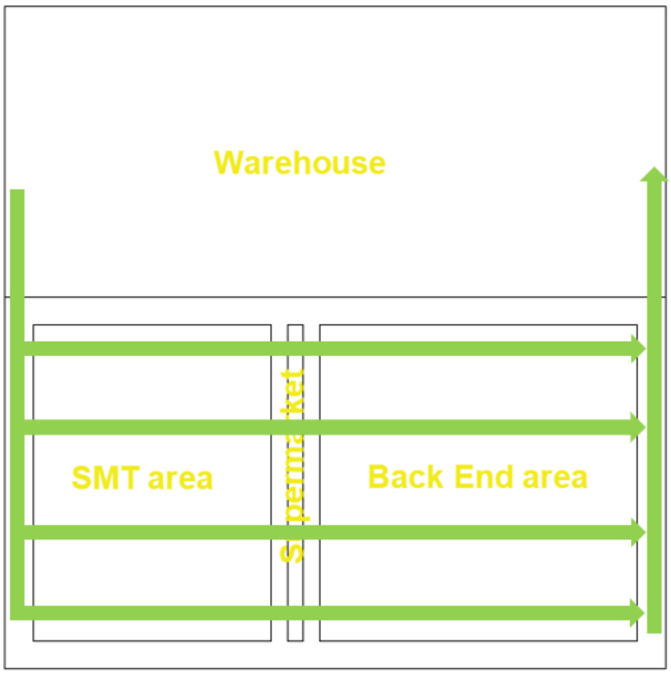
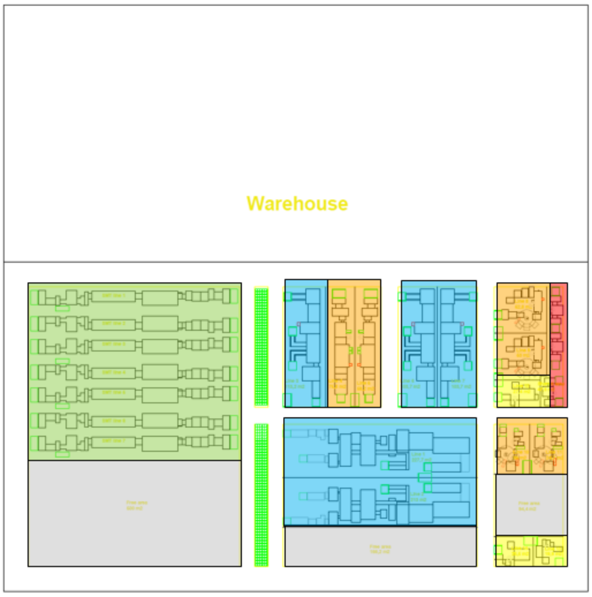


Figure 26. Layout of the Company X material flow

4.4.2. Company X Production Line Arrangement

Next step is placement of the production lines and creating of the material flow. All production lines has to have logical sequence. Fully automated lines with high volumes has to be closer to the SMT area and supermarket, in this way transportation time and distance will be shorter.
In the drawings below, the layout of the shopfloor is shown, where each color represents type of the line.



Type of the line	Number of lines	Color
SMT	7	
Fully-automated	5	
Semi-automated	6	
Manual	3	
Free area		

Figure 27. Production line placement in the shopfloor

The total area of the production lines adds up to nearly 1150 square meters, the biggest part of which, is dedicated for the fully automated lines.

Table 8. Area required for BE lines

Project	**Line No.**	**Area required (m2)**
Engine ECU	8	52,8
Resistrain control ECU	13	25,5
TPMS ECU	14	19,9
Parking aid module 1	4	78,8
Parking aid module 2	5	59,2
Instrument cluster 1	1	227,7
Instrument cluster 2	2	213
Body ECU	12	27,4
Driver seat control 1	6	103,7
Driver seat control 2	7	103,7
Data link	3	113,2
Driver door control	9	53
Keyless entry ECU	10	39
Telematics box	11	24,7
	Total:	1141,6

Planned production area of Company X could be divided in to 4 large sectors, presented in the table below:

Table 9. Shopfloor area requirement

	Used area (m2)	Free area (m2)	Total area (m2)
SMT Area	788	500	1288
BE area	1141,6	260,6	1402,2
Supermarket	62,5	15	77,5
Material routes	1443,3	0	1443,3
Total:	3435,4	775,6	4211

As it could be seen in the table, area with the production lines takes more than 60% of facilities space, while the material flow routes takes another 30%, supermarket has the lowest share of the space.

4.4.3. Micrologistics Concept in Company X

Company will use 4 main transportation ways:

- AGV transportation for magazines – AGV can carry one magazine at the time, therefore, the first group of AGV's will have the task to replace the full magazines with empty magazines, to ensure the continuous production flow in the SMT lines. Another group of AGV's, that are going to be used in Back End lines, will have the task to transport magazines from the supermarket to fully automated and semi-automated lines, in addition with unloading process, while for the manual lines, the goods will be left on the racks for manual loading process.
- AGV transportation for KLT boxes – AGV has the ability to transport two stacked KLT boxes. These AGV's will move from the SMT warehouse to the SMT lines, where KLT boxes will be left on the racks after manual loading.
- Conveyor system for KLT boxes – Conveyors' task is to transport the mechanical parts from the warehouse and in this case is only used for the Back end lines. Material handler has to pick up the box, transport it to the line and load the goods from the box to the production line. This conveyor is also used for the transport of the finished goods to the warehouse.
- Manual transportation – Operator has various tasks of transportation of goods, from finished goods to raw materials.

All these transportation types support each other and creates material flow reduces wastes.

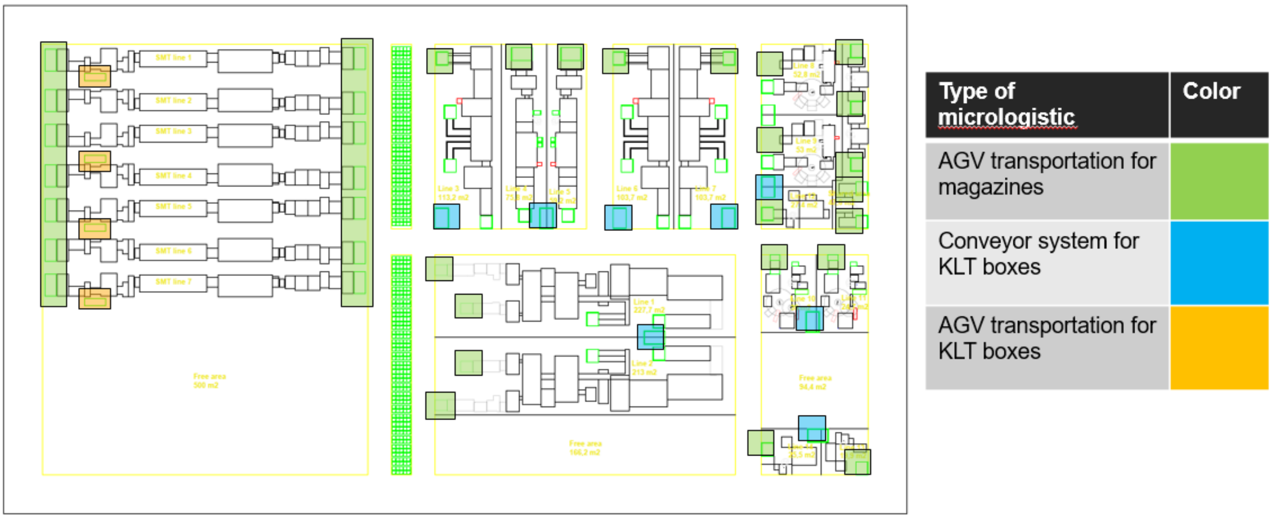


Figure 28. Material placement areas in the layout of the shopfloor

5. AGV Micro logistics Concept Economical Calculation

Implementation of Industry 4.0 tools to the production might result into quality improvements.

AGV path is a complex process, which is defined and configured while using special software provided by OMRON – Enterprise Manager 2100.

During the design phase of production layout, it was decided that AGV should be able to move in two way traffic system. In this particular case, two types of AGV's are going to be used – KLT boxes transportation AGV's and magazine transportation AGV's.

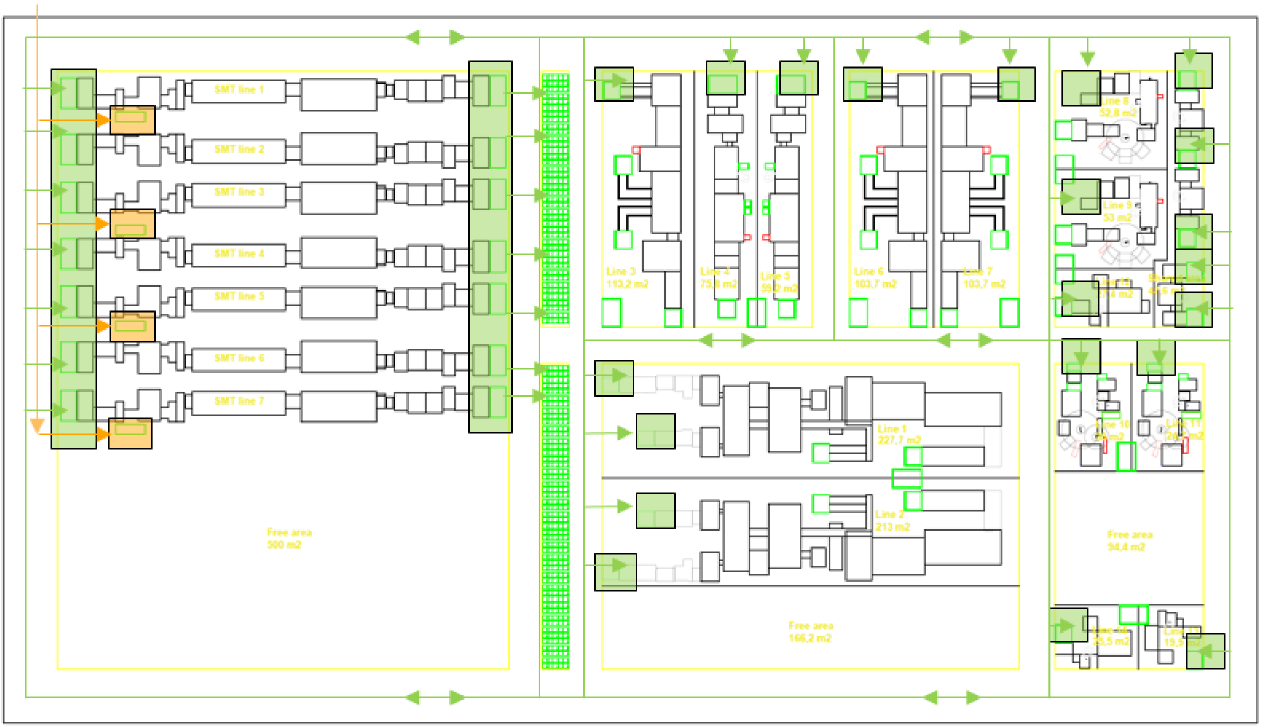


Figure 29. Layout of the AGV traffic

To calculate required number of AGV to load and unload SMT lines, it is important to measure the distances that AGV will need to cover, while transporting the materials. Product Engine ECU will be produced in SMT line 1, therefore, the distance of transportation of magazines to the production line is 35m, one way.

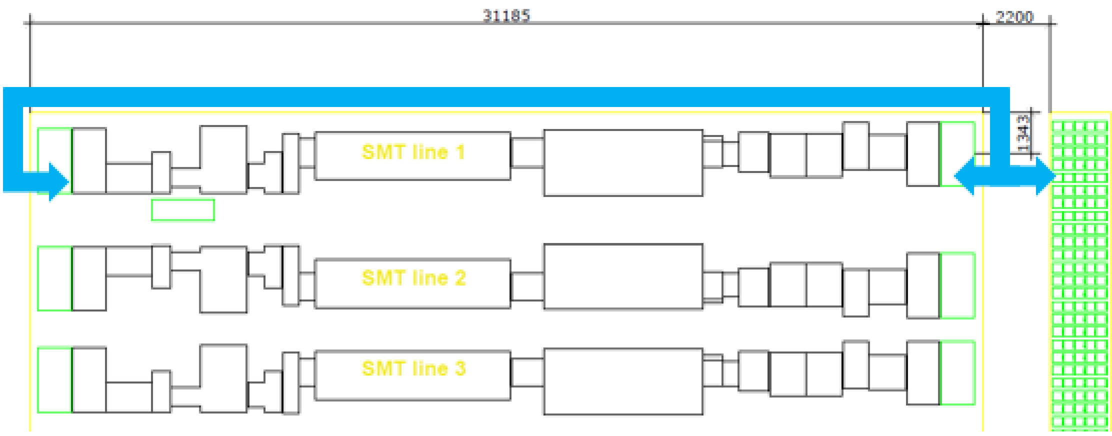


Figure 30. Distance to transport material to the SMT line 1

When distances that is required to transport magazines to the line is calculated, the next step is to calculate number of magazines that will be used per day.

$$\frac{Magazine}{day} = \frac{(\frac{Output}{day})}{\left(\frac{panel}{magazine}\right) * (\frac{PCB}{Panel})}$$

(9)

$$\frac{Magazine}{day} = \frac{7920}{24*4} = 82{,}5 \; magazines/\text{day}$$

(10)

To calculate delivery time in seconds, which will be required to transport materials for the project Engine ECU, we need to divide magazines/day, to receive magazines/hour. In this calculation 22 hours/days is value added time. Standard AGV transportation speed – 0.8 m/s [31].

$$Delivery\ time = \left(\frac{Magazine}{hour}\right) * (\frac{Distance * 2}{Transportation\ speed} + Loading\ time)$$

(11)

$$Delivery\ time = 3{,}75 * \left(\frac{35 * 2}{0{,}8} + 60\right) = 562\ s$$

(12)

When all delivery time required is calculated, sum of all delivery time has to be reevaluated to receive total hour requirement. Total delivery time in seconds is equal to 9209 seconds, time in hours is equal to 2.55 hour. This total time shows that in one hour AGV has to travel for 2.55 hour. This time has to increase 30% because of AGV charging time. With additional 30% total time required is 3.32 hour, it means that company has to have 4 AGV to fulfill SMT line magazine requirement.

Same calculation has to be done to receive required number of employee to fulfill SMT line magazine requirement. Average human walking time – 1.34 m/s [32].

$$Delivery\ time = 3{,}75 * \left(\frac{35 * 2}{1.34} + 60\right) = 418{,}66\ s \tag{13}$$

Total delivery time in seconds is equal 6781 seconds, time in hours is equal 1.88 hour. This total time shows that in one hour AGV has to travel for 2.55 hour. This time has to increase 20% because of tiredness during work day and short brakes. With additional 20% total time required is 2.26 hour, it means that company has to have 3 employees per shift to fulfill SMT line magazine requirement.

Table 10. AGV requirement to load and unload SMT lines

Project	**Line No.**	**C/T (Sec)**	**Output /shift**	**Output /Day**	**PCB/panel**	**(C/T) /Panel (Sec)**	**Panel/ magazine**	**Magazine /day**	**Magazine / hour**	**Distance (m)**	**Delivery time (Sec)**
Engine ECU	1	8	3960	7920	4	32	24	82,5	3,75	35	562
Resistrain control ECU	1	8	3960	7920	3	24	24	110	5,00	35	749
TPMS ECU	1	8	3960	7920	6	48	24	55	2,50	35	375
Parking aid module 1	2	8	3960	7920	24	192	24	13,75	0,63	43	106
Parking aid module 2	2	8	3960	7920	24	192	24	13,75	0,63	43	106
Instrument cluster 1	1	8	3960	7920	2	16	24	165	7,50	35	1124
Instrument cluster 2	1	8	3960	7920	2	16	24	165	7,50	35	1124
Body ECU	1	8	3960	7920	4	32	24	82,5	3,75	35	562
Driver seat control 1	3	8	3960	7920	4	32	24	82,5	3,75	49	696
Driver seat control 2	4	8	3960	7920	4	32	24	82,5	3,75	57	773
Data link	5	8	3960	7920	2	16	24	165	7,50	65	1699
Driver door control	6	8	3960	7920	16	128	24	20,625	0,94	70	224
Keyless entry ECU	5	8	3960	7920	16	128	24	20,625	0,94	65	212
Telematics box	6	8	3960	7920	4	32	24	82,5	3,75	70	897
										Total (s):	9210
										Total (min):	153
										Qty. of AGV:	3,325768

Table 11. Calculation of required number of people to load and unload SMT lines

Project	Line No.	C/T (Sec)	Output/ shift	Output/Day	PCB/ panel	(C/T) /Panel (Sec)	Panel/ magazine	Magazine/ day	Magazine / hour	Distance (m)	Delivery time (Sec)
Engine ECU	1	8	3960	7920	4	32	24	82,5	3,75	35	418,66
Resistrain control ECU	1	8	3960	7920	3	24	24	110	5,00	35	558
TPMS ECU	1	8	3960	7920	6	48	24	55	2,50	35	279
Parking aid module 1	2	8	3960	7920	24	192	24	13,75	0,63	43	77
Parking aid module 2	2	8	3960	7920	24	192	24	13,75	0,63	43	77
Instrument cluster 1	1	8	3960	7920	2	16	24	165	7,50	35	837
Instrument cluster 2	1	8	3960	7920	2	16	24	165	7,50	35	837
Body ECU	1	8	3960	7920	4	32	24	82,5	3,75	35	419
Driver seat control 1	3	8	3960	7920	4	32	24	82,5	3,75	49	497
Driver seat control 2	4	8	3960	7920	4	32	24	82,5	3,75	57	542
Data link	5	8	3960	7920	2	16	24	165	7,50	65	1173
Driver door control	6	8	3960	7920	16	128	24	20,625	0,94	70	154
Keyless entry ECU	5	8	3960	7920	16	128	24	20,625	0,94	65	147
Telematics box	6	8	3960	7920	4	32	24	82,5	3,75	70	615
										Total (s):	6631
										Total (min):	111
										Qty. of employees:	2,210168

Company X has two options how to transport magazines to the SMT line. To do this job company need 4 AGV or 3 employees per shift. This company is working 2 shift mode, because of that it will be necessary to have 12 employees to work as material handlers.

To calculate which option has to be chosen it is necessary to calculate expenses and consider advantages and disadvantages. Transportation with AGV has many advantages – reduced labor costs, increased safety, increased accuracy and productivity. Disadvantages – potentially high initial investments, maintenance costs, not suitable for non-repetitive actions and decreased flexibility of operations [31]. Manual transportation done by material handler has opposite AGV advantages and disadvantages.

Economical difference between AGV transportation and manual can be calculated. Average price of one AGV is around 50 000 Eur. It is important to mention that AGV require high initial investments and manual handling require yearly costs. Company X to transport magazines in SMT area will need 4 AGV, using average price of one AGV and number of AGV required we can calculate costs that will be required to invest.

$$\text{Number of AGV} * \text{Price of AGV} = \text{Investment required} \tag{14}$$

$$4 * 50000\ Eur = 200000\ Eur \tag{15}$$

To calculate expenses that is required to have manual transportation in SMT area is more complex. Minimal salary in country is growing every year, in 2020 minimal salary is 607 Eur. Material handler is a low qualification employee, and in this case salary could be around 700 Eur [33]. Company X will be working 2 shifts - day and night shifts, because of that every day it will be required to have two employees. Company X to transport magazines in SMT area will need 6 employees/shift.

$$\text{Number of employees} * \text{Number of shifts per day} * \text{Months per year} = \text{Expenses/year} \tag{16}$$

$$6 * 2 * 700\ \text{Eur} * 12 = 100800\ \text{Eur/year.} \tag{17}$$

Also, additional expenses has to be considered, that will be spent on mandatory equipment for the employee of a company (work clothes, coffee, and labor expenses).

To conclude we can say that after 2 years AGV transportation will pay off financially.

6. Future Improvement Proposal

For the Company X, future improvements and implementation of new products are a key aspect of success in the long term perspective. There is still room for expansion of the factory, which would increase the capacity of production, while reducing the load for the current lines, since new production lines would impact the availability of the production.

Implementation of automated solutions is another promising direction, which the company could pursue. For example, fully automated supermarket would have a positive impact to the production effectiveness.

There is still processes in the material flow, that are fully dependent on the decision making of the human personnel. Material handlers are determining the need of picking up and transporting the boxes of mechanical parts of already finished goods by their own decision, which may differ because of each handlers' perspective of "full box". Implementation of sensors, that could be connected to communication system, could inform worker about the need of transportation of a box, that is ready to be moved to a specific location.

Conclusions

1. To efficiently produce the required product range of the company X, 7 SMT lines and 14 Back End lines will be implemented during the upcoming 6 years. Product range will increase within each year, starting by 5 products in the first year of production, and continuously growing through the years till reaching 11 different products.
2. Layout of the company X was designed to fulfill customers' requirements and split into 2 production areas - SMT and Back End. Total production area, where 14 million parts per year will be produced, is 4211 m^2.
3. Company X, for its internal micro logistics, will use 3 automated and 1 manual transportation options. To fulfill SMT line requirement for magazine, company X has to have 4 AGV.
4. According to the calculations presented in this work, the implementation of AGV, as primary material handling solution, will pay off in 2 years, in comparison if the materials would be handled with manual transportation solutions.

List of references

1. Evannex, “Evannex”, [Online] Available: https://evannex.com/blogs/news/world-s-nations-fighting-to-get-next-tesla-gigafactory-india-looks-promising-video [Accessed 03 01 2020]
2. Invest Lithuania, “Invest Lithuania”, [Online] Available: https://investlithuania.com/lt/naujienos/investuok-lietuvoje-praejusiu-metu-rezultatai-vilniui-ant-kulnu-lipa-sergeicikai/ [Accessed 03 01 2020]
3. Lee, J., Bagheri, B., Kao, H., “A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems,” *Manufacturing Letters*, Volume 3, Pages 18-23, 2015.
4. European Commission, “The Fourth Industrial Revolution”, [Online] Available: https://ec.europa.eu/digital-single-market/en/fourth-industrial-revolution [Accessed 03 01 2020]
5. Steffen Bader et al., “Agile Shopfloor Organization Design for Industry 4.0 Manufacturing,” *Procedia Manufacturing*, Volume 39, Pages 756-764, 2019.
6. Javaid M. et al., “Industry 4.0 technologies and their applications infighting COVID-19 pandemic,” *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, 2020.
7. Robert Salek, “Micro-Logistical Aspects of Manufacturing Enterprises in Supply Chain,” *Logistics and Transport No 3*, 2013.
8. Baur, C., Wee D., “Manufacturing's Next Act? McKinsey & Company,” 01 06 2015. [Online] Available: https://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act [Accessed 03 01 2020]
9. Stock, T., Seliger, G., “Opportunities of Sustainable Manufacturing in Industry 4.0,” *Procedia CIRP* Volume 40, Pages 536-541, 2016.
10. Wang, S., Wan, J., Zhang, D., “Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination,” *Computer Networks*, Volume 101, Pages 158-168, 4 06 2016.
11. Mourtzis D., Doukas M., Lalas C., Papakostas N., “Cloud-based integrated shop-floor planning and control of manufacturing operations for mass customization,” *Procedia CIRP*, Volume 33, Pages 9-16, 2015.
12. Lindskog E., Berglund J., Vallhagen J., Johansson B., “Layout planning and geometry analysis using 3D laser scanning in production system redesign,” *Procedia CIRP*, Volume 44, Pages 126-131, 2016.
13. Havarda V., Trigunayata A., Richard K., Baudry D.,”Collaborative Virtual Reality Decision Tool for Planning Industrial Shop Floor Layouts,” *Procedia CIRP*, Volume 81, Pages 1295-1300, 2019.
14. Benderbal H.,Benyoucef L., “New Hybrid Approach for Machine Layout Design Under Family Product Evolution for Reconfigurable Manufacturing Systems,“ *IFAC-PapersOnLine*, Volume 52, Issue 13, Pages 1379-1384, 2019.
15. VolkanYavas, Yesim Deniz Ozkan-Ozen, “Logistics centers in the new industrial era: A proposed framework for logistics center 4.0,” *Transportation Research Part E: Logistics and Transportation Review*, Volume 135, 2020.
16. B. Scholz-Reiter, M. Freitag, Ch. de Beer, Th. Jagalski, “Modelling and Analysis of Autonomous Shop Floor Control,” *IFAC Proceedings Volumes*, Volume 42, Pages 846-851, Issue 4, 2009.

17. Beinshob P. et al., “Semi-automated map creation for fast deployment of AGV fleets in modern logistics,” *Robotics and Autonomous Systems,* Volume 87, Pages 281-295, 2017.
18. Mehami J., Nawi M., Zhong R., “Smart automated guided vehicles for manufacturing in the context of Industry 4.0,” *Procedia Manufacturing,* Volume 26, Pages 1077-1086, 2018.
19. Hozdic, E. “Smart factory for Industry 4.0: a review,” *International Journal of Modern Manufacturing Technologies,* Vol. VII, No. 1, 2015.
20. Thomas V., Maine E., “Market entry strategies for electric vehicle start-ups in the automotive industry – Lessons from Tesla Motors,” *Journal of Cleaner Production*, Volume 235, Pages 653-663, 2019.
21. IHS Markit, “Benchmarkit”, [Online]. Available: https://benchmarking.ihsmarkit.com/Services/420404/teardown-automotive-intelligence-service [Accessed 13 03 2020]
22. P. Patel, “Red News wire” 30 04 2018. [Online] Available: https://www.rednewswire.com/global-assembly-automation-market-2018-outlook-abb-yaskawa-kuka-hanwha-hirata/ [Accessed 13 03 2020]
23. Pro beam, “Pro beam”, [Online] Available: https://www.pro-beam.com/en/systems/weldingsystems-for-high- throughput/gearlinee-beam/ [Accessed 13 03 2020]
24. Scanditron, “Scanditron”, [Online] Available: https://www.scanditron.com/equipment_category/pcb-magazine-racks/ [Accessed 13 03 2020]
25. E. Cronkleton, “Healthline”, [Online] Available: https://www.healthline.com/health/exercise-fitness/average-walking-speed#average-speed-by-age [Accessed 14 03 2020]
26. CTS, “CTS”, [Online] Available: https://www.group-cts.de/en/robotics-inmatro/cts-AIV/ [Accesed 13 03 2020]
27. Conveyor systems, “Conveyor systems”, [Online] Available: https://www.conveyorsystemsltd.co.uk/vertical-elevators.htm [Accessed 14 03 2020]
28. Robotunits, “Robotunits”, [Online] Available: http://robotunits.org/en/products/conveyor-technology/modular-belt-conveyor/ [Accessed 13 03 2020]
29. Englishpreneurship, “Englishpreneurship”, [Online] Available: http://pacefred.blogspot.com/2017/04/factory-layout.html [Accessed 19 03 2020]
30. Ray P. Prasad, “Surface mount technology. Principles and practices,” *Springer Science Business Media*, 1997 [Online] Available: https://books.google.lt/books?hl= lt&lr=&id=cVHtBwAAQBAJ&oi=fnd&pg=PR5&dq=surface+mount+technology+principles+and+practice&ots=rnIsP4MGc2&sig=mlR9Ofixput4VukYiIuff0nHm1o&redir_esc=y#v=onepage&q=surface%20mount%20techn ology%20pri nc i ples%20and %20practice&f=false [Accessed 19 03 2020]
31. AGV Network, “AGV Network” [Online] Available: https://www.agvnetwork.com/types-of-automated-guided-vehicles [Accessed 19 03 2020]
32. Conveyco, “Conveyco” [Online] Available: https://www.conveyco.com/advantages-disadvantages-automated-guided-vehicles-agvs/ [Accessed 19 03 2020]
33. Finansistas, “Finansistas” [Online] Available: https://www.finansistas.net/minimalus-atlyginimas.html [Accessed 21 03 2020]

34. Sung, T. “Industry 4.0: A Korea perspective,” *Technological Forecasting and Social Change*, Volume 132, Pages 40-45, 2018.

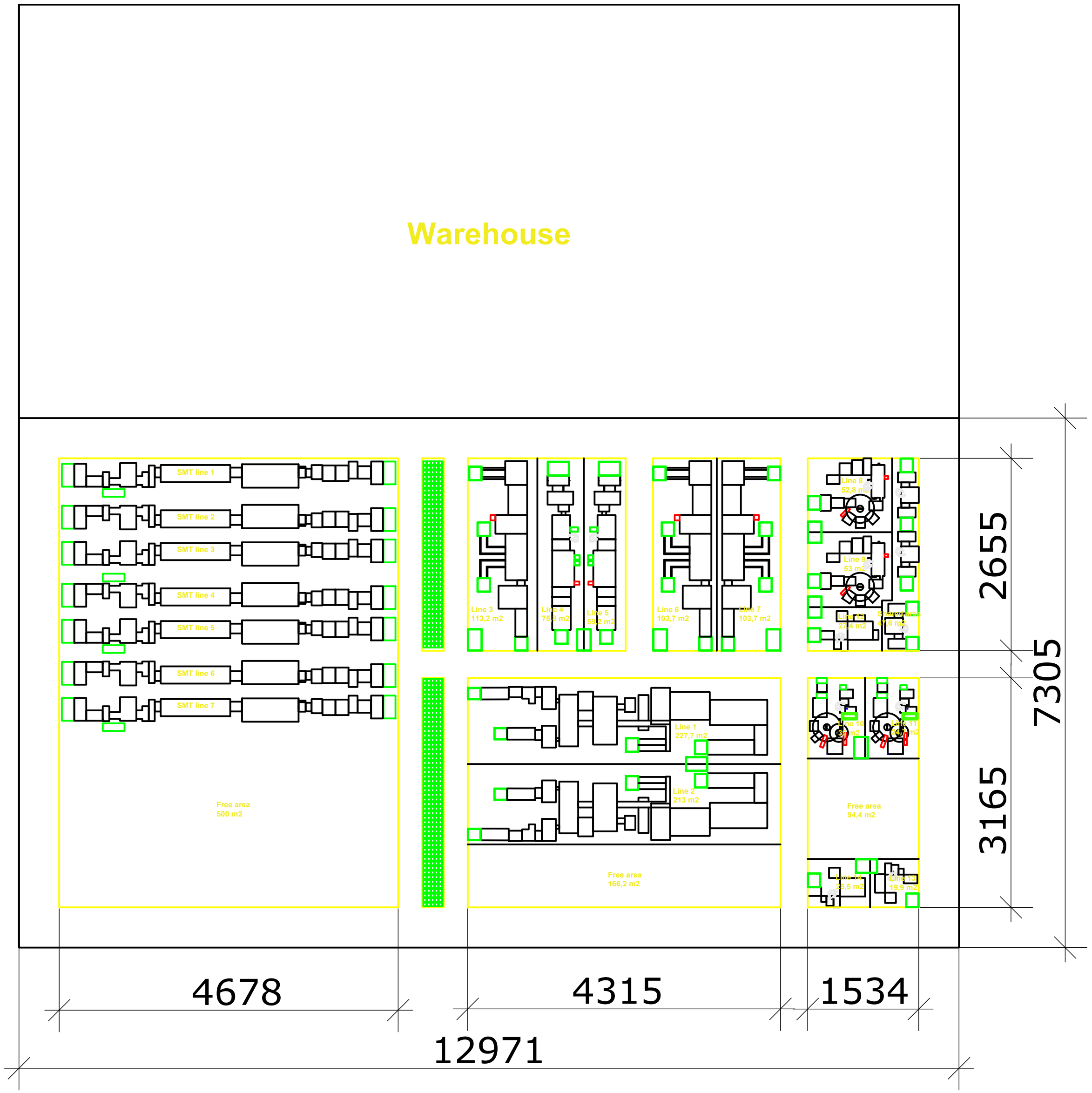
35. Kagermann, H., Wahlster, W., Helbig, J., “Recommendations for Implementing the Strategic Initiative Industrie 4.0,” 2013. [Online] Available: https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf [Accessed 21 03 2020]

36. M. Kirch, O. Poenicke, K. Richter, “RFID in Logistics and Production-Applications, Research and Visions for Smart Logistics Zones,” *Procedia Engineering*, Volume 178, Pages 526-533, 2017.

37. Teisės aktų registras, “LIETUVOS RESPUBLIKOS PRIEŠGAISRINĖS SAUGOS ĮSTATYMAS”, [Online] Available: https://www.e-tar.lt/portal/lt/legalAct/TAR.9CBB77180BFE/asr [Accessed 18 03 2020]

Appendices

Appendix 1. Company X Shopfloor Drawing



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