Master Thesis

Lean Production of Agricultural Equipment

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Analysis and replanning of a tractor cab assembly line

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Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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Abstract

This master thesis was drawn up in cooperation with CNH Industrial Österreich GmbH and under the scientific supervision of the Institute of Production Science and Management at Graz University of Technology. The CNH Industrial Österreich GmbH, located at St. Valentin in Lower Austria, is part of CNH Industrial N.V. based in Amsterdam, Netherlands. The company CNH Industrial N.V. designs, produces, and sells agricultural and construction equipment, trucks, commercial vehicles, busses, special vehicles, engines, and transmissions under 12 brands manufactured at 64 production sites worldwide.

At the location St. Valentin, CNH Industrial Österreich GmbH is producing a volume of 8.000 to 10.000 tractors per year of the brand Case IH and Steyr for the agricultural market of Europe and Australia.

The aim of this thesis was to design an I-Shape Assembly Line for Cab Assembling in the existing building under consideration of the principles of Lean Production. To achieve this goal, the first step was to analyze the current Cab Assembly Line, which has the shape of an “L”. In detail, the focus was on the single work steps with the highest potential of improvement and shifting work form the assembly line to a pre-assembly station for a better utilization of the workforce. To identify these work steps, a systematic procedure from the rough overall product mix to the detailed product type with the highest non-value adding time rate has been carried out. Based on the data of the analysis, a first re-planning of the assembly line was done. In several iterations and in collaboration with the experts of the company the developed I-Shape was refined to fit the needs of manufacturing and logistics the best possible way. Afterwards, the potential savings of the new planned assembly line compared to the current situation have been calculated and confronted with the estimated cost of switching to the I-Shape in order to see the economic efficiency of the developed solution.

Additionally, a concept of the developed I-Shape assembly line with ideas for further optimization after the implementation of the I-Shape layout had been carried out and documented with a blue print layout plan and explanations.

Kurzfassung

Diese Masterarbeit wurde in Kooperation mit der CNH Industrial Österreich GmbH und unter wissenschaftlicher Betreuung des Instituts für Production Science and Management der Technischen Universität Graz erstellt. Das Unternehmen CNH Industrial Österreich GmbH hat seinen Standort im niederösterreichischen St. Valentin und gehört zu CNH Industrial N.V. mit Hauptsitz in Amsterdam, Niederlande. CNH Industrial N.V. entwickelt, produziert und verkauft Nutzfahrzeuge für die Landwirtschaft und den Tiefbau, Lastkraftwagen, Kleintransporter, Omnibusse, Spezialfahrzeuge, Motoren und Antriebskomponenten. Gefertigt werden diese Produkte für 12 konzerneigene Marken an 64 Produktionsstätten weltweit.

Am Standort St. Valentin produziert CNH Industrial Österreich GmbH jährlich 8.000 bis 10.000 Traktoren der Marke Case IH und Steyr für den europäischen und australischen Markt.

Ziel dieser Arbeit war die Planung einer geradlinigen Traktorkabinen-Fertigungslinie im bestehenden Umfeld unter besonderer Berücksichtigung der Prinzipien der Lean Production Philosophie. Um dieses Ziel zu erreichen wurde zuerst die bestehende Traktorkabinen-Fertigungslinie analysiert. Besonderes Augenmerk wurde dabei auf die einzelnen Arbeitsschritte gelegt. Durch eine systematische Analyse vom Gesamtprodukt aus startend konnten die einzelnen Arbeitsschritten mit den höchsten nicht wertschöpfenden Zeitanteilen identifiziert und in weiterer Folge direkt an der Fertigungslinie genauer untersucht werden. Basierend auf dem mit dieser Analyse erarbeiteten Wissen wurde die Neuplanung der Fertigungslinie begonnen. In mehreren Schritten wurde das Konzept nach Rücksprache mit den Experten von CNH Industrial Österreich GmbH überarbeitet um das bestmögliche Ergebnis zu erreichen. Anschließend wurden die erwarteten Einsparungen durch die Neuplanung den erwarteten Implementierungskosten gegenübergestellt um eine Aussage zu der wirtschaftlichen Sinnhaftigkeit einer Umsetzung urteilen zu können.

Im letzten Abschnitt dieser Arbeit wurden Ideen für weiterführende Verbesserungen der entwickelten Fertigungslinie gesammelt und anhand eines Layout-Plans und Erklärungen dokumentiert.

Acknowledgement

This thesis was drawn up in collaboration with CNH Industrial Österreich GmbH and under the scientific supervision of the Institute of Production Science and Management at Graz University of Technology.

I would like to thank my supervisor from the Institute of Production Science and Management Dipl.-Ing. BSc Alexander Pointner for the numerous advices and scientific supervision during this project.

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Reprehensive for all employees of CNH Industrial Österreich GmbH I would like to say thank you to Dipl.-Ing. (FH) Michael Czelecz for the outstanding cooperation. The individual knowledge of each single worker and the willingness to cooperate during the analysis and idea generation had a big influence on the execution of this project.

Finally, my biggest acknowledgement goes to my family who has supported me during my study time and my whole rode of life.

Table of Contents

1 Introduction

This master thesis deals with the optimization of the cabin assembly line of the CNH Industrial Österreich GmbH company in St. Valentin in Lower Austria. Below the objectives of the thesis and the company will be described briefly.

1.1 Initial situation

To remain competitive and maintain the market share, despite a decreasing market volume, continuous improvement of both, the product and the production, is indispensable. In both cases, CNH Industrial produces outstanding results. The production had been improved by the use of the concern internal World Class Manufacturing program over the last years and thereby reached a very high standard. To sustain and improve the status of the production, further improvements have to be investigated and implemented. For this reason, the decision of analysing and optimizing the cab assembly line at CNH Industrial Österreich GmbH had been made to increase the productivity and simultaneously decrease the production costs.

1.2 Objectives

The objective of this thesis was to design a straight Assembly Line for cab assembling in an existing building. To achieve this goal, the first step was to analyze the current Cab Assembly Line, which has the Shape of an "L". In detail, the focus was on the single work steps with the highest potential of improvement and shifting work form the assembly line to a pre-assembly station for a better utilization of the workforce. Based on the data of the analysis, a first re-planning of the assembly line was done. In several iterations and in collaboration with the experts of the company the developed I-Shape was refined to fit the needs of the different departments the best way. Afterwards, the potential savings of the new planned Assembly Line have been calculated and confronted with the estimated cost of implementing the I-Shape to see the economic efficiency of the developed solution.

1.3 About the company

Agricultural machinery has been produced in St. Valentin since 1947. In the beginning, it was the 26hp green Type 180 tractor with its twin-cylinder engine, and the legendary Type 15, producing 15hp from its single-cylinder power unit; these tractors were the first to provide mechanisation to small farms. Since then, both, technology and application profile, have evolved over time. Steyr has always been a leader in expertise and technical innovation. With new ideas, practice-related technology, and an open ear for customer requirements, Steyr set new standards that contributed decisively to shaping the agricultural landscape in the 20th century. The red and white livery became the Steyr trademark. It stands for Austrian quality that has proved to be future-safe on the international market.[1]

In the year 1996 Steyr Landmaschinen AG was taken over by Case Corporation and renamed Case-Steyr Landmaschinentechnik.[2]

Today CNH Industrial Österreich GmbH is producing Steyr and Case IH tractors in St. Valentin, both of which brands are owned by CNH Industrial.

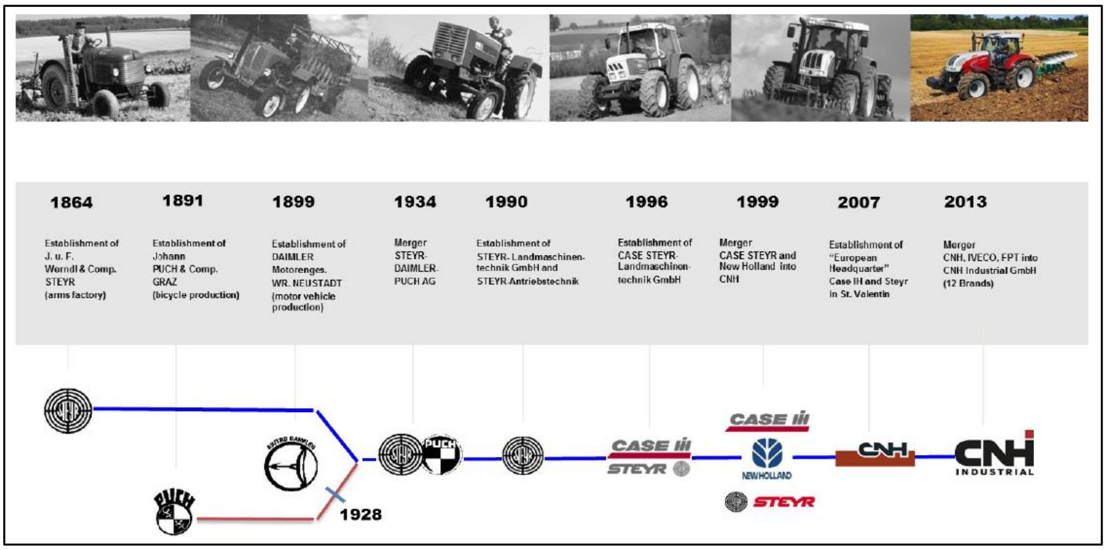

Figure 1: History CNH St. Valentin[3]

CNH Industrial is a global leader in the capital goods sector that, through its various businesses, designs, produces and sells agricultural and construction equipment, trucks, commercial vehicles, buses and specialty vehicles, in addition to a broad portfolio of powertrain applications.[4]

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[1]Cf. The Success Story
http://www.steyr-traktoren.com/distributor_en/Pages/ALongHistory.aspx [26.09.2016]

[2]The Success Story
http://www.steyr-traktoren.com/distributor_en/Pages/ALongHistory.aspx [26.06.2016]

[3] CNH Industrial Österreich GmbH

[4] CNH Industrial Österreich GmbH

Figure 2: CNH INDUSTRIAL Brands[5]

At the location St. Valentin, CNH Industrial Österreich GmbH is producing a volume of about 8.000 to 10.000 tractors per year (see Figure 3) for the agricultural market of Europe and Australia. With 511 employees from which 309 are working in manufacturing. The plant in St. Valentin has an area of about 170.000 m² whereof 42.000m² are under roof area.

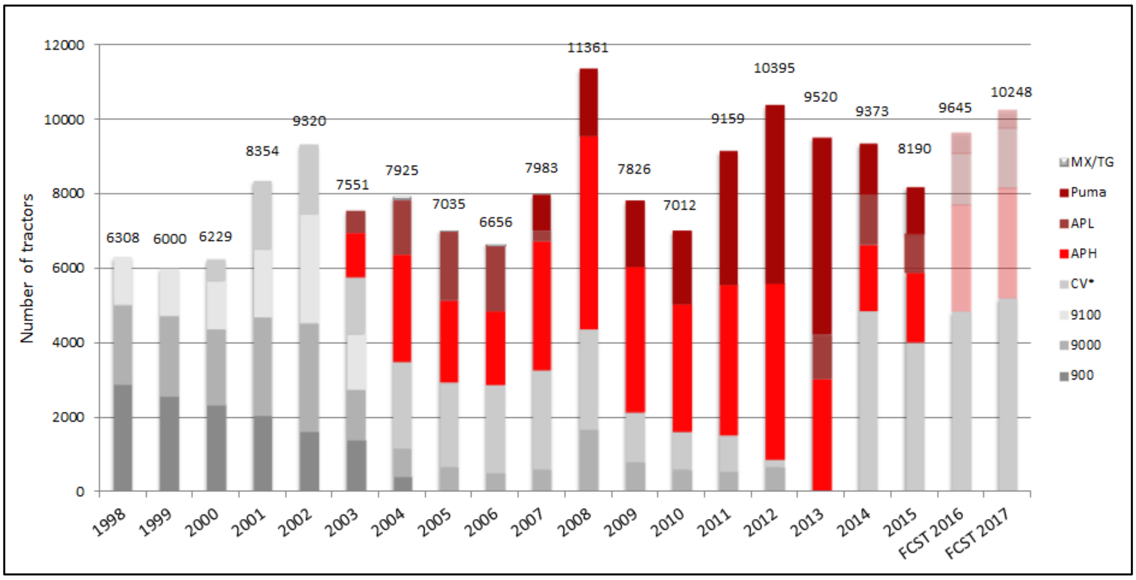

Figure 3: Production Volumes CNH Industrial Österreich GmbH[6]

The most important markets for CNH Industrial Österreich GmbH are France and Germany, where about 42% of the turnover are generated. In 2016 the Case IH brand accounts for approximately 82% of the product mix, whereas of the Steyr brand contain the remaining 18%.

[5] CNH INDUSTRIAL Österreich GmbH

[6] CNH INDUSTRIAL Österreich GmbH

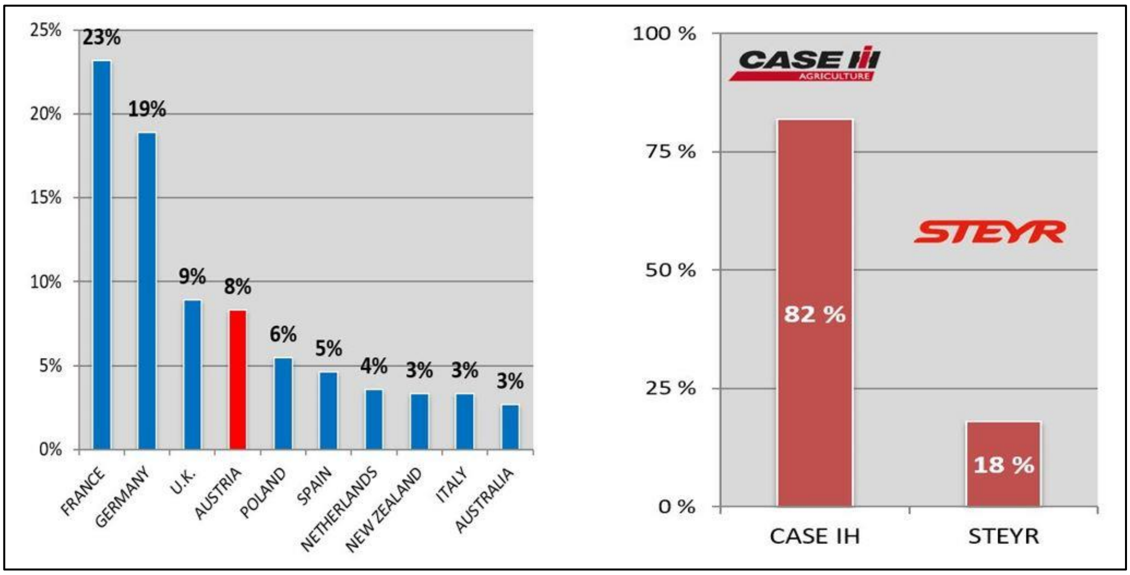

Figure 4: Top 10 Markets & Brand Mix 2016[7]

Product portfolio

In the plant St. Valentin currently 163 tractor models, which can be ordered in 9366 variants, are assembled. The customer can select between the brand Case IH and Steyr within 20 performance ranges for agricultural, municipal, industrial, ground care, and forestry use; the smallest one with 95 horsepower, the biggest one with 300HP. A general overview can be found in Figure 5. The customer can customize his or her tractor precisely to its purpose off use and personal preferences. These variation options lead to a repeatability of 1,51 times of every tractor per year.

[7] CNH INDUSTRIAL Österreich GmbH

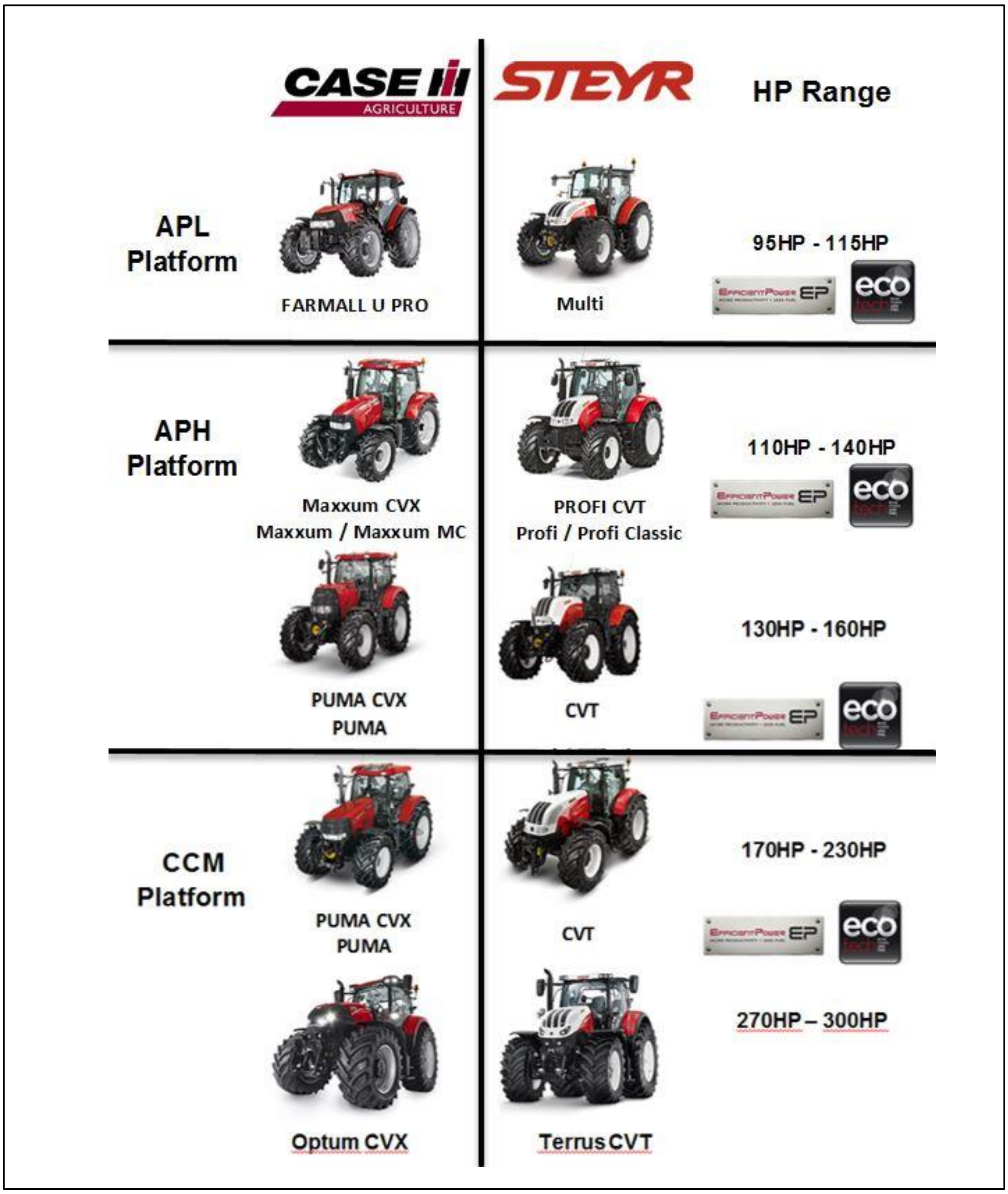

Figure 5: Product portfolio [8]

1.4 About the agricultural tractor machinery market

Tractors produced by CNH Industrial Österreich GmbH are sold mainly in Europe. Therefore, the agricultural tractor machinery market of Europe and following the market of Austria are addressed briefly.

[8] CNH INDUSTRIAL Österreich GmbH

1.4.1 Europe

The agricultural tractor machinery market is strongly influenced by the general economic situation, the prices for food and the energy prices. Also the furtherance of the European Union and the government have a big impact on the sales of tractors. After the economic crisis in 2008 the market volume of agricultural tractor machinery in Europe has dropped within 2 years from 2008 to 2010 by more than 20 percent. The farmers felt precarious by the economic situation and the fluctuating prices of food and energy and didn't invest in new machinery. In the year 2011, the markets began to recover. Three years later, 2014 the free trade agreement CETA (Comprehensive Economic and Trade Agreement) between Canada and the European Union was presented to the public. The European farmers fear a price collapse by cheap imported food from Canada and stopped their investments again. The Transatlantic Trade and Investment Partnership short TTIP caused a continuation of this trend. It is a trade agreement between the European Union and the United States mostly carried out in secret without anything reaches the public. This is one of the reasons why farmers are insecure and postpone investments in new machines or buildings. This is also reflected in the sales figures of the last years.

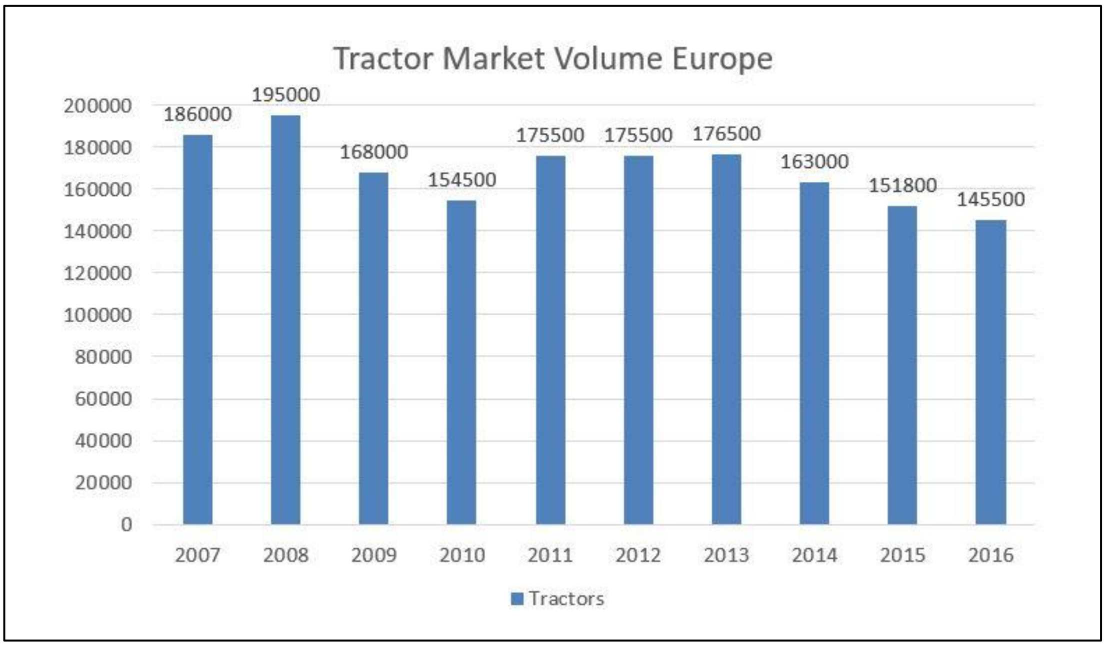

Figure 6: Tractor Market Volume Europe[9]

[9]Own figure, Data provided by CNH Industrial

1.4.2 Austria

The Austrian market behaves quite the same as the total market in Europe wherein the dips not be as strong after the crisis in 2008. In the recent years, the sales figures in Austria fell sharply to the lowest value for over 15 years.

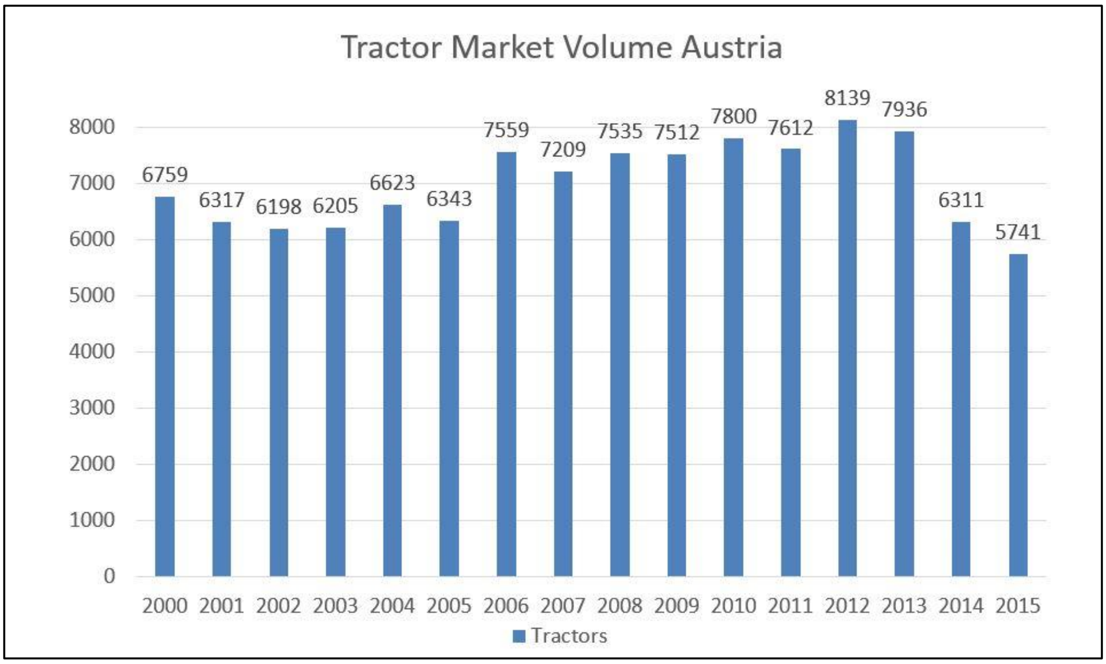

Figure 7: Tractor Market Volume Austria[10]

[10] Own figure, Data provided by Thomas Ritt CNH Industrial Österreich GmbH

2 Literature review Lean Production

In this chapter it will be discussed the theoretical basics which were used to work out this master thesis. The main focus thereby will be set on the principles of lean production.

2.1 Historical Background of Industrial Production

In the history of industrial engineering four formative inventions or innovations can be found. Before 1765, the industrial manufacturing was dependent on waterpower, to run the production machines in the companies. With the most important innovation of this time, namely the innovation of the steam engine by James Watt the industry gets a lot more opportunities of placing the factories and reaching independence form the rivers. This was the trigger for the first industrial revolution.
At the end of the 19^{th} century, the American engineer Frederick Winslow Taylor was one of the first who started to analyze the production with time and motion studies, by using a scientific approach. He separated and standardized the processes to find the easiest and most efficient way to perform the given task in a given time, the so called takt time. With his studies, he is regarded as the father of the Taylor system of manufacturing, in literature often called Taylorism. (see Figure 8)

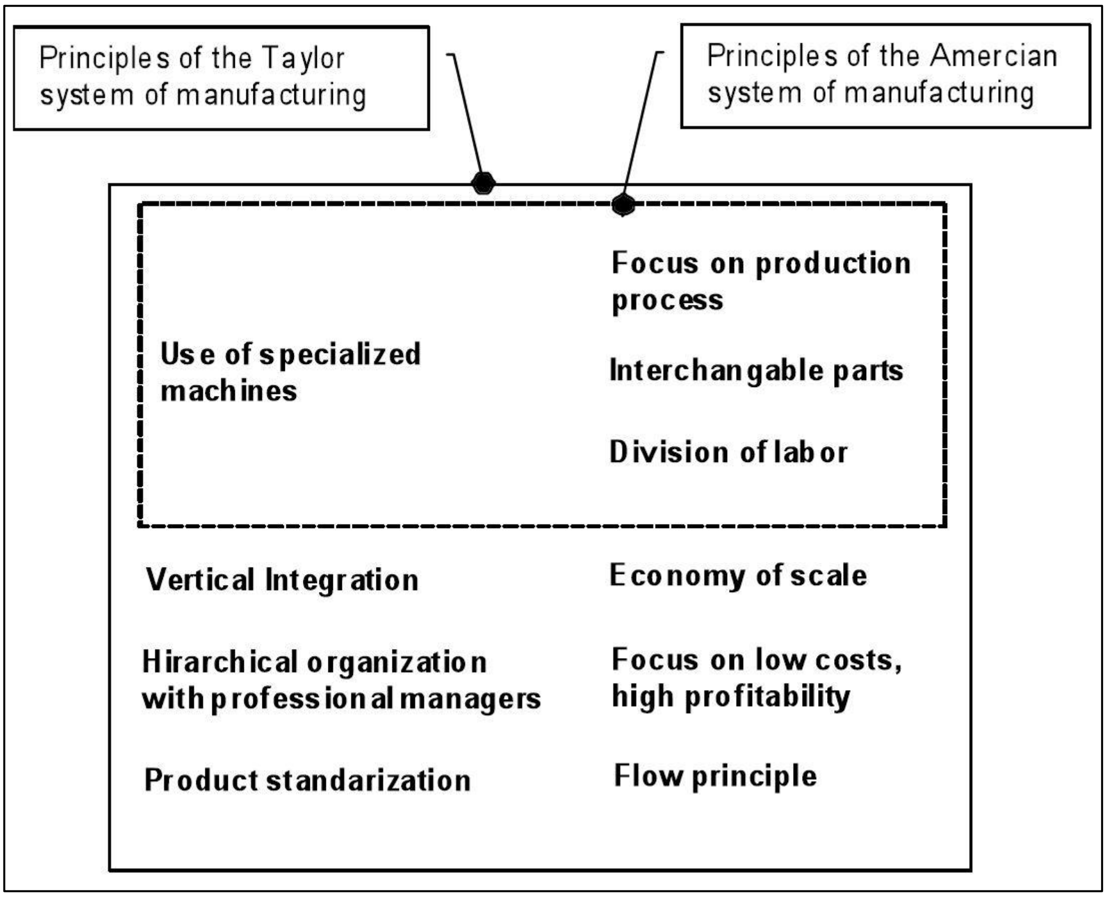

Figure 8: Principles of the Taylor system of manufacturing[11]

At the early years of the 20th century Henry Ford started with the production of the Ford Model T. It was the first car which was built on a moving assembly line. Standardized parts and the highly efficient assembly line made it possible to manufacture a large number of cars which cost less than cars form the competitors. The focus of production was on cheap products, quality had been subsequent and therefore the defect rate of the products was very high.

After the 2nd world war the western companies focus on mass production according to the principle of Henry Ford. For more than half a century, Ford's mass production has been the most common production system in the auto industry and has been used also in nearly every other industrial activity in North America and Europe.[12] Until the entrepreneurs and scientists recognized that in the 1980s that the Japanese care producers are doing something different and reach in sections like quality and efficiency better results than their western competitors. The durability of Japanese cars was much higher and in addition

[11] Pine (1994), p. 42

[12] Cf. Womack et al. (1990), p. 30

to that they needed fewer maintenance compared to American cars.[13] This is reasoned by the way Toyota engineered and produced their product. When they had a problem it was solved in a short time and the came back even stronger after fixing the issue. The quality of Toyota´s cars was outstanding and therefore the Toyota customers made them to one of the world´s biggest car producers. In the late1980s a research group form the Massachusetts Institute of Technology (MIT) analyzed the Toyota Production System (TPS) and came up with the term Lean in connection with manufacturing and producing. In the year 1990, the book titled The Machine That Changed the World form James P. Womack based on his research at Toyota was published.[14]

2.2 Production Systems

Basically, there are three main production methods used in industry. Job production, batch production, and mass production. Each of this methods have his own advantages and disadvantages concerning quality, productivity, flexibility, and costs per unit. Depending on the quantity of the produced products, it makes sense to use an appropriate system; job production for low production output, batch production for medium production output, and mass production for high production output.

Classification by quantities:

- Low production: Quantities in the range of 1 to 100 units per year.
- Medium production: Quantities in the range of 100 to 10,000 units annually.
- High production: Production quantities are 10,000 to millions of units per year.

The boundaries are set arbitrary by Mikell P. Groover (2001). Depending on the types of the products these boundaries may shift by an order of magnitude or so. [15]

[13] Cf. Liker (2004), p. 3

[14] Cf. Womack et al. (1990), p. 6

[15] Cf. Groover (2001), p. 3

2.2.1 Job Production

Job production is normally used for a single unit production. The often unique products may be small or large and are quite often custom-built according to the customer requirements. Each individual product is completed before the production of the next product starts, so that there is always only one product in process.[16]

Job or single-unit production is the oldest way of producing. The product is normally only produced on demand with general purpose machines or handwork. Therefore, well trained, highly skilled labour force is very important. The quality of the product is generally higher than with other production methods, because of the motivation of the worker; he or she is building the whole product from the beginning to the finished good what is very satisfying. With this labour-intensive production method, the use of labour and equipment may be inefficient, which leads to high unit costs and long production times.

2.2.2 Batch Production

Batch production pertains to repetitive production. It refers to the production of goods, the quantity of which is known in advance. It is that form of production where identical products are produced in batches on the basis of demand of customers' or of expected demand for products. This method is generally similar to job production except the quantity of production. Instead of making one single product as in case of job production, a batch or group of products are produced at one time. It should be remembered here that one batch of products may not resemble with the next batch. Under batch system of production, the work is divided into operations and one operation is done at a time. After completing the work on one operation it is passed on to the second operation and so on till the product is completed.[17]

This leads to a high amount of WIP (Work In Progress) between the different operations. By the division of labour into small work steps, the work gets easier for the employee, as he or she doesn't need to be as well trained as in job production and can learn the tasks faster. Often, the work is not as satisfying

[16] Cf. Choudhari et al. (2012), pp. 1356

[17] Types of Production: with it's Characteristics and Limitations. http://www.yourarticlelibrary.com/project-management/types-of-production-with-its-characteristics-and-limitations/26120/ [17.05.2016]

as in job production due to the high number of repetitive and simple work steps and high quantity of the products. The utilization of the equipment is higher than in job production because the set-up time per unit is lower. With a high frequently repetition of the operation, the worker is more efficient and so the use of labour force is higher. To assemble the parts produced in batches to one finished product, the parts have to be interchangeable; therefore, every part has to be designed in the right way and manufactured between specified tolerances. For example, a typical use of batch production is a bakery. A defined number of rolls is shaped until the baking plate is full and then the whole batch is carried over to the next operation, the baking in the oven. While the first batch is baking, the next batch is prepared.

2.2.3 Flow and mass production

Flow production also called mass production, is used to manufacture a high quantity of standardized products with frequently repeated, small work steps, mostly on specialized assembly lines with specialized machines. With the aim of the lowest possible production costs, the highest possible productivity, and the best utilization of the machines, the mass production often manufactures to expected future demand. Optimization of the work steps and the continuous flow of the products lead to the shortest possible manufacturing time of the product. With a strict monitored assembly line, standardized tools, standardized materials, high-accuracy assembly machines, and a well-designed product, the quality of the finish products can reach high standards and does not need much effort for quality control. If there is any problem at one work step within the production, the system claims an immediate correction. Otherwise the whole production will be influenced and has to be stopped in the worst-case scenario. The highly automation and standardization makes mass production very inflexible for product changes or fluctuation in demand.[18]

Interchangeable parts

When parts in mass production do not fit together the flow of the production is interrupted, which influences the whole production since there is no time for modifications on the parts. Therefore, it is very important that every part is

[18] Cf. Liker (2004), pp. 87

manufactured within the required tolerances and is interchangeable by its product design.[19]

Division of labour

By division of labour is meant that complex work steps with a big content of workload are split up into small and simple work steps which are frequently repeated. This simplifies the work task for the employee and makes it easier to learn and optimize the operations. Small work steps make it also simpler to arrange the workload for the single workstations and reach a well-balanced line. These plannings and optimizations are done by a special planning department so that the production employees have the opportunity to concentrate completely on their task in the production process.[20]

Focus on production process

Due to the highly frequented repetitions of the work steps, caused by the high quantities in mass production, it is reasonable to focus on the single production steps and processes to improve them.[21] Even small improvements multiplied by a huge number of produced units can cause big savings.

Use of specialized machines

With the high quantity of products, which leads to a high repetition of the production procedures, it makes sense to use specialized machines which are optimized for the operation and perhaps can perform some operations simultaneously.[22] Concerning the production of large unit numbers, it pays off to use an automated machine with the required accuracy to ensure the interchangeability of the parts. For example, a worker clamps several parts in the machine and the parts are machined at the same time or the workpiece is machined with multiple tools at the same time.

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[19] Cf. Womack (1990), pp. 27

[20] ibidem

[21] Cf. Schonberger (1986), pp. 125

[22] Cf. Schonberger (1986), pp. 64

Economy of scale

Scale economies consist of potential reductions of average costs associated with higher levels of productivity, which is measured by the quantity of output that can be produced in the time unit. [23] Or, they may also describe the economic advantages that show when higher volumes of output are produced with respect to smaller ones and that result in cost reduction per unit for that particular output, and for the same price of inputs.[24]
The fixed costs of specialized machines and inventory and also the overhead costs broken up on the single unit, decrease proportionally with a rising quantity of units. A higher number of produced parts has a positive influence on the learning curve of the employee, which leads to a higher productivity and fewer defects. With a large quantity and division of labour it is easier to create a well-balanced working plan.

Vertical integration

A high output of products on an assembly line requires a high input of sub-components and material which is followed in a high logistic effort for the line feeding. To reduce the transport of material and make the assembling more efficient, it makes sense to locate the production of the sub-components near to the assembly line.[25]

Flow principle

To reach a continuous flow of the product according to the flow principle, the workstations are arranged and linked by the assembly line in an order to fit the production sequences the best possible way. As a consequence, to prevent a standstill of the whole assembly line if there is a problem at one workstation, buffers between the single stations are needed. Material and tools are provided where the worker needs them, so he can concentrate fully on carrying out her or his task according to the principle of division of labour. The time between two products is predefined by the takt time. Compared to job production, with the application of the flow principle in mass production the use of specialized machines is standard to gain the advantage of fewer or no tool

[23] Pratten et al. (1970), p. 12

[24] Bellandi (1995), p. 29

[25] Cf. Womack (1990), pp. 33

changes and higher accuracy. Tool changes, breakage, or maintenance should be absorbed by the buffer if possible. Summarizing flow production can increase the productivity clearly when all the work steps, the workstations with the tools, and the material supply is well planned and organized.[26]

Product standardization

Every additional product or variation of a product causes additional effort of planning and organization, start-up downtimes, and changeover activities. Therefore, it makes sense to produce standardized products to optimize the whole assembly line in an optimal way and increase the profitability.[27]

Focus on low costs, high profitability

The sold units have a direct linkage to the product price. If the product gets cheaper, the quantity of soled products increases automatically. If an assembly line is producing more units, the fixed costs for the products decrease, thereby the price of the product can be reduced which increases sales and the profitability of the production increases.[28]

Hierarchical organization with professional managers

The high unit quantity and the division of labour in mass production require a high number of workstations and employees. To keep the system running smoothly the manufacturing processes needs to be planned and controlled by independent planning departments leaded by professional managers.[29]

2.3 Basics of Lean Production

Lean Production is not a single tool that can easily be implemented to get a fast improvement of your production system, rather it is a long term journey to a different way of working.[30] For the successful implementation of the Lean Production System it is important that every employee of the company understands the principles and values and, furthermore, identifies himself with

[26] Cf. Liker (2004), pp. 87

[27] Cf. Womack (1990), pp. 37

[28] Cf. Womack (1990), pp. 64

[29] Cf. Womack (1990), pp. 32

[30] Cf. Drew et al. (2004), p. 1

them.[31] It is a long term way of thinking and acting according to the principles of Lean, eliminating waste which is not adding an additional value for the customer during the complete process of manufacturing. For example, Toyota focuses first on the customer, second on the dealer, and at the end at themselves, the manufacturer. The demand is coming from the customer; therefore, it makes sense to focus on the features the customer is willing to pay for. Everything the purchaser does not want or need is *muda* (Japanese for waste). This is relevant for the whole manufacturing process; a customer is not interested in paying for storage of big lot sizes between the different working steps or at the end before shipping to him. This is the occasion overproduction is one of the biggest reasons of producing waste in the sense of Lean Production and also causes other kinds of muda like motion, waiting, inventory, and many more.[32] By implementing a Pull system where you only produce what the customer orders and continuative flow of the products and material through the whole production process it´s possible to double the productivity, reduce throughput time in production by 90 per cent and shorten the storage also by 90 per cent.[33]

2.3.1 Toyota Production System

The Toyota Production System (TPS) is a quantity control system built on a solid foundation of quality, and was the manufacturing system perpetuated by the strong culture of Toyota. Herein are the two differences between Lean Manufacturing and the TPS: the strong Toyota culture and the solid quality foundation. Both are strong manufacturing philosophies designed to make your business more secure and a better money-making machine through the total elimination of waste, thereby supplying what the customer wants: value. It needs to be understood that Lean is primarily a manufacturing philosophy and is not a business philosophy. Finally, the tools of Lean were designed for—and work best in—what I call the Lean Stereotype, although you are only a little hard work and imagination away from applying these tools very broadly.[34]

[31] Cf. Schröders (2015), p.803

[32] Cf. Dennis (2015), p.33

[33] Womack et al. (2013), p. 37

[34] Wilson (2010), p. 39

2.3.2 The 4P model

The 4P model, developed by Toyota, can be seen as the basic attitude of Lean Production. The four Ps, which stand for Philosophy, Process, People and Partners, and Problem Solving, illustrated in Figure 9, can be described as following:[35]

- Philosophy

  The 4p Modell goes back to the founder of Toyota Company, Sakichi Toyoda. The principles of the company, which are based on Mr. Toyoda's thoughts and ideas, are to worship the people they interact with, no matter if purchaser, business partner, or anyone else the company gets in touch with. This goes back to Mr. Toyoda's aspiration after a weaving loom for women on the rural side and his wish to facilitate their lives. Later on, his son Kiichiro Toyoda followed in his father's footsteps to improve the life of people and contributed to a substantial progress by founding an automobile establishment. Even today, this philosophy is an inherent part of the daily work of the heads of Toyota Company—it creates the basis for various other principles.

- Process

  By experience and mentorship, the leaders of Toyota Company gained the knowledge that both, short time and longtime processes have advantages. The most important factor of their success is to follow the right and appropriate process. Short term processes, like shedding inventory or removing unnecessary human motion in jobs, which bring a favorable result with a narrow time frame, are compared to the more difficult processes, namely the long term processes. Their results may not be obvious at first glance, but rather on the long term. The accomplishment requires courage—on the one hand some of these investments are a key to success, but on the other hand it cannot always be guaranteed that the change is really an improvement. An example is the flow principle. It may seem to be uneconomical to supply an assembly with the necessary parts every hour, but actually it is conducive to the flow. It might seem inefficient to spend time on collecting information and growing consensus, but the temporization of the process which can be short-circuited once, will pay off if you can

[35] Cf. Liker (2004), pp. 6

apply this new method in the future and consequently, short-circuit it more often.

- People and Partners
  In order to guarantee consistent further development, Toyota sticks to the Toyota Production System (TPS), also known as "respect for humanity" system. The aim of the system is not to make the working process pleasant and stress-free, but rather to raise problems on purpose and bring them to the surface. There is no need to explain that these problems are not always easy to handle, but they ensure that the worker thinks about the problem, spends time to learn more about it, and in the end overcomes it.
- Problem solving
  Saving problems is part of one's daily routine. Very often it is the case that problems are solved temporarily but occur again and again, due to the fact that they are not treated at their root. No matter if it was a product launch or a team project—mistakes were part of many of them and seen as opportunities to learn, as employees should take care that these mistakes do not happen again. Moreover, it is common to share the newly acquired knowledge with other Toyota colleagues who might come across a similar problem.

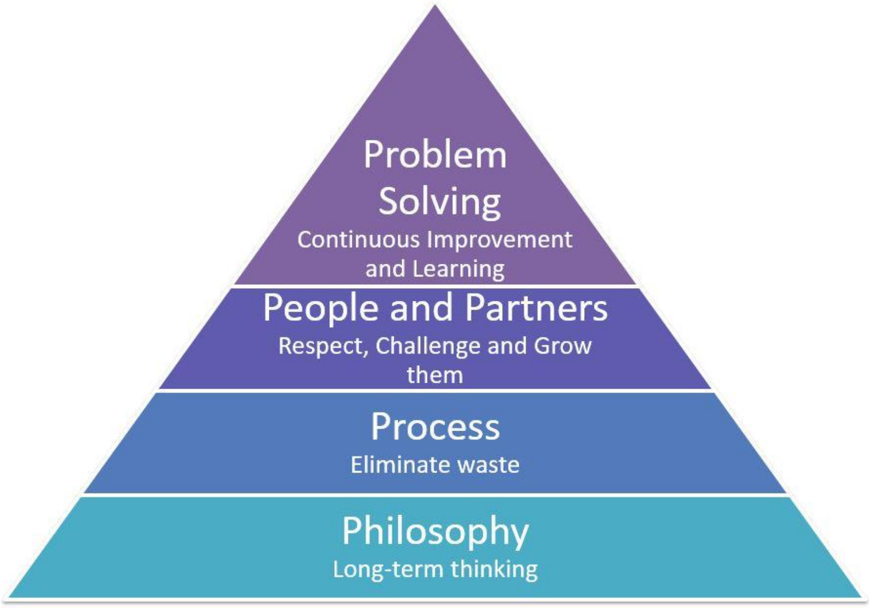


Figure 9: 4P Model of the Toyota Way[36]

2.3.3 Muda – Mura – Muri

Muda, Mura, and Muri are called the three Ms in Lean production and are strongly connected to each other. When one of this Ms is treated to eliminate waste, it is also important to consider the other Ms; otherwise, there will be added waste to one of the other Ms.[37]

Muda

MUDA is the Japanese word for waste. In Lean Production everything that does not add a value, form the customer point of view, to the product is a wastage of resources.

Motion

The main focus of wasted movement in literature of Lean Production is usually on the worker but also the movement of machines is a big source of waste. Very often, a big amount of the motion an employee makes during the production processes do not add, from the customer point of view, any value to the product. In the customer-oriented thinking of Lean Production these

[36] Liker (2004), p. 6

[37] Cf. Herrmann (2013), p. 4

movements are called Non Value Adding Activities. [38] For example, one source of wasting motion is to travel between workstations or walking to grab up the next needed part for the assembling process. Also the movement of a machine can be waste, for example a CNC machining center moves the tool between the process steps not in the shortest possible way.

Transportation

Material movement between two locations adds zero value to the product for the customer or the producer, and in addition to that it costs money. Therefore, the aim should be a transport way as short as possible with as less as possible handling of the material.[39]

Waiting

While an employee is waiting for a machine to finish a process or for a response from another, person he cannot add any value to product. This implies that waiting time is wasted time and also disrupts the flow. A counteraction can be that one worker operates more machines, so the machine is waiting for the worker and not reverse, what normally costs more.[40]

Over-Processing

By adding features the customer does not need or is not willing to pay for, it is more effort than required is put into the product; consequently, this additional input is waste. The goal should be to evaluate the customer requirement and transfer it to the product by clear specification and quality requirements and to manufacturing by standardization of the operations. Typical over-processing can be painting of unseen areas or unnecessary tight tolerances.[41]

Overproduction

One of the biggest sources of waste is overproduction. It effects other wastes, like inventory or unless use of labor time for producing higher quantities than the actual demand or obscures other problems in the production process. More

[38] Cf. Liker (2004), pp. 28

[39] ibidem

[40] ibidem

[41] ibidem

material is transported than necessary. A higher stock-level of raw materials, work in progress, and finished products is created. By all this factors more capital is bounded or more work force is used than actually would be needed.[42] Often a reason for overproduction is the production of large batch quantities to run machines with long setup times economically or creating buffers between the manufacturing steps to compensate a potential machine downtime or other interruptions. Furthermore, a wrong forecast of the future demand or fluctuation in demand can cause overproduction. A way to counteract overproduction is the installation of a pull system and produce only what the customer is asking for. Therefore, flexible machines with short setup times and a corresponding production capacity are important.

Inventory

To keep the business running, liquid cash is prerequisite. Inventory, regardless which kind of inventory; raw materials, semi-finished products, work in progress or finished products are bounding money which cannot be used for other activities. Additionally, higher inventory causes more transportation and handling what effects higher costs of transportation, labor and also more space for storage. With a level of inventory which is too high, a lot of problems are covered under the surface of the material-sea (see Figure 10). Once the level of inventory is reduced, the problems become visible like rocks in the see. After that, problems can be analyzed and fixed and the level of inventory can be reduced again until the next problems occur. Step by step the problems can be detected, fixed, and the bounded capital is released and can be used for business.[43]

[42] Cf. Liker (2004), pp. 28

[43] Cf. Aiello (2008), pp. 68

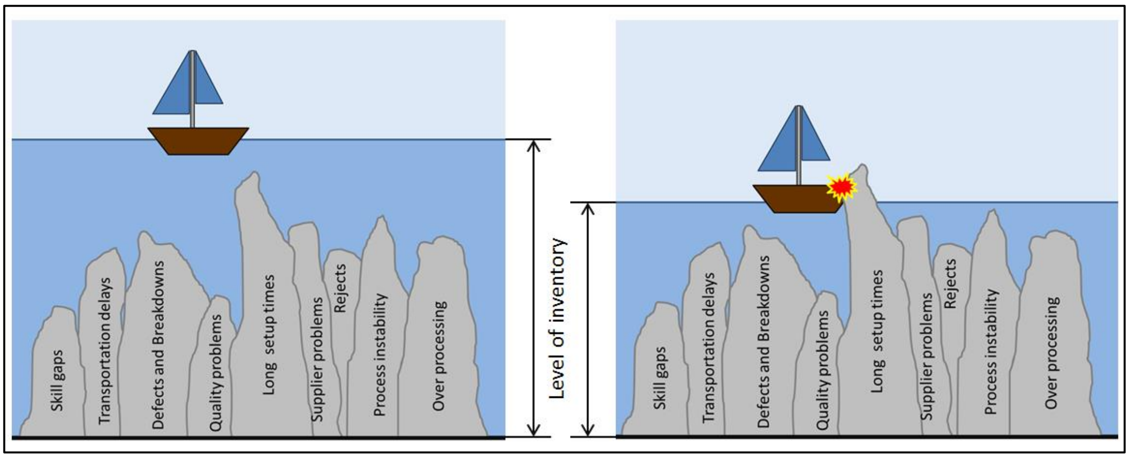


Figure 10: Level of inventory[44]

Defects

Rejects and defects can bring a lot of cost which are not visible at first glance, like the obvious costs of the initial scrap. To name but a few, hidden costs of defects can be the following: delivery failures, unsatisfied customer, setups, transport, materials, searching to identify the problem and many more.[45]
Defects can have a various number of reasons which can often be avoided by simple actions, like poke yoke solutions for assembling or training of the employees. Non-standardized operations can lead to a changeable stability of the process and cause rejects. Poor maintained fixtures or tools are also accountable for defects. Lack of knowledge, stress, unmotivated employees, and problems in private environment often are tried to be hidden but can as well be the trigger for problems. To eliminate or reduce defects caused by these reasons, it is important to implement the awareness in the company that failures and problems are nothing negative, but rather a possibility to improve something and make the product better than before. Standardized operation procedures, short SOP, are a good solution to prevent failures and make the process auditable for the managers and supervisors. The sooner a defect is detected during production or manufacturing, the lower are the costs to fix it.

Mura

Unevenness and variation (mura in Japanese) represent inconsistency in the flow of work, caused by changes in volume (uneven demand), mix

[44] Own Figure based on Davis (2009), p.68

[45] Cf. Liker (2004), pp. 28

(variation), and quality. Customers desire variety and flexibility, but these should be achieved while avoiding unnecessary complexity and chaotic behaviour. It is the responsibility of management to minimize the impact of variation by encouraging standardized product and process design, leveling demand, and introducing flow, pull, and just-in-time production control and delivery systems.[46]

Muri

Muri means overburden or unreasonableness. It is associated with waste of overloading equipment, facility or people resources beyond its capacity. The overload puts employees and machines into unnecessary stress, reducing their ability to perform. Muri can be also identified as the exact opposite of overburden – the underutilization of man and equipment, which causes long periods of idle time.[47]

Connection of Mura, Muri and Muda

All three types of waste are connected with each other. This connection can be described as a chain of causes and effects, where Mura creates Muri and the two of them together create Muda (see Figure 11). Simply stated, variation in production volume, forces a company to alternate overloading and underutilizing its resources, creating Muri and overproduction. This, in turn, leads to downtime, mistakes, backflows and waiting time causing other types of Muda. Therefore, Mura and Muri are the root causes of Muda, creating more non-value added activities and undercutting previous efforts to eliminate waste.[48]

[46] Bell et al. (2011), p. 34

[47] Pieńkowski 2014, p. 11

[48] Pieńkowski 2014, p. 13

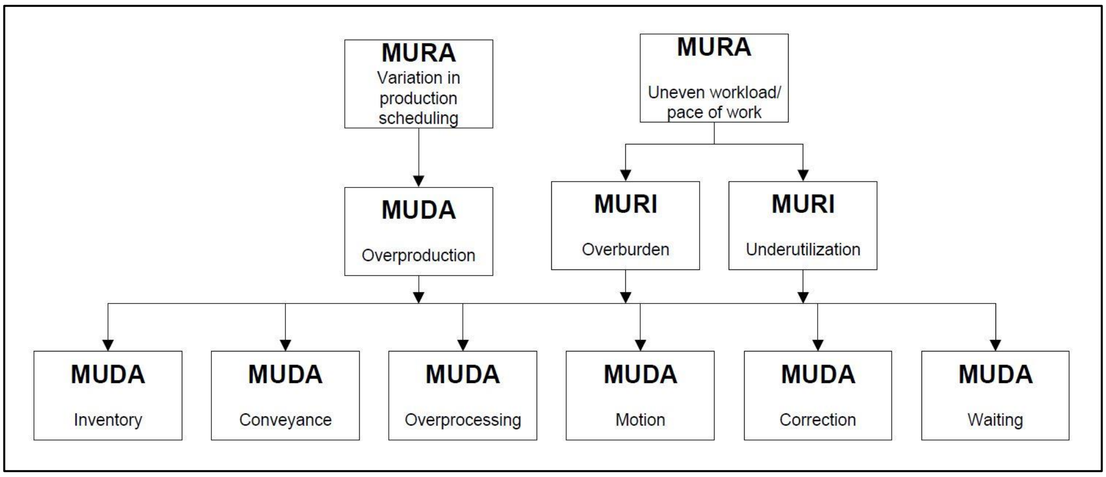


Figure 11: Connection between Mura, Muri and Muda[49]

2.4 Philosophy of Lean Production

Lean Production concentrates on simplification of the production and the organization system by eliminating waste and changing the attitude of the employees.[50] The aim is to reduce costs and deliver products the customer is willing to pay for. By a step by step improvement, a lean organization is trying to satisfy the customer with the perfect product, the lowest possible price, and creating zero waste along the entire value stream. To reach this ambitious aims there are a lot of concepts and methodologies which can be applied. Principally, the different concepts and methodologies of Lean Production are divided into three main categories; first the foundation, second the Just in Time pillar and the Jidoka pillar, and third the objectives of Lean. Figure 12 shows a "House of Lean" where the different categories and their interactions, which are also explained below, are visualized.

[49] Pieńkowski 2014, p. 13

[50] Cf. Wu (2013), p. 47

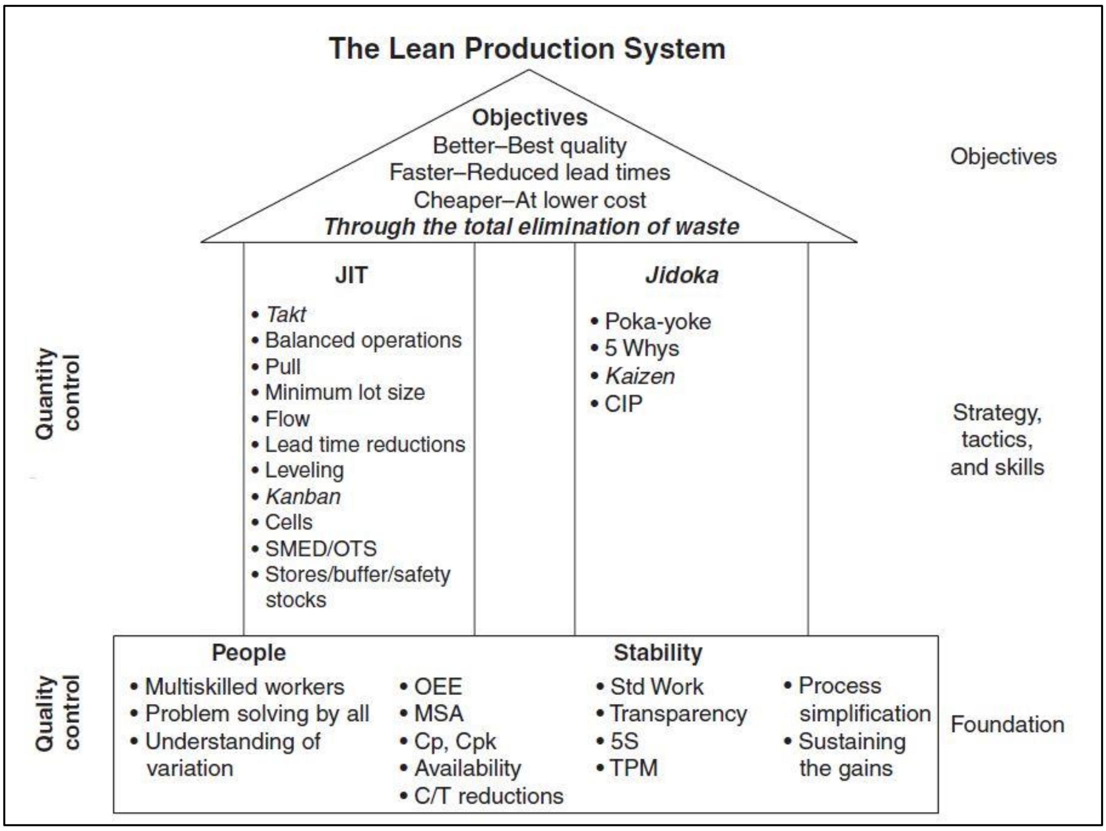


Figure 12: House of Lean[51]

2.4.1 Lean Production – Foundation

The foundation of the Lean Production System are well-trained people who understand the Lean Principles and stable processes. Various tools and methods how this can be reached are introduced below.

Total Productive Maintenance

The aim of **TPM** is to increase the equipment-efficiency by generating a sense of responsibility of the operators to their machines. They should learn to clean, inspect, and maintain their equipment autonomous or order maintenance at an early stage, before the machine performance decreases or the machine breaks down. This becomes a major role once we have a flow of goods in Lean Production and as small as possible lot sizes or puffers between the working steps. When a machine becomes inoperative, the whole following production system will become inoperative in a short time.[52]

[51] Wilson (2010), p. 300
[52] Cf. Liker (2004), p. 33

OEE

Overall **E**quipment **E**ffectiveness is a KPI (Key Performance Indicator) to identify the overall equipment or machine performance by accounting all losses like down time loss, quality loss and speed loss compared to a perfect production with zero losses.[53]

Process simplification

Process simplification is a basic concept, but is frequently overlooked by most. It is the idea of eliminating and simplifying steps in the production process. This is one of the most powerful variation reduction techniques you can employ. [54]

Transparency

To identify problems timely and also evaluate the performance of a process, transparency is needed. The foundation of transparency is the 5 S concept. Cleaning up and standardization makes it more simple to detect variations. [55] Visual controls like andons boards, heijunka boards, and space markings allow the managers in a short time to determine the performance of the process by visualizing the most important information like, for example, if the process is running how it should be or the actual production quantity and the production quantity goal.

[53] Cf. Wilson (2010), pp. 189

[54] Wilson (2010), p. 64

[55] Cf. Wilson (2010) p. 18

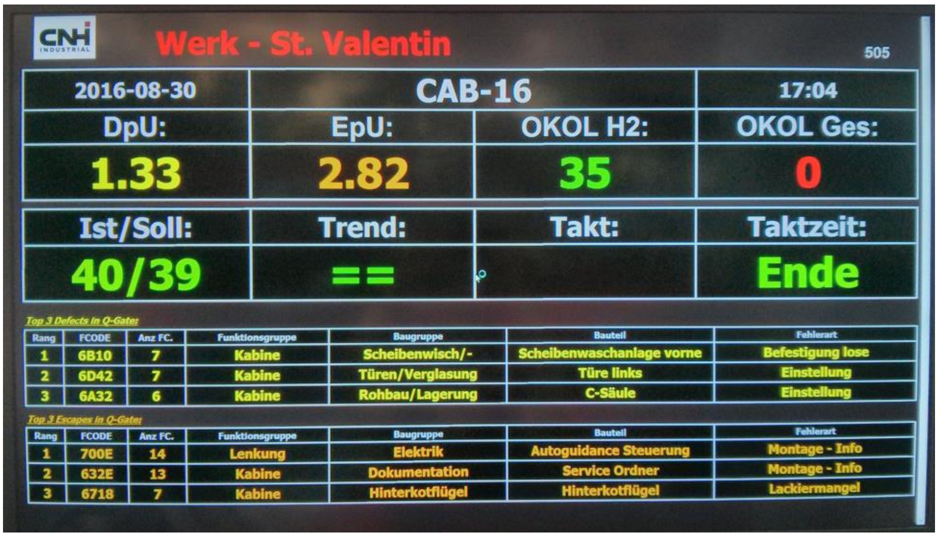


Figure 13: Andon Board at CNH Industrial[56]

5 S

The 5 S method provides easy and powerful rules for a clean, safe, clear, and well maintained workplace. A continuous improvement of the standards, rules, and discipline helps to enhance the workplace. Within the 5 S philosophy, the waste of searching tools or parts, the possibility of making mistakes, and the accident risk decreased and the quality of the product improved.

The 5 S can be described as following:[57]

- **Seiri** (Separate, Sorting Out)

  Seiri means to keep only the necessary things on the work place; all the other less frequently or never used tools or items should be stored somewhere else.
- **Seiton** (Set to Order, Systematic Arrangement)

  Looking and searching for tools and material is one kind of waste in production. Seiton means to give every tool and every item a specific fixed place to avoid spending too much time on searching. This is done, for example, with a simple shadow board for tools.

[56] Own Picture photographed at CNH Industrial St. Valentin

[57] Cf. Liker (2004), pp. 150

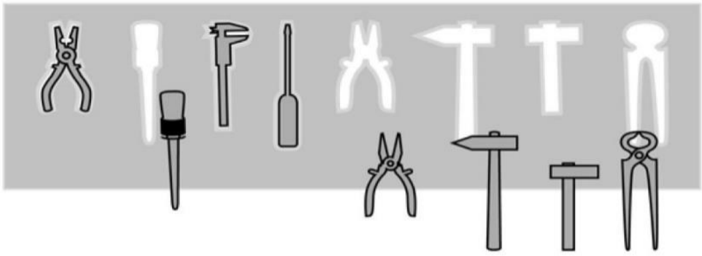


Figure 14: Shadow Board[58]

- **Seiso** (Shine, Sweep)
  The third S is about to clean workplace and machines to ensure safety and quality. Cleaning is not only for a good looking tidy workplace, it also helps to determine damages on machines and equipment in an early stage, hopefully, before the machine or the tool become inoperative.
- **Seiketsu** (Standardize)
  Without standardization the implementation of the first three S will not last very long and the system returns to its old habits. The aim of Seiketsu is to keep the high standards of workplace organization and housekeeping. For a long-term success, it’s important to involve the employees in developing the standards.
- **Shitsuke** (Sustain, Education)
  The last part of the 5 S is a continuous improvement technique to keep and enhance the benefits of the 5 S. Managers should show their commitment to the 5 S program and hold periodical audits at the working area to give feedback to the concerned people until
  5S become part of the natural behavior.

Cycle-time reductions

A shorter cycle-time gives you the opportunity to produce more in the same time, which leads to a higher productivity of the production. It also stabilizes the process and helps to improve quality.[59]

[58] Meran et al. (2013), p. 273
[59] Cf. Wilson (2010), p. 62

MSA

Measurement System Analysis is a statistical method to determine the usefulness of the measurement system for both, products and processes. Its chief benefit is the ability to find and classify variation in the measurement system.[60]

Availability

Availability means that the product can be produced when it is needed and scheduled; an important feature in Lean Production that can be reached with a stable production process.[61]

Standard work

Standardized work defines and documents the most effective method to accomplish a task. There are usually a variety of ways to perform the same work, depending on who is doing it. Variation in work practices creates variation in time, quality, and cost.[62]
Standardized working processes, standardized material, standardized tools, and standardized cycle times help to prevent failures and, therefore, improve the quality. Standardization also makes it easier for manager and supervisor to recognize the status of the process and audit it.

People

The key to success of a well working Lean Production are the employees of the company. Today, technology is more or less available for everybody, patents expire, and innovations can be reverse-engineered. High qualified people who have understood the Lean Philosophy can improve processes which can result in high quality, low prices, short cycle times, and less waste. If a company employs and trains qualified people, this leads to a competitive advantage.[63]

[60] Wilson (2010), p. 305

[61] Cf. Wilson (2010), p. 62

[62] Bell et al. (2011), p. 42

[63] Cf. Black (2008), pp. 1

Multiskilled workers

Flexibility is an indispensable part in Lean Production. The most flexible "inventory" or "machine" in a production system are multiskilled workers who can easily change workplaces, according to the needs of the process, like changes in demand or improvements of the process itself.[64]

Problem solving by all

When problems are seen as a harassment or failure of a specific department like management, engineering, or in the worst case as a failure of one specific worker himself, nearly every time it's tried to hide the problem. The longer a problem is unsolved, the higher becomes the damage.[65] For example, when a problem is solved during the product development, it costs not much money compared to solving the problem after the production has started or even the product has been delivered to the costumer. Therefore, it is important not to blame people if they find a problem, rather the should get some appreciation for finding the issue.

2.4.2 Lean – Strategy, tactics and skills

Just in time delivery of parts and jidoka (automation with a human mind) are the two pillars of the house of lean to enables the system to align to daily and monthly fluctuations in demand of quantity and variety.[66] Also, the quality of the product and the process should be improved by the use of tools and methods of these pillars.

Just in Time Pillar

The central idea of JIT is to have the right product at the right time in the right quantity and the right quality at the right place. [67] This can be achieved with the following tools and methods.

[64] Cf. Wilson (2010), p. 60

[65] ibidem

[66] Cf. Dennis (2015), p. 25

[67] Dombrowski (2015), p. 126

Takt Time

Takt Time is the pace of production (e.g. manufacturing one piece every 34 seconds) that aligns production with customer demand. In other words, it is how fast you need to manufacture product in order to fill your customer orders.[68]

Takt Time = Planned Production Time / Customer Demand

The planned production time is the available working time per day without production down time like breaks. For example, 8.5 hours shift subtracted 45 minutes of break gives a Planned Production Time of 7.75 hours per day. With a Customer Demand of 46 units per day, the result is a Takt Time of 10 minutes and 6 seconds.
Producing at a cycle time lower than the calculated Takt Time leads to overproduction, which increases your inventory or forces you to stop the production. According to Lean Production, both of these cases are waste and should be avoided.
Producing at a cycle time higher than the calculated Takt Time means there is a bottleneck in the production process which is limiting the production volume and therefore, the customer demand cannot be satisfied.[69]

Balanced operations/ Line balancing

For a continuous flow of the goods without bottlenecks during production, the fluctuation of the workload between the workstations should be as small as possible. This is reached with a well-balanced line, what means that the time needed for the operations on the workstations is as close as possible to the takt time. [70] For a later optimization and eventual reduction by optimization of the needed workstations, it is meaningful to make sure that all workstations have a work content which is equal and close to the takt time except for the last workstation. The last workstation is mostly operating distinctive under the

[68] Takt Time
http://www.vorne.com/pdf/lean-brief-takt-time.pdf [05.04.2016]

[69] Cf. Daneshgari (2008), pp. 46

[70] Cf. Hitomi (1996), p.130

takt time and eliminated when there are find some further improvements on the assembly line.

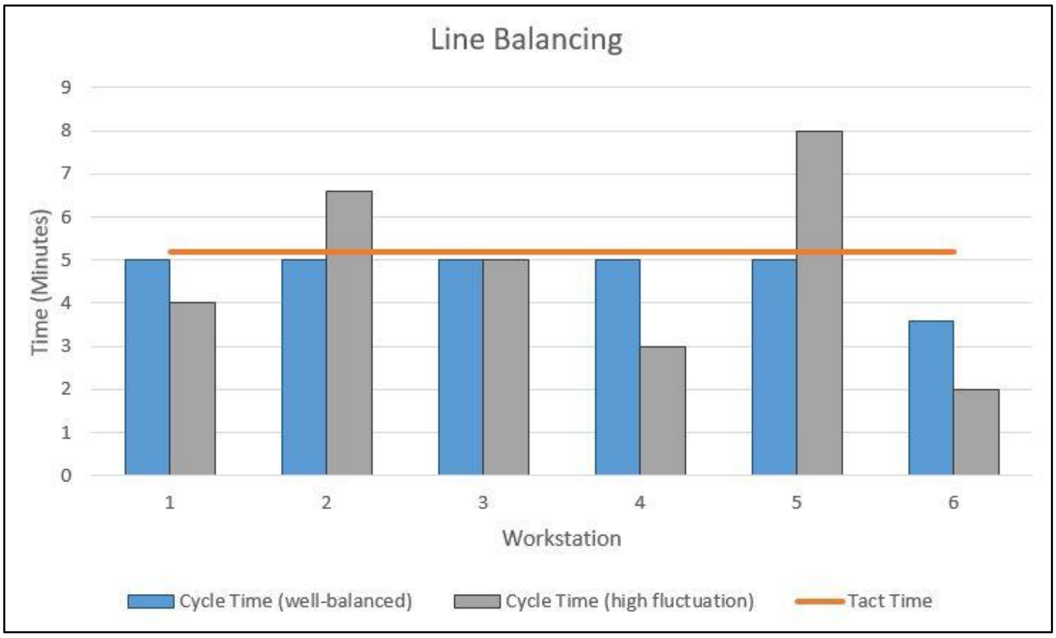


Figure 15: Line Balancing[71]

Pull

The aim of a pull-system is to produce by taking the real demand into account. when this system is running satisfactorily overproduction and delivery problems should be prevented. Material and products between the stations, buffers or work in process, should be reduced to a minimum which, also decreases the throughput time.[72]

Minimum lot size

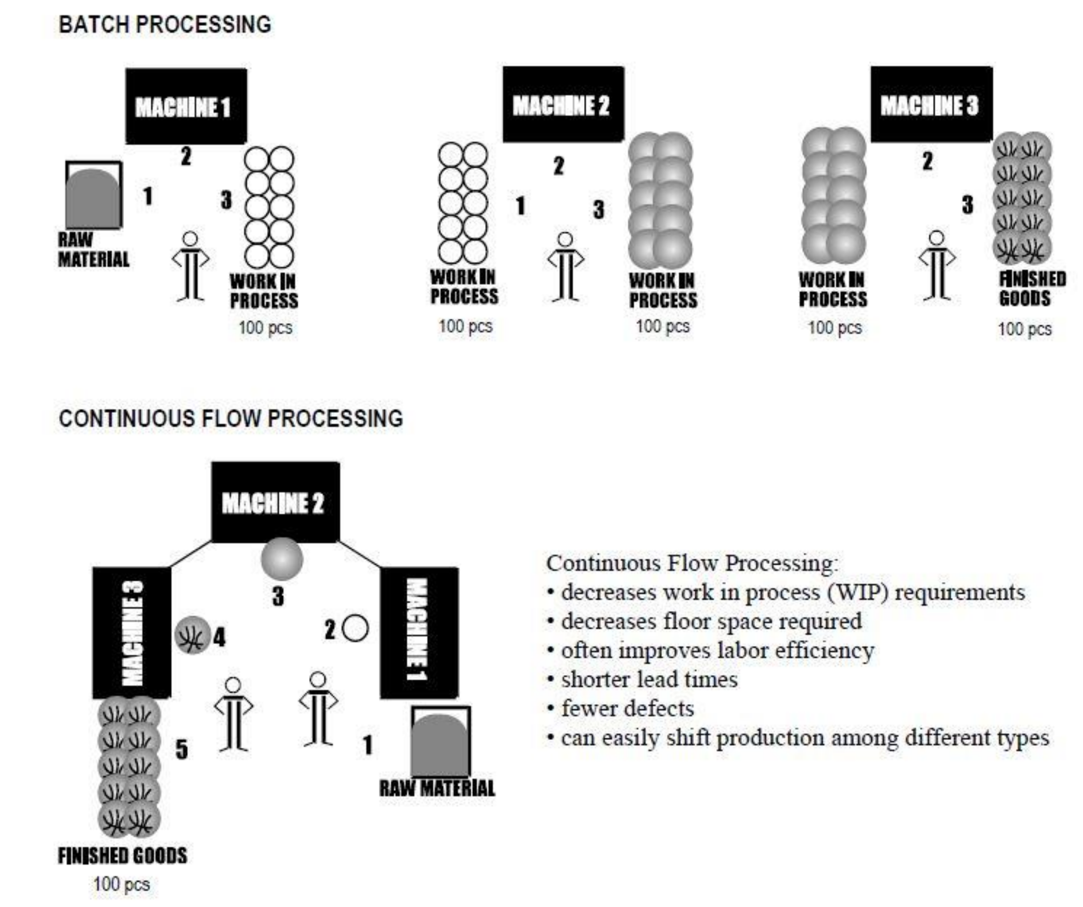
The intended target of the lot size in Lean Production should be one piece, every additional part means a certain kind of wastage, like for example overproduction or a longer throughput time than theoretically needed. With a minimum lot size and a maximum of flexibility for changes of the product or fluctuation in demand is guaranteed.

[71] Own figure based on CNH Industrial training document

[72] Cf. Wilson (2010), p. 67

Flow

Flow means that the product is moving as continuous as possible through the production. The ideal production system works with a one-piece-flow where the product only stops for value adding activities.[73] The advantage of the one-piece-flow is that the WIP is reduced to a minimum compared to batch production. Furthermore, the lead time is reduced as well and fewer defects occur. Additionally, the inventory at the work station can be reduced and the required space lowers to a minimum.



	Batch Processing	Continuous Flow Processing
Daily Demand	100 pieces	100 pieces
WIP	400 pieces	3 pieces
Finished Goods	100 pieces	100 pieces
Lead Time	30 cycles	3 cycles

Figure 16: Continuous Flow vs. Batch Production [74]

[73] Cf. Wilson (2010), p. 67

[74] TOYOTA PRODUCTION SYSTEM BASIC HANDBOOK, p. 28

Lead time reductions

The time between a customer orders a product and the manufacturer delivers the product is called lead time.
Lead-time reductions are the essence of waste reduction in Lean. They give the process both the maximum flexibility and maximum responsiveness to changes; especially changes in demand either in quantity or model mix.[75]
By reducing the lead time there is a business and a manufacturing advantage for the company. On the one hand, the cash flow in the company is improved by shortening the time between order and delivery. On the other hand, manufacturing flexibility and capacity will improve, if products are produced faster. Lead time can be improved by reduction of setup times, reduction of production times, reduction of transport time and transport delay, reduction of piece or lot waiting times, simultaneous engineering and various other options.[76]

Leveling

Production smoothing, leveling, or heijunka is used to reduce the unevenness (Mura) in a production process. Mostly, the orders form the customer came with a high fluctuation to the manufacturer. For example, on one day a quantity of 500 units is ordered and on the next day only 100 units of the same product are requested. Production leveling is a tool to keep the production running smoothly, even if there are big changes on demand.
Product smoothing is a tool to prevent batch production. It regulates the production quantities in a way that at the end of a given time frame all ordered products are available.
The benefits of a leveled production are smoothened demand peaks, increase in flexibility, reduction of inventory, quicker quality feedback and less overproduction.[77]

[75] Wilson (2010), p. 68

[76] Cf. Charney (1991), pp. 6

[77] Interview with Lean expert Dec. 2015

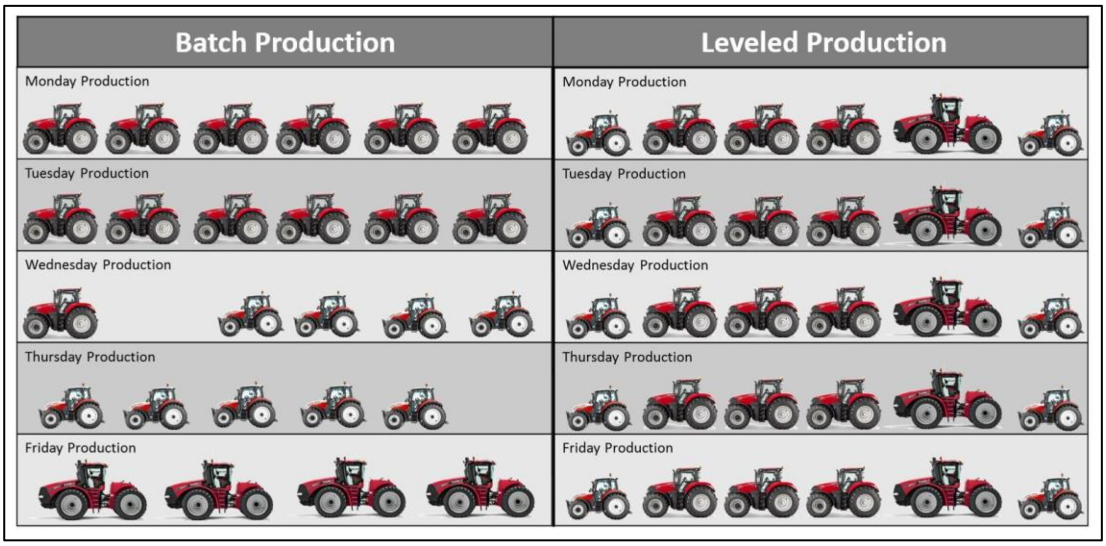


Figure 17: Batch Production vs. Leveled Production[78]

Kanban

Kanban is a signal causing work to begin or to move to the next step of production. Kanban pulls workflow by demand, rather than being pushed by a predetermined schedule. In a factory where work is tangible, Kanban signals are often physical: cards, containers, flashing lights, or other signals.[79]
The cards a positioned on the container, when the worker removes the first part of the container the card is brought to the previous upstream station. At the upstream station, the worker starts to produce the required amount of parts and the parts are delivered to the downstream station. Every card is assigned to a defined number of parts. With the number of cards in a system, the amount of inventory in the system can be controlled easily by adding or removing cards.

[78] Own Figure based on Shingō (2006), pp. 126

[79] Bell et al. (2011), pp. 183

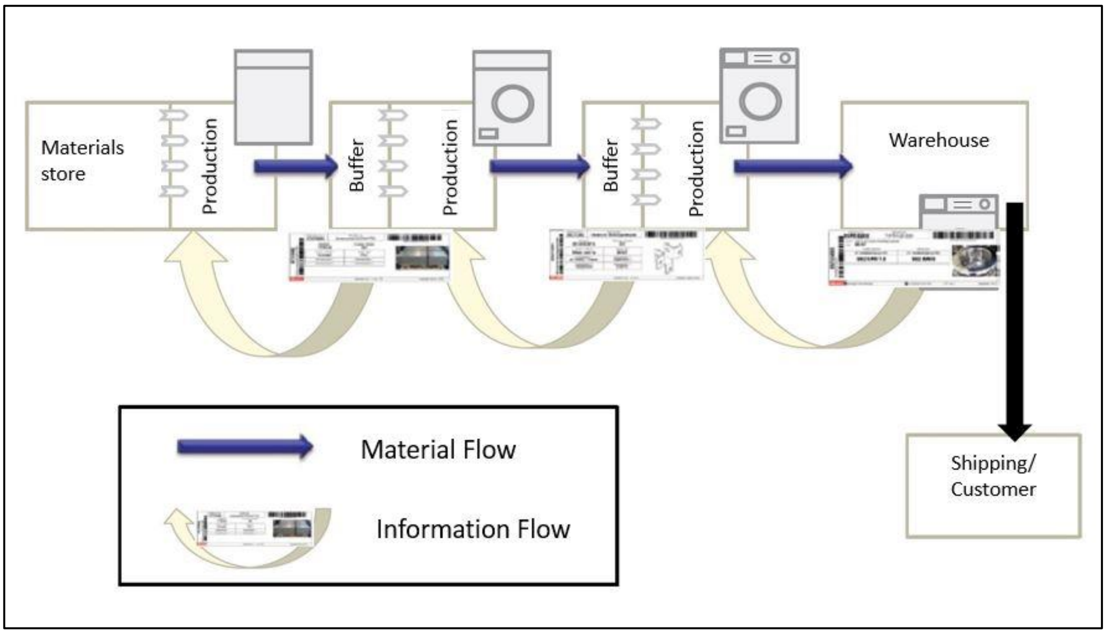


Figure 18: KANBAN[80]

Cells

Cells are work areas that are arranged so the processing steps are immediately adjacent to one another. This lets parts be processed in near-continuous flow either in very small batches or in a one-piece flow. This, in turn, allows minimization of the wastes of transportation and inventory—in this case, WIP (work in process). The most common shape is the “Inside U” cell. This cell minimizes walking distance when standing operators are used. Cells have some natural advantages over the classic assembly line. First, the ability to use people for more than one activity in a cell allows the control of demand variations by staffing differently.[81]

[80] Cf. Dombrowski (2015), p. 115

[81] Wilson (2010), p. 69

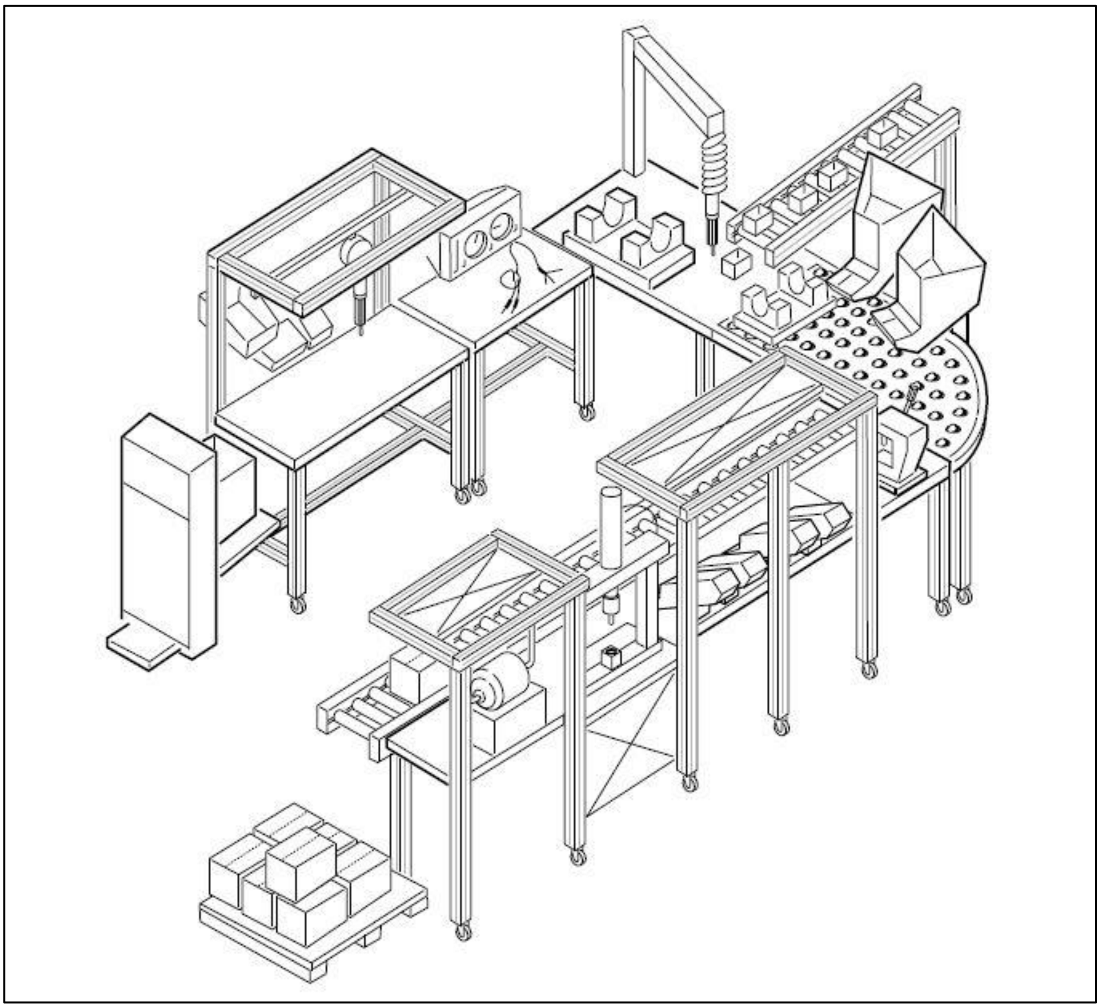


Figure 19: U-Shaped Cell[82]

SMED and OTS

Single Minute Exchange of Dies and One Touch Setups are principles to reduce setup times and reduce changeover losses. With shorter setup or changeover times, the production of smaller batches can be performed much more efficiently and economically. Simple fixtures which require as few tools as possible, supporting devices for adjusting, and poka-yoke solutions are good opportunities to realize improvement for setting up machines. Since flexibility is one of the most important characteristics of a production system in Lean Production, a quick changeover of the production machines or assembly lines is very important. Leveling gets easier, lead time can be reduced, the flow

[82] Bosch Rexroth Corporation (2009), p. 4

of the material and products is improved, and various other benefits are the result of the SMED/OTS.

Jidoka Pillar

Jidoka loosely translated means “automation with a human touch”, according to the TPS. It means that if there is an abnormality detected during the production process, the production is stopped automatically and only restarts if the failure is fixed. By this it is prevented, that the problem stays uncared and an unnecessary high number of reject goods are produced. Moreover, it helps to improve the processes continuously because the production is not running smoothly until the problem is solved.

Poka-yoke

A poka-yoke is any mechanism in a lean manufacturing process that helps an equipment operator avoid (yokeru) mistakes (poka).[83] Many mistakes happen unintentionally if the worker is not fully focused on the process or due to many other reasons. A Poka-yoke solution gives the operator only one possibility to mount the part; therefore, it is guaranteed that the assembly is correct. This is ensured by the design of the product, often with a special hole pattern so that the part can only be screwed on in the requested way or some geometrically features so that a wrong mounting is impossible. For example, on a harness with various plugs, every plug should be shaped differently and fit only to the corresponding counterpart to avoid a wrong connection of the electrical wires. Poka-yoke solutions can be very simple and cheap opportunities to eliminate failures through wrong mounting. Furthermore, Poka-yoke can also be applied to mounting aids so that the parts cannot be mounted in the wrong way and a failure is impossible.

[83] Patel Parikshit K. et al. (2013), p. 95

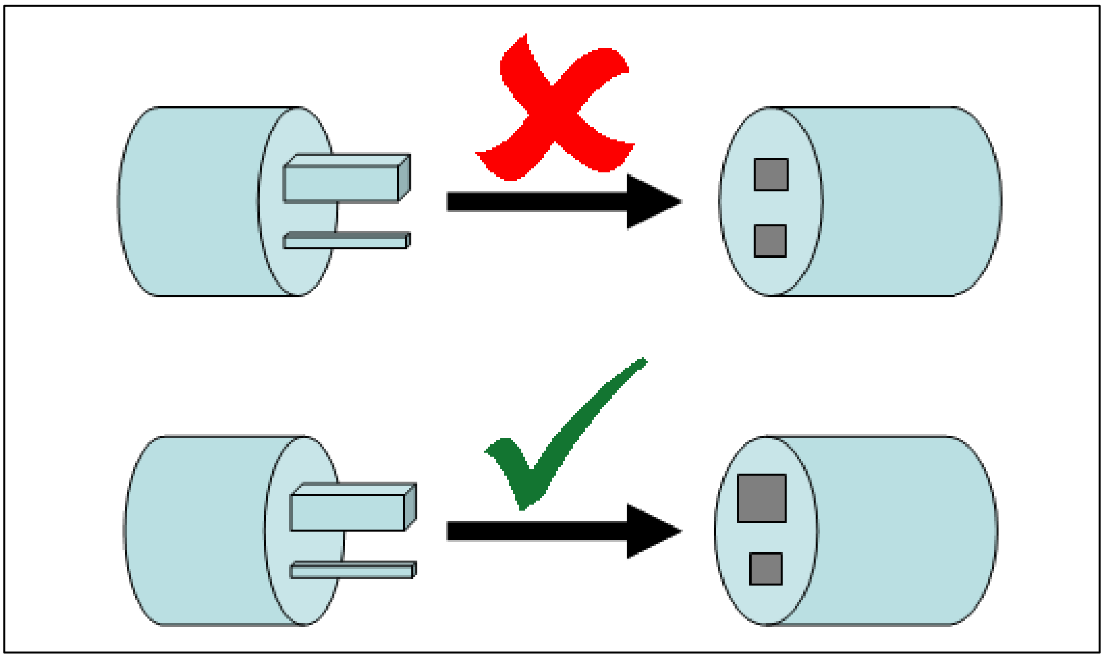


Figure 20: Poka-yoke Example[84]

Another possibility which is not bounded to an error proof design, is to control the process is operated in the required way or not.

There are three types of Poka-Yoke methods where a control function is installed, as Darren Dolcemascolo explains in his findings (2004) in more detail: [85]

- **Contact methods**
  A sensing device proves if a product makes a physical contact during assembling. One example for a physical contact can be an electrical limit switch which is pushed when a part has reached its correct position. The same can be ensured by an energy contact, a photoelectric beam sense when the part has reach his position. Some of the best methods are already integrated in the product, like guide pins or blocks to prevent the possibility of a wrong mounting of the part.

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[84] http://pdcahome.com/english/wp-content/uploads/2013/06/pokayoke-example.png [05.09.2016]

[85] Cf. Mistake Proofing Overview (2004) http://www.emsstrategies.com/dd110104article1.html [06.09.2016]

- **Fixed-value methods**
  These methods are used when a fixed number of operations is required to be done. The number of repetitions is counted and when the needed value is reached, a signal occurs. Afterwards the product is released.
- **Motion-step methods**
  This method detects if a motion or process has been performed within a certain period of time (for example once every takt cycle). By sensors and devices, which are connected with a timer, it is controlled if the needed operation has been done. This can be, for example, the removal of a label.

5 Whys

5 Whys is a tool to determine the root cause of a defined problem. With every asked “why” you get one step closer to the reason of the problem. The quantity five is a guide value to be sure to get as deep as necessary to the root cause; sometimes there are more “whys” needed, and sometimes fewer.[86]

[86] Cf. Wilson (2010), p. 65

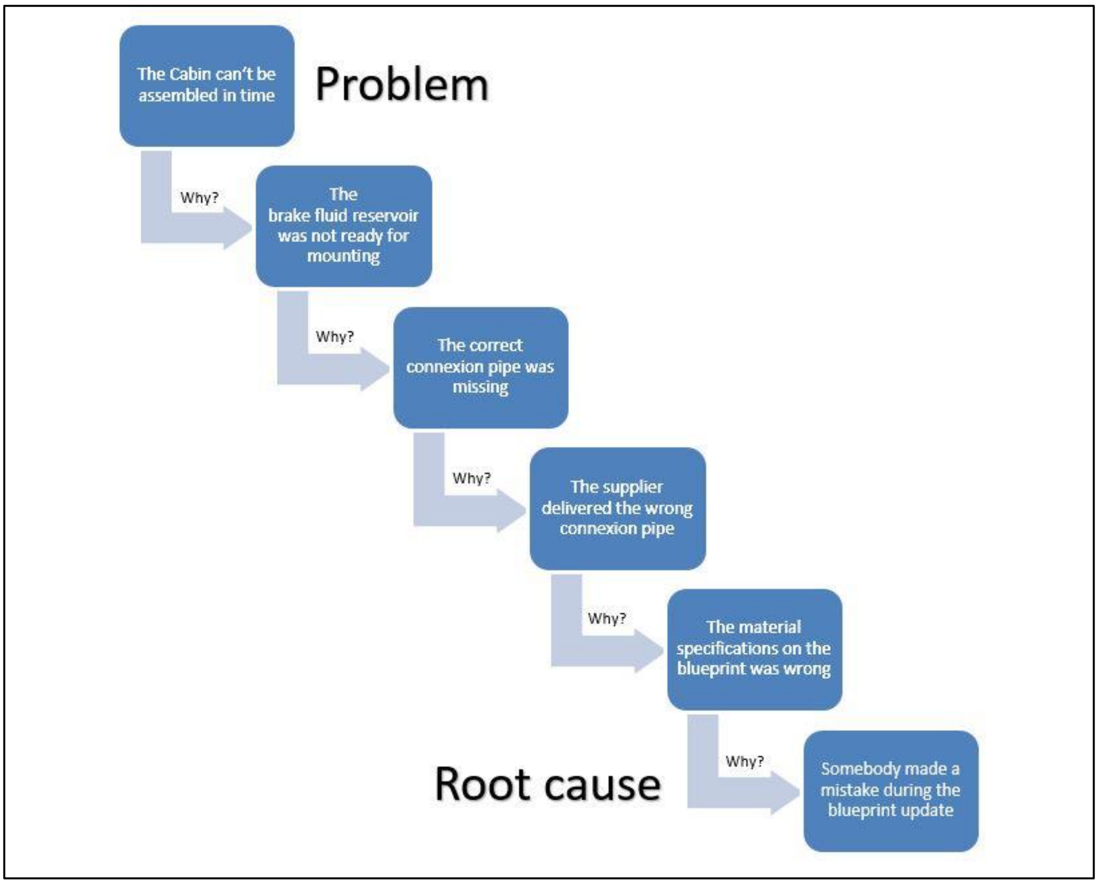

Figure 21: 5 Why Example[87]

Kaizen

Kaizen is a culture of sustained continuous improvement focusing on eliminating waste in all systems and processes of an organization. With a Kaizen approach, the intent is to be better today than yesterday. In other words, numerous small changes over time will yield large improvements. This approach is contrary to common business practices where big returns, large projects, and huge budgets are the expectation. Key to Kaizen success is not to look for perfection in solutions, but make less-than-perfect incremental changes that improve the process, and continue to build on prior successes and yes, failures.[88]

In contrast to innovation, Kaizen is a constant long-term improvement process with small steps.

[87] Own figure based on a fictional problem at CNH Industrial Österreich GmbH

[88] Yenkner (year unspecified), p. 158

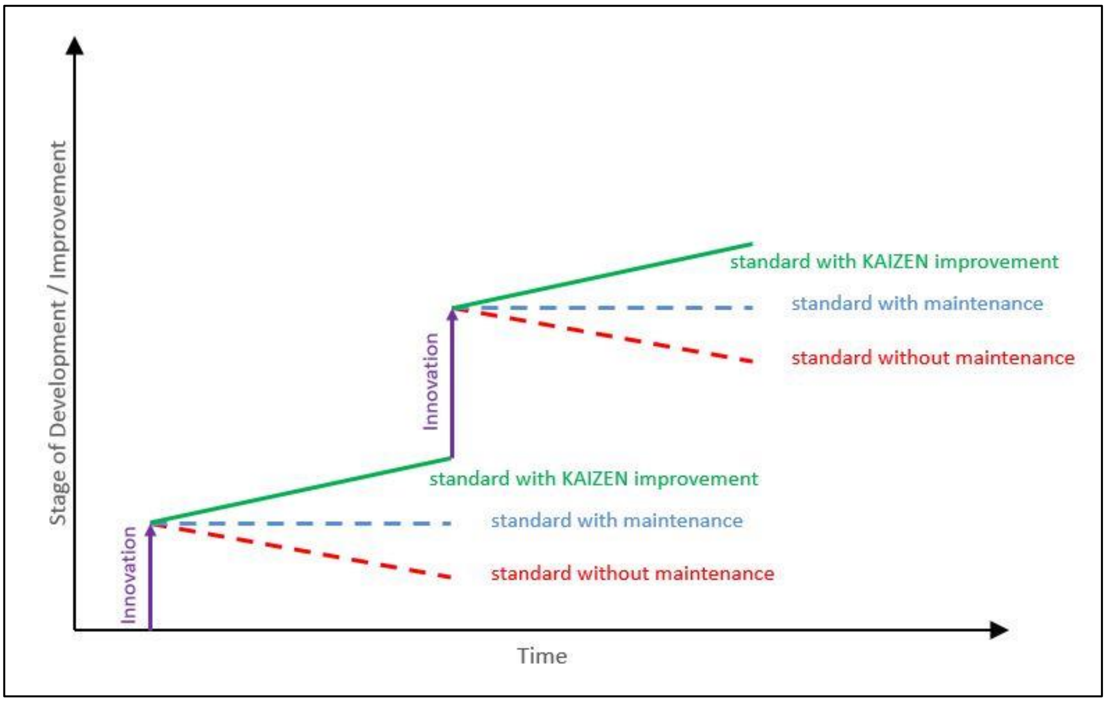

Figure 22: Innovation, Maintenance and Kaizen[89]

According to Masaaki Imai, the Kaizen system can be seen as an umbrella. When the process is done in the right way, redundant hard work will be eliminated. In a Kaizen system, everybody within the company, the upper management as well as the cleaning crew is involved. Each employee should come up with ideas for improvement. [90]

[89] Own figure based on Imai (2012), pp. 2

[90] Cf. Prošić 2011, pp. 173

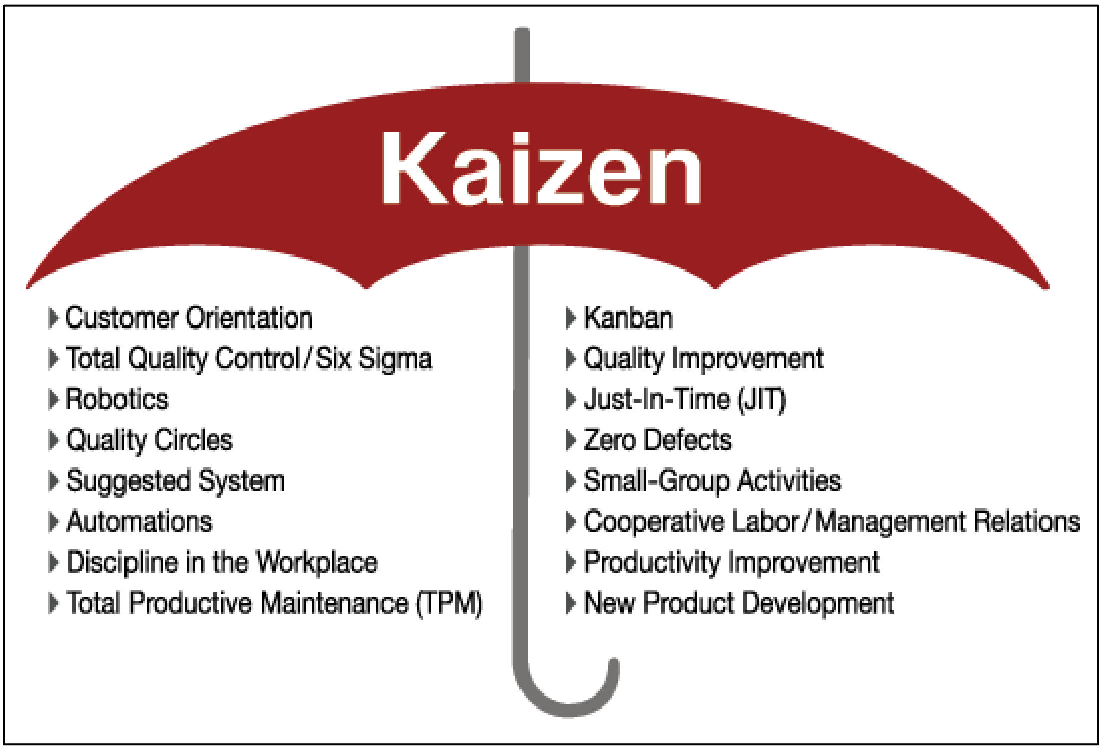

Figure 23: Kaizen Umbrella[91]

CIP

The **C**ontinuous **I**mprovement **P**rocess is part of the Kaizen process. It is based on small, inexhaustible improvements to develop a process and bring it closer to perfection. Many small improvements over a short period of time mostly result in a higher developmental stage than few, big long term improvements (see Figure 24).[92] Within the thinking of CIP, an imperfect improvement makes sense as well and brings the process one step closer to perfection. The weaknesses of the current improvement can be enhanced in the next step.

[91] http://www.kanbanchi.com/wp-content/uploads/2015/05/Kaizen_umbrella.png [05.09.2016]

[92] Cf. Drozda (1993), p. 1

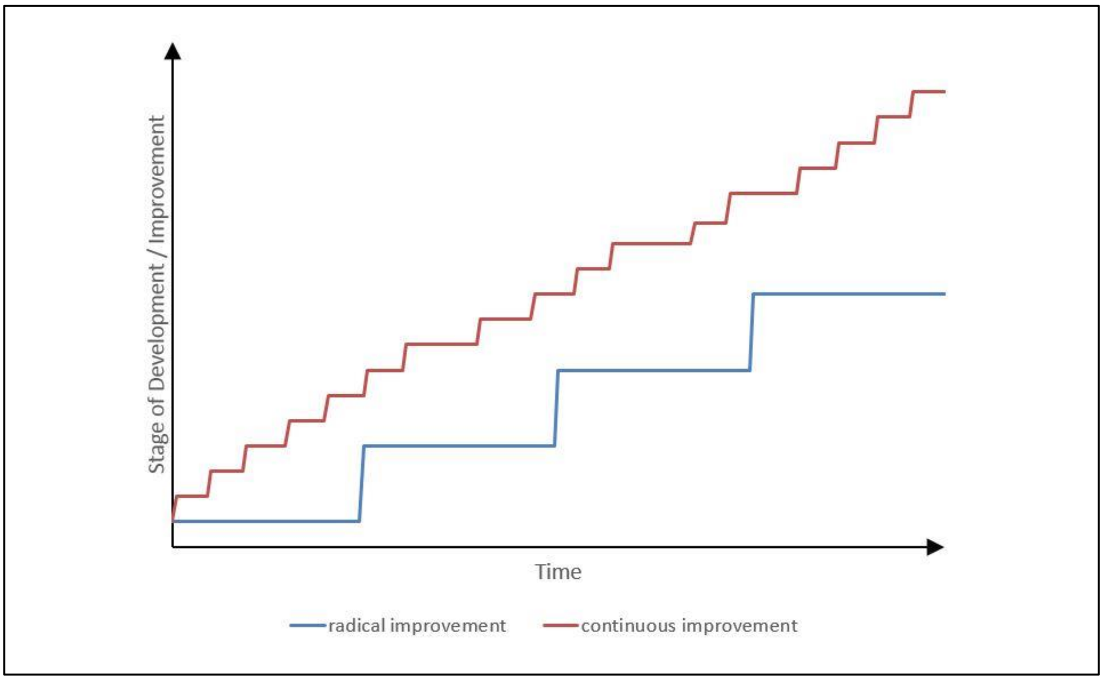

Figure 24: radical (Kaikaku) vs continuous (Kaizen) improvement[93]

2.4.3 Lean Production - Objectives

The roof of the house of lean, the objectives, is the customer focus. The aim is to deliver the best quality by the shortest lead times and the lowest price to the customer. This should be reach by the incremental total elimination of waste.

2.5 Problem identification and solving

Within the Lean Production System there are various tools and techniques for problem identification and solving. Following, a small range of tools and techniques will be introduced shortly.

PDCA

Plan-**D**o-**C**heck-**A**ct is a four-step problem solving cycle for continuous improvement.[94] The cycle can only be completed when the problem is solved and there is no better solution. Thus, it is attempted to always find the best solution for a problem and do not stop too early to be sure that there is a better

[93] Own figure based on Duffy et al. (2010), p. 132

[94] Cf. Kreitner (2009), pp. 482

solution with a higher standard missed. The process starts with the first step – Plan:[95]

- Plan
  - Defining the problem
  - Collecting data of the current state
  - Determine the goal
  - Set a timeframe
  - Develop an approach to reach the goal
- Do
  - Implement the new solution and test it
- Check
  - Collecting data of the new solution
  - Compare the new data with the old standard
  - Check if the goal is reached
- Act
  - Is the solution satisfying?
  - Can the solution be enrolled to other areas?
  - Document the new standard
  - Is a higher standard possible – next cycle

[95] Cf. Kreitner (2009), pp. 482

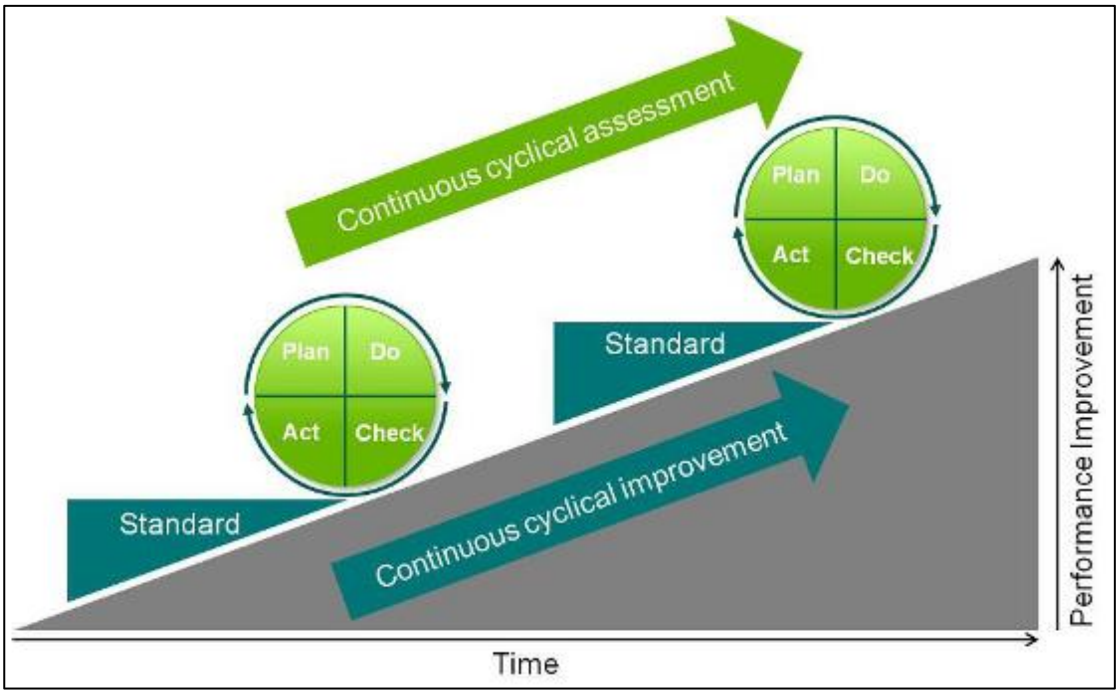

Figure 25: PDAC Cycle[96]

Ishikawa diagram

The fishbone or Ishikawa diagram is used to find the cause of a problem step by step. The initial problem is formulated as a question and represents the head of the "fish". The main cause categories methods, machines, materials, measurements, manpower and mother-nature shape the main fishbones. In the next step subordinate causes are assigned to every main cause and in further consequence these subordinate causes again get causes assigned. This process is finished when a satisfying level of detail is reached and the root cause of the initial problem is determined. For a better overview and decision making, it makes sense to categorize the causes according to their influence or frequency.[97]

- Methods
    - Is the right process used to perform the task?
    - Is the process stable?
- Machines
    - Is there any defect?
    - Is there a maintenance problem?

[96] https://www.roedl-benchmarking.de/_en/pics/PDAC_Cycle.jpg [15.09.2016]

[97] Cf. CNH Industrial training document

    - Is the used technology suitable for the process?
- Materials
    - Is the needed material available for the process?
    - Is the quality okay?
    - Are the tolerances achieved?
- Measurements
    - Are there variations due to the measurement system?
    - Is the accuracy of the system okay?
    - Are the right parameters measured?
- Manpower
    - Is there a lack of know-how or training?
    - Is there a motivation problem?
- Mother-nature
    - Are there environmental issues like rain, temperature, light and so on which influences my process?

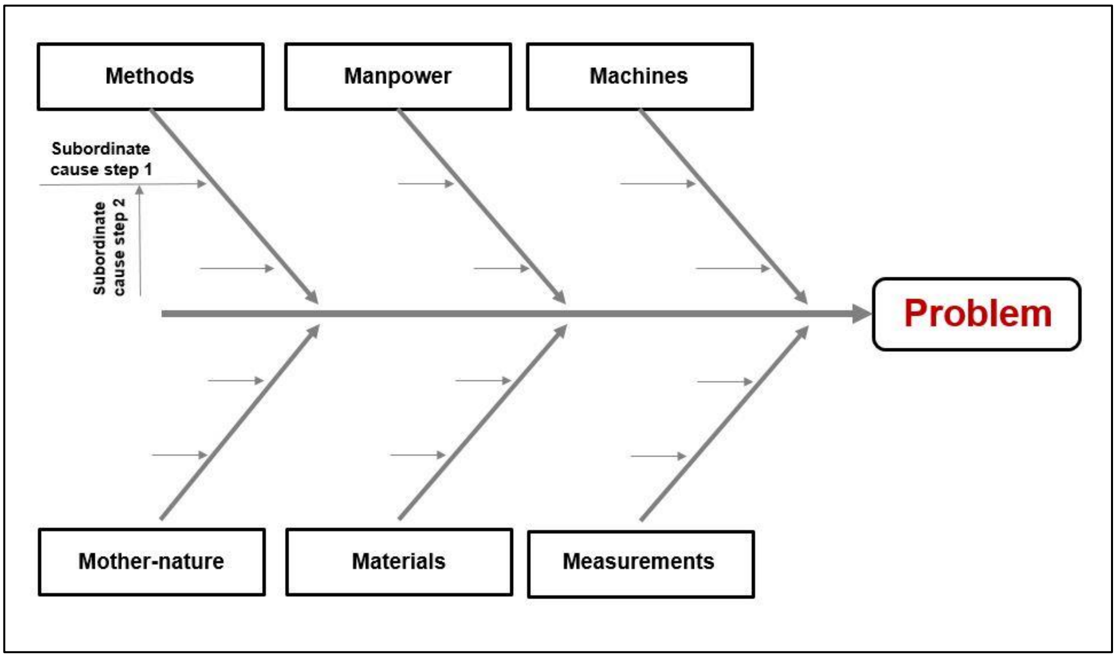

Figure 26: Ishikawa diagram[98]

Value Stream Map

Value stream mapping is used to analyze the material and information flow of a process to find potential losses. Wolfgang Apel states in his research

[98] Own figure based on CNH Industrial training document

(2007):[99] Derived from the TPS, the manufacturing tool called Value stream mapping (VSM), also known as “material and information flow mapping”, investigates and assesses work procedures in a manufacturing tool by the use of lean manufacturing. Identification, demonstration, and reduction of waste, and the creation of flow in the manufacturing procedure are the main goals of VSM. There can be distinguished five basic steps in the creation of a VSM. Firstly, it is necessary to identify the product. Secondly, an existing VSM needs to be created. Thirdly, the present map needs to be assessed and problematic areas identified. This step is followed by the creation of a future state VSM and last but not least, the final plan has to be realized.

The first phase, the identification of the product, deals with the selection of the product, the VSM should concentrate on. When this selection is done, a first VSM of the present process can be created. The evaluation process which follows this step is done by the team, who will then use the information they gain through the evaluation in order to construct a map and analyse this data. Normally, all steps are part of a VSM and for each single step parameters could contain takt time, work in progress, assembly line or machinery set up time, non-operating time, cycle time, quantity of workers, and also number of defect parts. Not only the areas where value is added during the process are identified by VSM, but also the steps where this is not the case. When the evaluation process of the present procedure is completed, it is time for the identification of the problem areas. As soon as these problems are adapted, the creation of a final state VSM is of vital importance. To guarantee a more efficient lean manufacturing procedure, the new ideas need to be worked into the plan.

[99] Cf. Apel et al. (2007), pp. 10

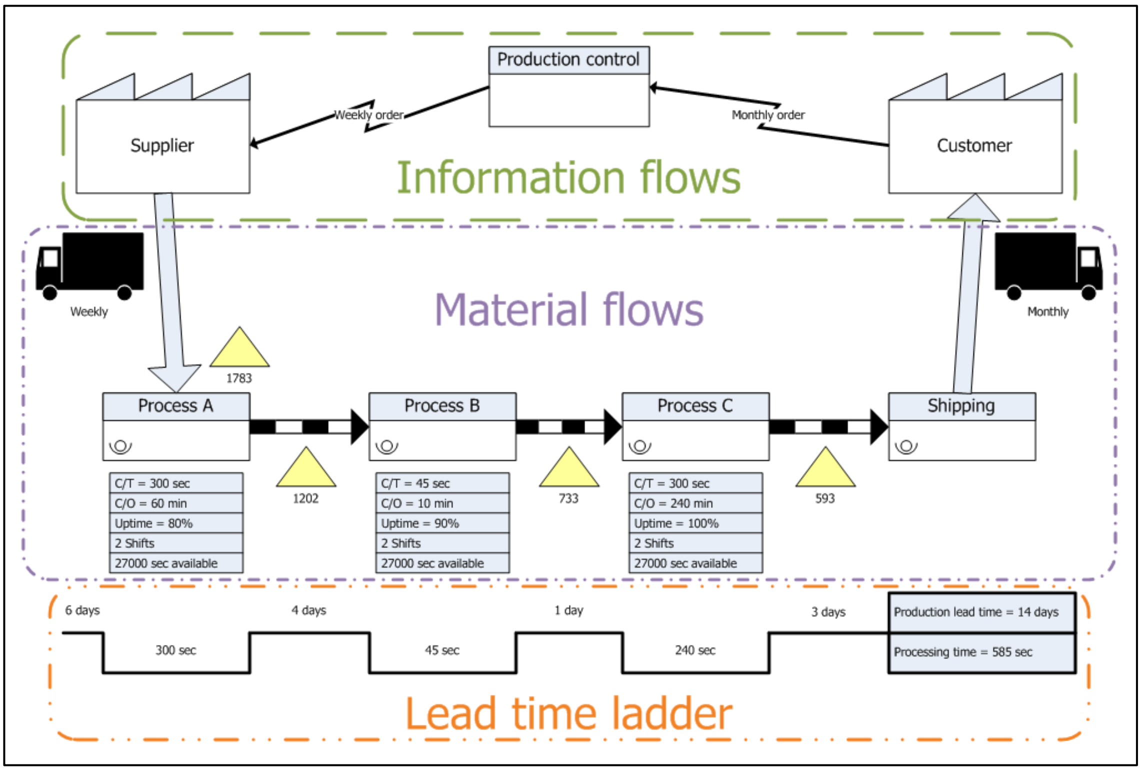

Figure 27: Value Stream Map Example[100]

Spaghetti chart

The spaghetti diagram is a simple, yet powerful tool to visualize movement and transportation. When the transportation paths are visible, it is often easy to spot opportunities to reduce these wastes. A spaghetti diagram is normally hand-drawn on a simple floor layout.[101]

[100]Value Stream Mapping: Lean Manufacturing Principles Part 4 http://blog.cnccookbook.com/2014/08/18/value-stream-mapping-lean-manufacturing-principles-part-4/ [08.09.2016]

[101] Wilson (2010), p. 127

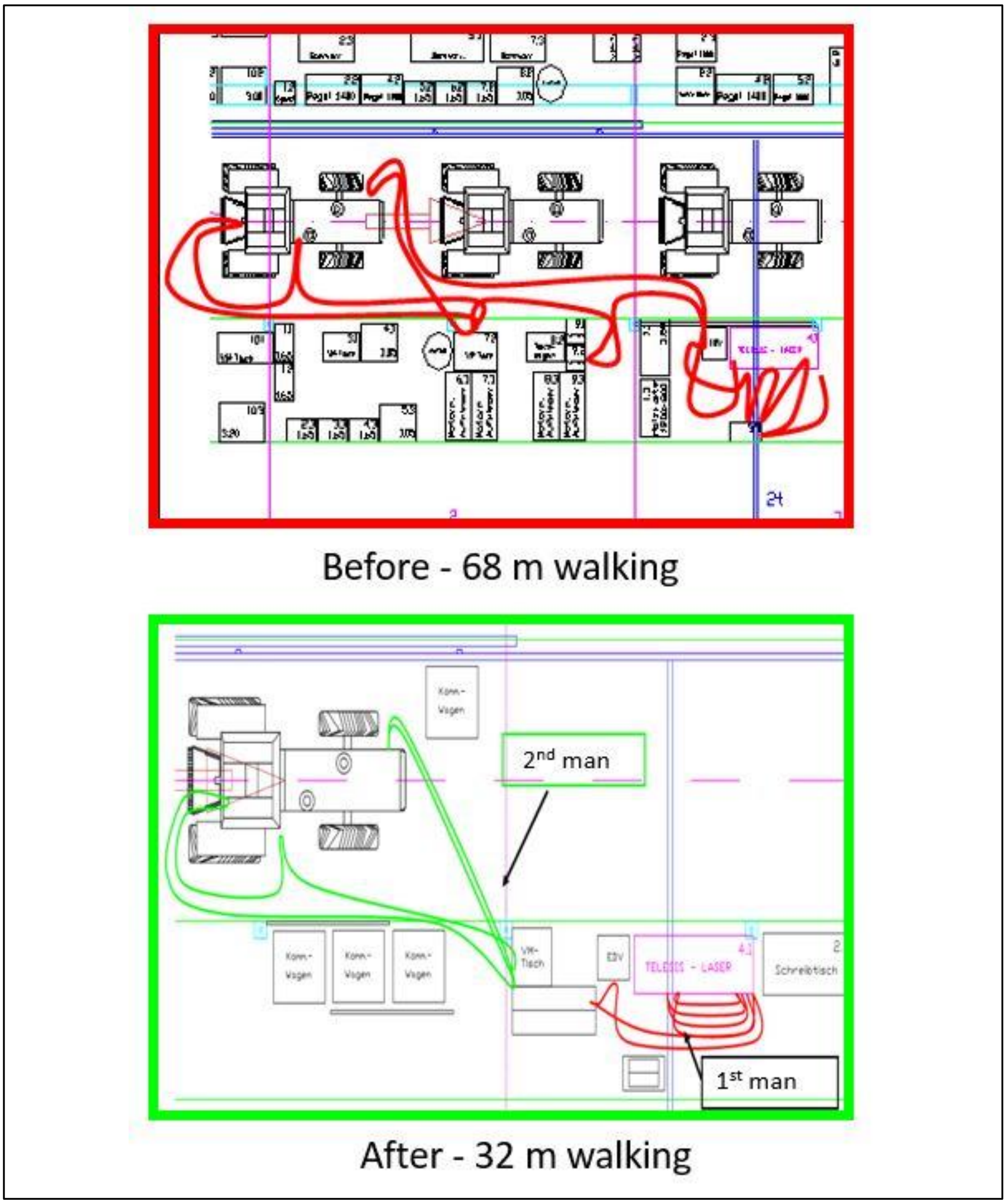

Figure 28: Motion optimization with Spaghetti chart[102]

Golden Zone – Strike Zone Analysis

The “golden zone” and the “strike zone” analyses are used to minimize activities which are not in the best physical moving area of the human worker. To conduct such movement analysis, there is a specific knowledge of the physical efforts and working conditions needed. Figure 29 illustrates the zones

[102] CNH Industrial Österreich GmbH

in which the operator can move easily with a minimal effort and therefore, perform the work step the most efficient way. All tools and parts should be placed in the green “AA” zone and if this is not possible in the yellow “A” or “B” zone.[103]

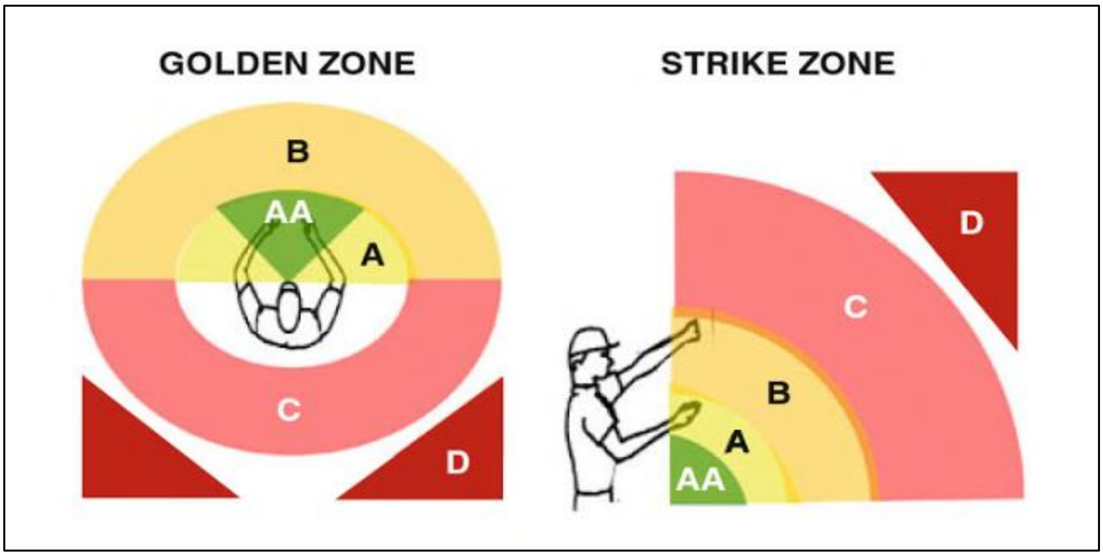

Figure 29: Golden Zone - Strike Zone[104]

	Golden Zone	Strike Zone
AA	All the items can be provided to the assembly point within the field of vision and without changing the heights of the item supply points	All the items can be handled at the right height without raising hands
A	Items are placed within a region three times as big as the assembly unit. Items can be taken by stretching out elbows. Both hands can be used	Items can be handled at the right height but by raised hands
B	Items can be taken by stretching out elbows although they go up beyond shoulder height. Items are placed within a region six times as big as the assembly unit	Items can be handled by raised hands through extending arms and raising elbow over the shoulder
C	Items can be picked up by turning the body	Items can be handled only through considerable extension of body and arms and/or using additional step/ladder, etc.…
D	Items can be fetched by walking	Items are totally out of range and the worker needs specific aids to reach them

Table 1: Strike and Golden Zone areas classification[105]

[103] Cf. Gobetto (2014), p. 95

[104] Gobetto (2014), p. 96

[105] Gobetto (2014), p. 96

2.6 World Class Manufacturing

According to Fiat Group Automobiles, “World Class Manufacturing (WCM)” is: a structured and integrated production system that encompasses all the processes of the plant, the security environment, from maintenance to logistics and quality. The goal is to continuously improve production performance, seeking a progressive elimination of waste, in order to ensure product quality and maximum flexibility in responding to customer requests, through the involvement and motivation of the people working in the establishment.[106]
Summarizing, World Class Manufacturing is in a way the concern internal lean manufacturing program of CNH Industrial separated to 10 technical pillars and 10 managerial pillars.

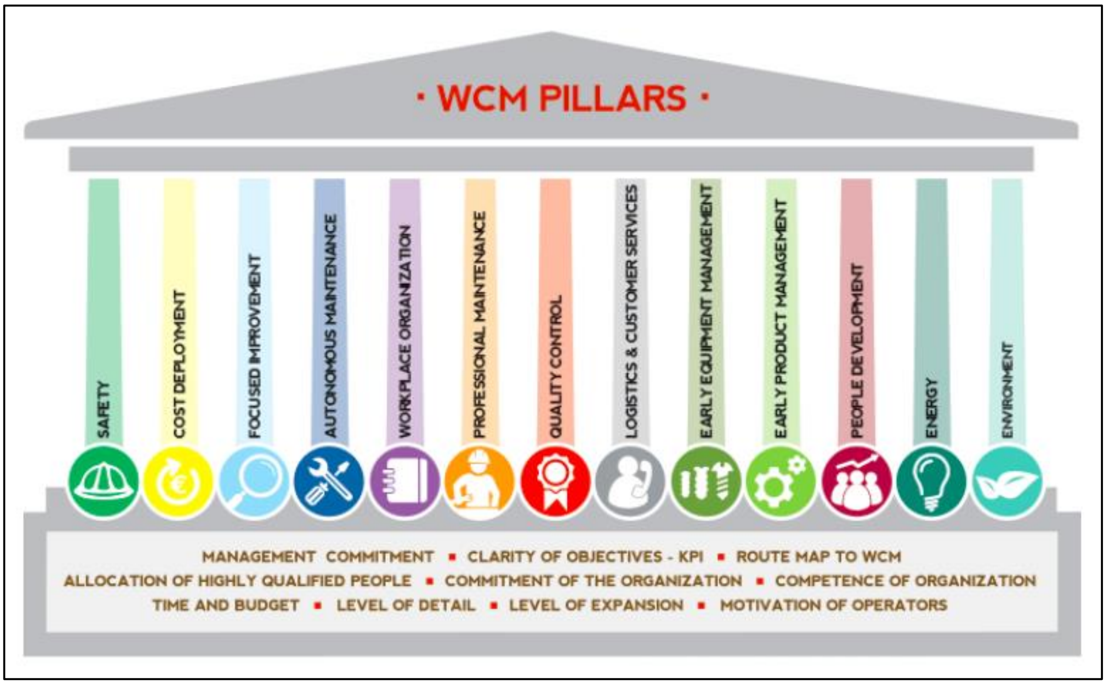

Figure 30: WCM PILLARS[107]

[106] Felice et al. (2013), p. 4

[107] CNH Industrial Österreich GmbH

Technical pillars:

- Safety
- Cost Deployment
- Focused Improvement
- Autonomous Activities
- Professional Maintenance
- Quality Control
- Logistic & Customer Service
- Early Equipment Management
- Early Product Management
- People Development
- Environment & Energy

Managerial pillars:

- Management Commitment
- Clarity of Objectives
- Rout map to WCM
- Allocation of Highly Qualified People to Model Areas
- Organization Commitment
- Competence of Organization towards Improvement
- Time and Budget
- Detail Level
- Expansion Level
- Motivation of Operators

WCM is developed in seven steps for each pillar and the steps are identified in three phases: reactive, preventive and proactive. In Figure 31 an example of a typical correlation between steps and phases is shown, but this correlation could change for each different technical pillar; in fact, each pillar could have a different relation to these phases. The approach of WCM needs to start from a "model area" and then extend to the entire company. WCM "attacks" the manufacturing area. WCM is based on a system of audits that give a score that allows to get to the highest level. The highest level is represented by "the world class level".[108]

Two times a year, this audits take place on each production site of CNH Industrial. With the point system, the production sites are ranked and awarded with medals. For every technical and managerial pillar, maximum 5 points are possible to reach so that the maximum quantity of points possible to achieve is 100. The bronze medal is conferred when a site reaches 50 points or more, from 60 points up to 69 points the site gets the silver status, and above as mentioned previously, the "world class level" with the golden medal is distributed.

[108] Felice et al. (2013), p. 5

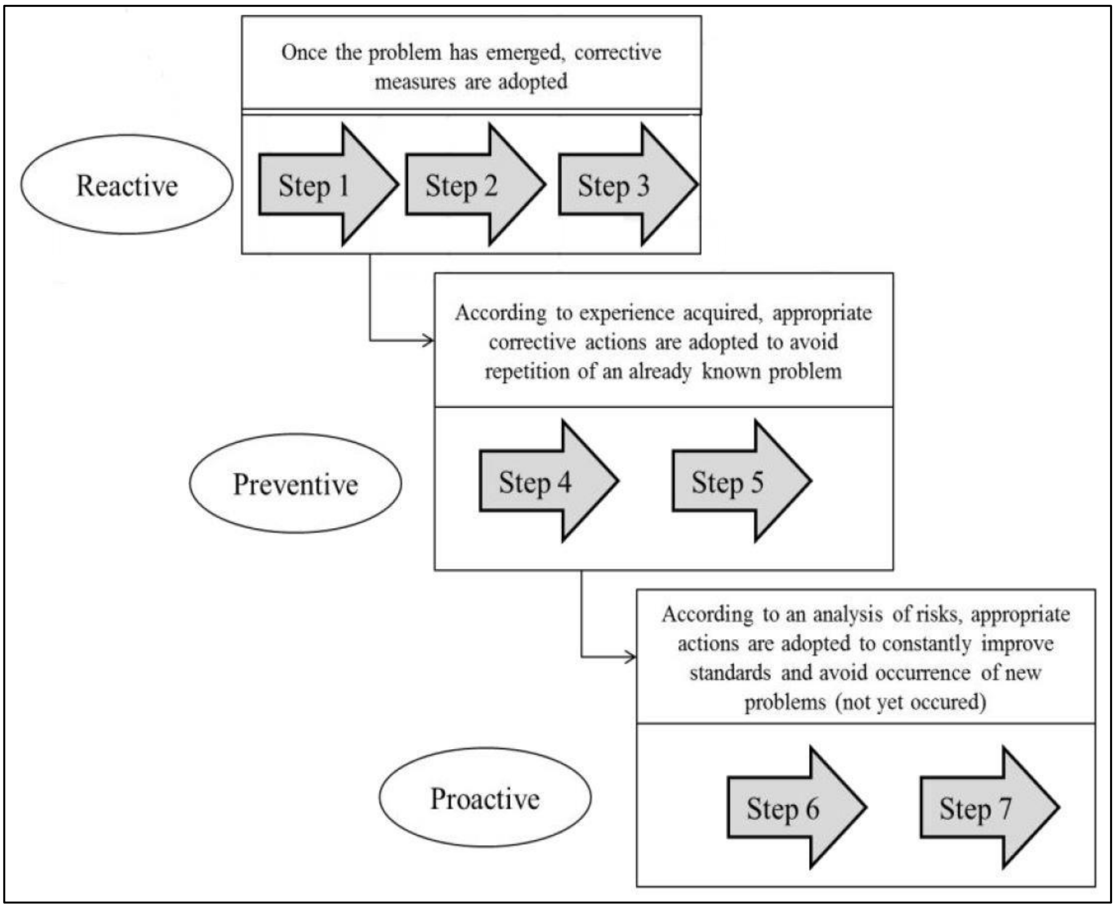

Figure 31: World Class Manufacturing Steps[109]

World Class Manufacturing Steps:[110]

- Step 1 − Initial cleaning
- Step 2 − Re-organize the process
- Step 3 – Initial Standards
- Step 4 – Training in Product Characteristics
- Step 5 – JIT supply of materials
- Step 6 – Improvement of standards
- Step 7 – Standard work sequence

Within the WCM-system, every decision is made based on analysis and objectively measured data. To achieve this, an extensive tool box with training material including various tools and methods is provided, ready to use blanc forms and also trained in workshops. Inside the concern, the knowledge is

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[109] Felice et al. (2013), p. 5

[110] Cf. CNH Industrial training document

frequently documented and shared with, for example, “Best Practice” documents, teleconferences, workshops, and visits of other production sites.

3 Practical Approach

This chapter deals with the practical part of the master thesis to find a solution for achieving the goal of developing an I-Shape assembly line for assembling a tractor driver´s cab. After the currently crocked assembly line, the straight I-Shape is the next logical improvement. Expectations of the I-Shape are an improved material supply of the line, an optimized flow of the cabins, and throughput time reduction. Foundation for designing the new assembly line was the analysis of the current state assembly line. Finally, the economic efficiency of the developed solution was determined to evaluate the outcome.

Figure 32: Cab Assembly Line at CNH Industrial St. Valentin[111]

3.1 Analysis of the Cab Assembly Line

Within the scope of the current state analysis of the Cab Assembly Line at CNH Industrial Österreich GmbH first there was set the region which should

[111] Own picture photographed at CNH Industrial St. Valentin

be under examination. Further on there were analysed and collected existing time data of the single work steps, KPI´s of the assembly line, connections between assembly line and logistics, needed workforce for logistics and assembling, distances of line feeding, current layout of the building and area usage of the assembly line. Figure 33 illustrates the procedure of the current state analysis with the three main activities and the associated sub-activities.

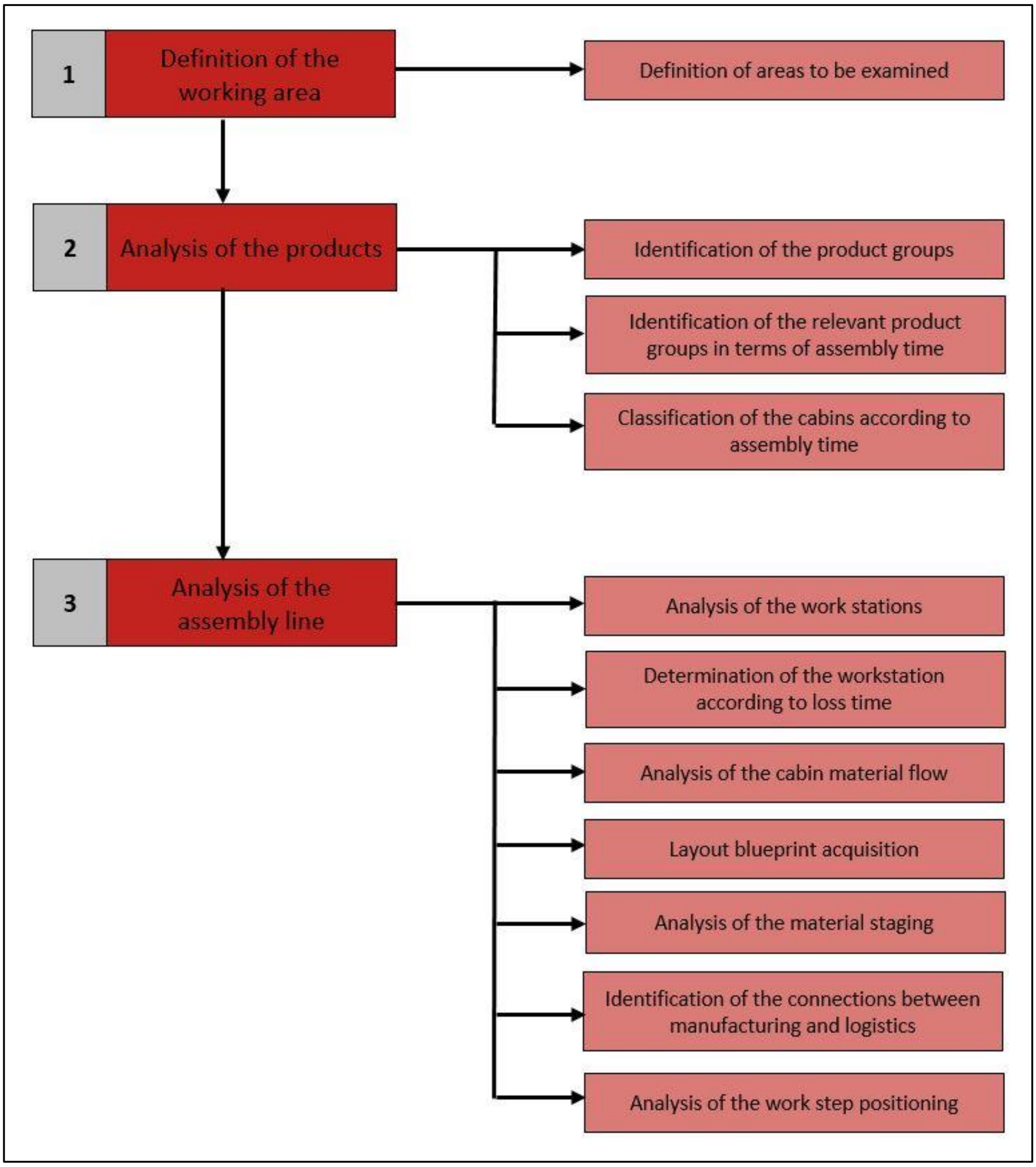

Figure 33: Current State Analysis[112]

[112] Own figure based on current state analysis

3.1.1 Definition of working area

The improvement and optimization of the Cab Assembling in the recent past was started at the end of the line, station 18, and focuses mainly on the workstations with the higher numbers. This leads to a much higher evolution of the workstations from CAB 10 up to CAB 18. For that reason, there was expected the biggest benefit of optimization on the first part of the assembly line, starting with workstation CAB 01 up to workstation CAB 09, including the additional workstations for the APL-Cabs starting at CAB 001 until CAB 003 and all, for this assembly area important pre-assembly stations which are called CAB-PRE-H2-VM2, CAB-PRE-H2-VM4 and CAB-PRE-H2-VM7. According to this aspiration, the focused area was fixed to the above mentioned sector. At the station CAB 001 the APL-Frame (**A**ll **P**urpose **L**ight) (different types are explained in the chapter “Identification of the product groups”) enters the assembly line and mounting processes, which are too time-consuming for the main assembly line. At the station CAB 01 the cabin of the APH-Type (**A**ll **P**urpose **H**eavy) enters the assembly line. From now on all cabin types are assembled on the same assembly line. A short overview about the main activities of the workstations CAB 01 to CAB 09 can be found in Table 2.

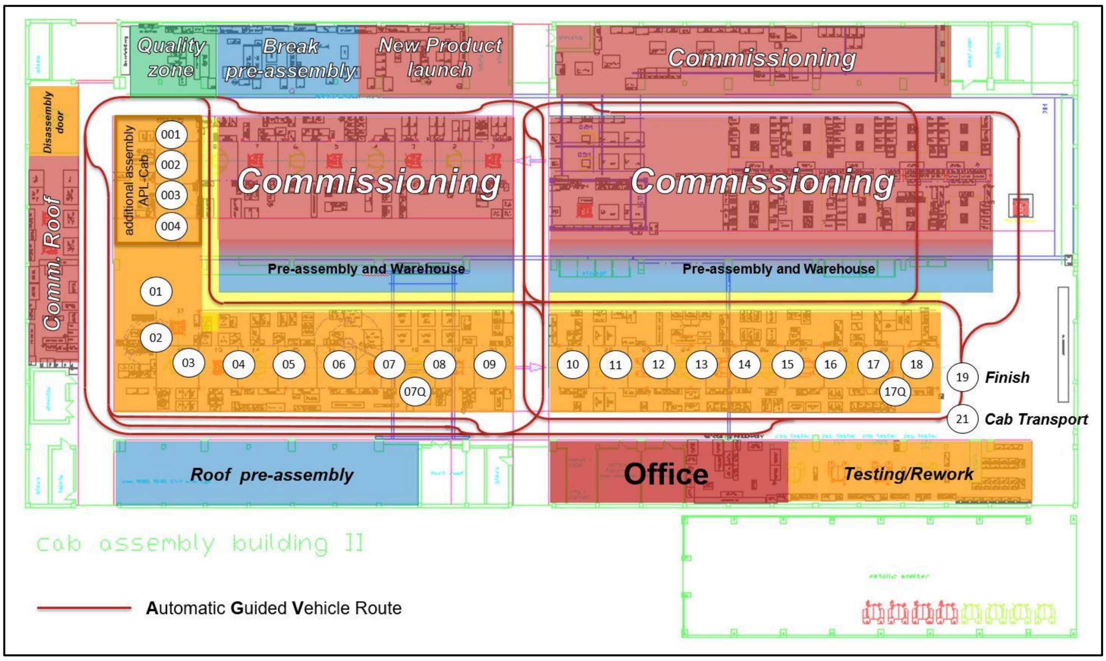

Figure 34: Cab Assembly Hall overview[113]

[113] Own figure based on layout analysis

Workstation	Task description/mounted parts
CAB 01	air conditioner
CAB 02	Servostat, bulkhead
CAB 03	Wiring harness, steering pipes
CAB 04	Wiring harness
CAB 05	Steering post, hand break
CAB 06	Pedals, control device
CAB 07	Relapse, cover steering post
CAB 08	Passenger seat, cover left
CAB 09	Cover right, air filter box

Table 2: Workstation CAB 01- CAB 09 Task overview[114]

3.1.2 Analysis of the products

Currently, there are 20 different Cab frames, which are supplied intragroup by manufacturers form France and Italy, used for assembling cabins of 163 different tractor models that can be ordered in 9366 variants by the customer. For this high number on variants, 9284 parts from 414 suppliers are required. The various number of configuration opportunities leads to an average annual repeatability from the tractors of 1,51 times per year. This fact leads to a high variation of the work steps on the assembly line because there is almost never a cab assembled twice.

Identification of the product groups

Basically, there are two different frames for the cabins, the APL-Frame and the APH-Frame. On closer inspection, there are three variants of the APL-Frame currently in use. The APH-Frame is mounted in 17 different subversions.

[114] Own table based on layout analysis

Figure 35: APH Cab Frame[115]

Figure 36: APL Cab Frame[116]

Identification of the relevant product groups in terms of assembly time

For the defined work area, 378 individual working steps or working activities are listed in Assembly Planner, the Production Planning Software used at CNH Industrial Österreich GmbH. Since an analysis of all working steps would have exceeded the scope of this thesis, the working steps with the highest impact on the production have been filtered out systematically. First step, to get an

[115] Own picture photographed at CNH Industrial St. Valentin

[116] Own picture photographed at CNH Industrial St. Valentin

overview which cabin types are having the biggest influence on the production of the cab assembly line an ABC-Analysis of the most important cabin types, according to assembly time per year, was carried out. [117] To get a reproducible result, the assembly time of each of the as “important” defined cabins had to be calculated. Since the working steps in the Assembly Planner are weighted according to their frequency, some working steps are listed but never occur and there was no opportunity to generate an assembly time report for the single cabin types, therefore, another solution was necessary. In discussion with an expert from production, it was decided to use the possibility of Assembly Planner to generate a report from 1st of January 2016 to 1st of August 2016 for each cabin type with all working steps which occur in this time frame. By this solution it was expected to acquire all important working steps and exclude old or not used working steps which are still listed in the database. Since this report only contains the identification number of the working step and not the working times, there had to be generated a second report including every work step which is listed in the database. Subsequently, to get processibility data for every single cabin type, these two reports were imported to Microsoft Excel and further processed with a customized macro. Consequently, it was possible to calculate the total assembly time for each cabin type per year and generate an ABC-Analysis according to these times. By this Analysis it was possible to classify the different cabins and make a decision which one had to be investigated further.

Procedure of creating the ABC-Analysis:

- Calculation of the total assembly minutes per cabin type
- Calculation of the total assembly minutes for all cabin types
- Accumulation of the shares
- Allocation of the cabin types to the groups A, B and C
    - A-Cabins: 80% of the total assembly time
    - B-Cabins: 15% of the total assembly time
    - C-Cabins: 5% of the total assembly time

The result of the ABC-Analysis shows that 80% of the assembly time per year can be assigned to 42,86% of the different cabin types. In further consequence, it was decided also to investigate the B-Cabins to obtain a more

[117] Defined with Michael Czelecz CNH Industrial (04.05.2016)

accurate result. Table 3 shows the ranking of the different cabin types according to the non-value adding activity times per year and the "A.-", "B.-" or "C-classification" used for the ABC-Analysis which is illustrated in Figure 37.

No.	Type	NVAA per Year [min]	SVAA per Year [min]	VAA per Year [min]	Σ [min]	Classification	Percentage of total number of cabin types
1	APL32	103956	132995	37961	274911	A	42,86%
2	CCM T4B	69067	150577	40843	260486	A	
3	SWBCV T4B	65591	139320	38131	243042	A	
4	APHG4	44597	98340	26031	168969	A	
5	APHCV	43677	93102	25027	161806	A	
6	SWBG T4B	34466	71120	19599	125185	A	
7	CCM HD	25306	53059	14793	93158	B	21,43%
8	APH4	22377	53995	13445	89817	B	
9	PUMA T4B	17723	37409	10233	65365	B	
10	APH3	10900	27205	6701	44806	C	35,71%
11	PUMAG	6230	13831	3637	23698	C	
12	SWBG	4226	9264	2459	15950	C	
13	APHCV T4B	4155	8646	2395	15196	C	
14	CCM	2774	6259	1660	10693	C	
	Σ	455045	895122	242916	1593083		

Table 3: Division of the assembly time[118]

[118] Own table based on assembly time analysis

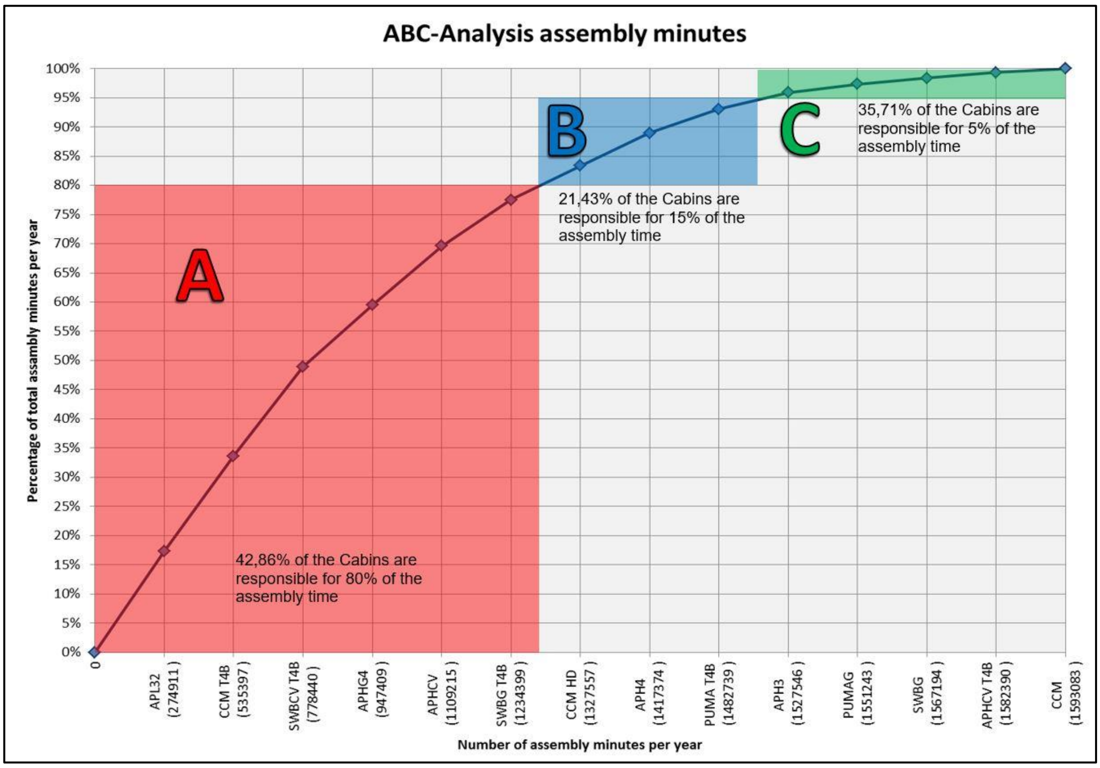

Figure 37: ABC-Analysis of the cab types[119]

Determination of the workstations according to loss times

With the previously produced data in Microsoft Excel it is possible to generate a table for every cabin type. This makes the workstations with the highest NVAA (Non Value Added Activity) visible and gives the possibility to rank them (see Table 4). This analysis has also shown that there is a large proportion of SVAA (Semi Value Added Activity) and, therefore, there has been generated a ranking (see Table 5) as well.

[119] Own figure based on assembly time analysis

CCM T4B				
NVVA Ranking	Workstation	NVAA [min]	SVAA [min]	VAA [min]
1	CAB-09	9,24	16,48	4,03
2	CAB-08	5,46	10,32	2,47
3	CAB-07	4,92	13,23	4,73
4	CAB-03	4,68	9,42	4,01
5	CAB-PRE-H2-VM4	4,04	5,12	2,49
6	CAB-01	4,00	7,70	2,07
7	CAB-02	3,89	6,38	1,32
8	CAB-06	3,74	6,71	2,35
9	CAB-04	2,63	10,27	1,42
10	CAB-05	2,50	7,98	0,98
11	CAB-PRE-H2-VM2	1,35	7,67	1,61
12	CAB-00	0,00	0,00	0,00
13	CAB-PRE-H2-VM7	0,00	0,00	0,00
	∑	46,45	101,26	27,47

Table 4: Station rated by NVAA[120]

CCM T4B				
SVVA Ranking	Workstation	NVAA [min]	SVAA [min]	VAA [min]
1	CAB-09	9,24	16,48	4,03
2	CAB-07	4,92	13,23	4,73
3	CAB-08	5,46	10,32	2,47
4	CAB-04	2,63	10,27	1,42
5	CAB-03	4,68	9,42	4,01
6	CAB-05	2,50	7,98	0,98
7	CAB-01	4,00	7,70	2,07
8	CAB-PRE-H2-VM2	1,35	7,67	1,61
9	CAB-06	3,74	6,71	2,35
10	CAB-02	3,89	6,38	1,32
11	CAB-PRE-H2-VM4	4,04	5,12	2,49
12	CAB-00	0,00	0,00	0,00
13	CAB-PRE-H2-VM7	0,00	0,00	0,00
	∑	46,45	101,26	27,47

Table 5: Station rated by SVAA[121]

[120] Own table based on time analysis

[121] Own table based on time analysis

With this knowledge it was possible to go one step closer and generate a list. For the first three stations listed in the tables this list contains the seven work steps with the highest NVAA respectively SVAA which should be investigated closer. (see Figure 38)

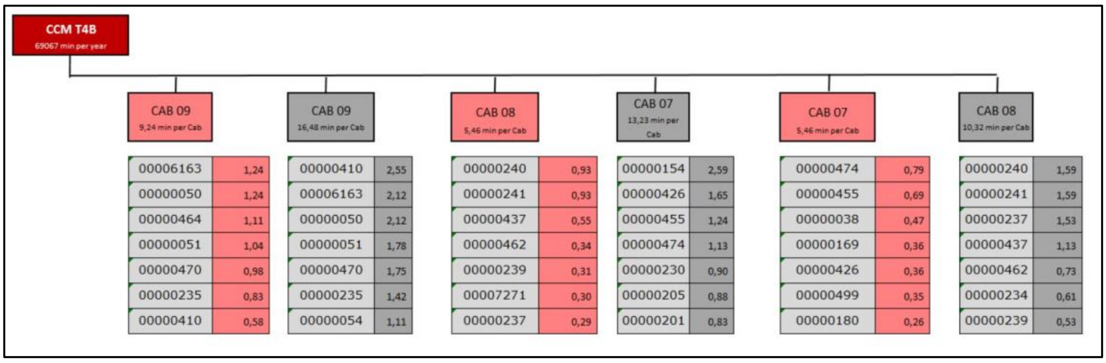

Figure 38: Work Steps to Investigate[122]

The evaluation with the Methods-Time Measurement - Universal Analysing System data short MTM-UAS from the Assembly Planner Time Report was done in the first step (see Figure 39) to get a feeling which elements of the activity are responsible for the high NVAA-amount. Afterwards, the single work steps had been observed directly at the assembly line.

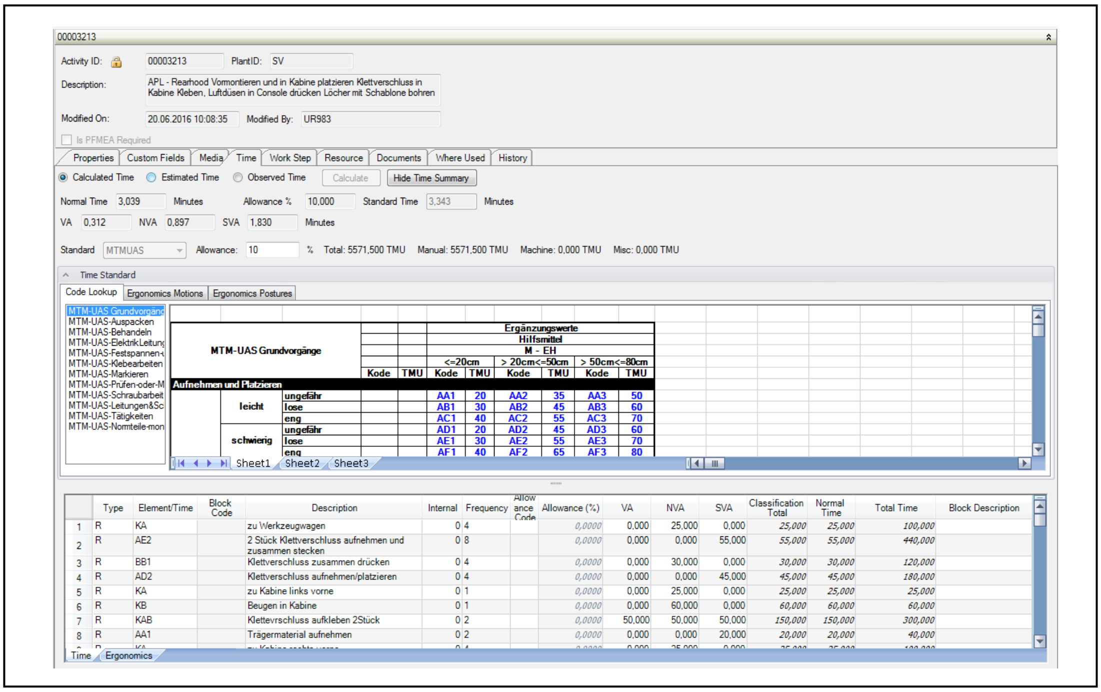

Figure 39: MTM-UAS Time Report[123]

[122] Own figure based on work step time analysis

[123] Own figure based on CNH Industrial time analysis

3.1.1 Analysis of the production

After the product analysis, the study of the production, to be more accurate the study of the assembly line, takes place. Therefore, the workstations, the cabin material flow, the work step positioning, and material staging has been analysed. Also the blueprint of the assembly line has been updated for the previously defined operating area of this project.

Analysis of the workstations

The workstations have a length form 4,5 meters up to 5,5 meters and a width of 3,8 meters. This is visualized with yellow markings on the floor. For an easy transport and ideal positioning of the cabins on the trolleys through the station, a guidance is mounted on the ground. The material and the tools are placed to the left and the right of the assembly line on defined areas. Compressed air, electricity, and if it is necessary a network connection is supplied by the overhead beams which are also carrying the lighting (see Figure 40). Due to the variation of the work content between the different cab types, there is no fixed takt time and the workers are floating with the product over the workstation borders or buffering the cabs at the end or beginning of the workstation. The tools have a defined position on the tool trolleys or on the material shelves along the station. For an easy mounting the trolleys can be carried directly to the place where the assembly process takes place.

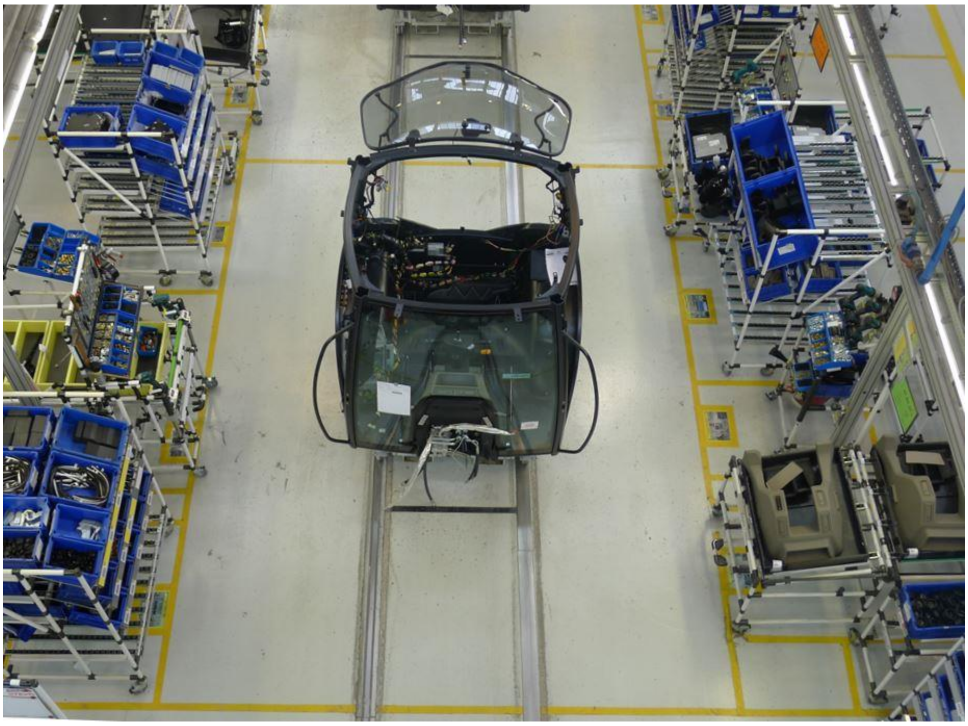

Figure 40: Workstation[124]

Analysis of the cabin material flow

Before the frames enter the assembly area, they are mounted on a transport frame with wheels, thus the cabin can be shoved during the whole assembly process. The cabin frames of the APH-series are delivered with windscreens and doors. The first step after entering the hall is dismounting the doors for a better accessibility during the assembly process. The doors are stored on a trolley and delivered just in time to the assembly line where they are mounted to another cabin of the same type. After the door disassembling, the cabin frame is transported by use of an elevator to the first floor of the hall, where the quality check and small rework is done, if required. The same steps are also done for the APL-series cabins with the difference that they are delivered without doors and therefore no dismounting is necessary. After a quality check, the cab frames are stored on the first floor and delivered just in sequence to the start of the assembly line with another elevator located at the other side of the assembly hall. The APL-series frames enter the assembly line at station

[124] Own picture photographed at CNH Industrial St. Valentin

CAB 001, three stations before the main assembly line starts where the APH-series frames enter the assembly line. From this time on, the cabins are shoved from one station to another until the finished cabin leaves the line and is transported with a forklift to hall 6, where the cabin is mounted to the chassis of the tractor.

Layout blueprint acquisition

In this phase, the layout blueprints of the building, provided by CNH Industrial Österreich GmbH, has been updated to the current state of April 2016. Special attention was payed to the defined work area from CAB 001 till CAB 09 (see Figure 41). The other parts of the building H2 had been, due to time reasons and minor importance for this project, skipped. This collection of data was done with a tablet computer and the applicable software AutoCAD 360. Since the possibilities of the software for the tablet computer are very limited, the refining and annotation had to be done on a personal computer with the required software.

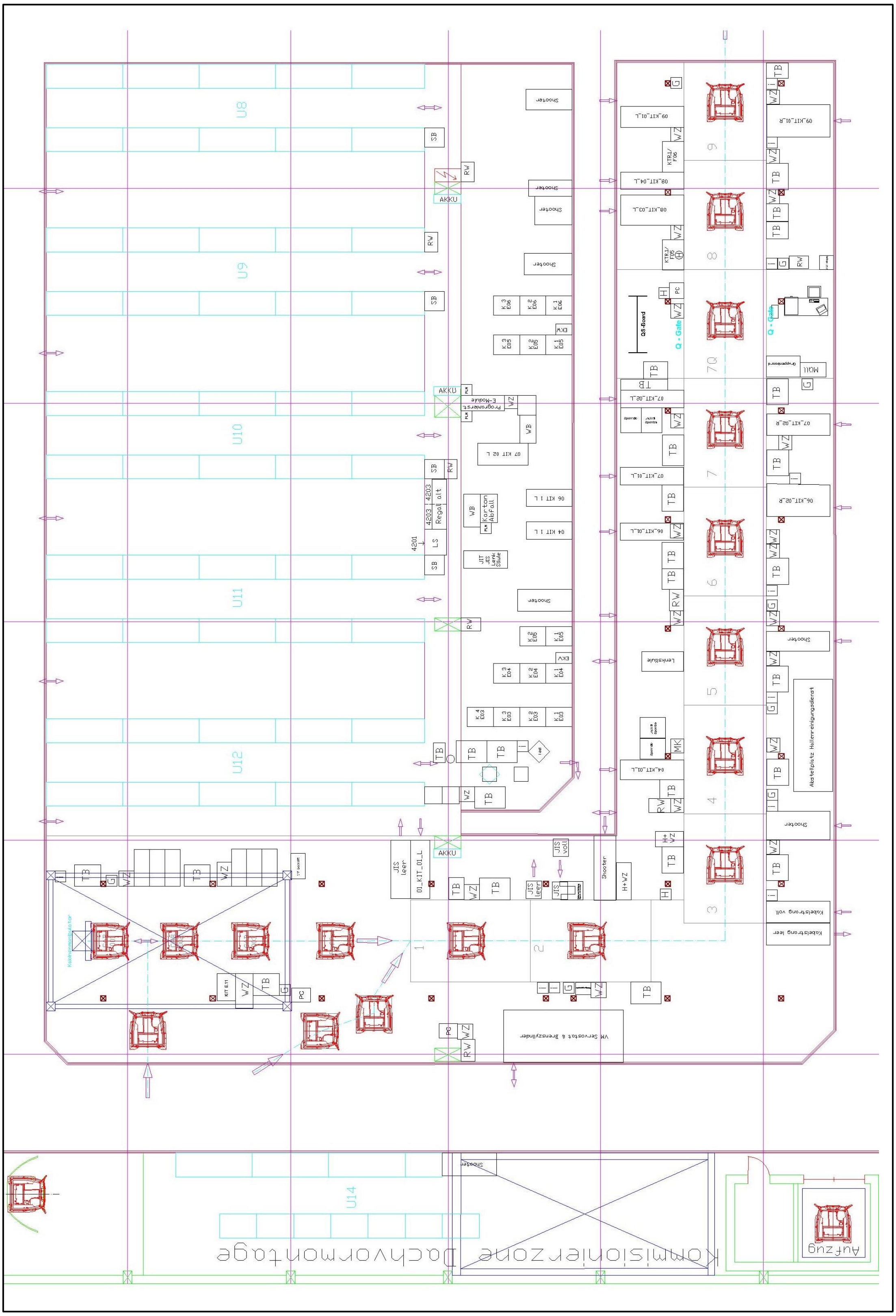

Figure 41: Initial State of the Assembly Line[125]

[125] Own figure based on layout analysis

Analysis of the material staging

For a continuous assembly process, it is necessary that the worker has the right parts when needed. Therefore, the parts are stored on the lateral borders of the assembly line. To avoid redundant walking of the worker to grab up the parts, the stored material is as close as possible or transported directly to the place of use. The material staging on the assembly line at CNH Industrial Österreich GmbH works basically with four systems:

- The needed parts for assembling are commissioned in kitting-boxes already sorted in the order the worker uses the parts. At the assembly line, the kitting-boxes are stored in FIFO-gravity-shelves, in CNH-Industrial-intern-language called shooter. This system is used for expensive parts which have a big variation due to the high complex product mix.

Figure 42: Shooter with Kitting Boxes[126]

- Small parts−like nuts and screws−are stored in carry caddies and refilled, as needed at the supermarket refilled. The caddies are normally stored at the tool trolleys.

[126] Own picture photographed at CNH Industrial St. Valentin

Figure 43: Tool Trolley with Material Carry Caddie[127]

- The parts are stored in a shelf with a 2Bin-System or Kanban boxes. This is used for parts which are cheap and high frequently used (e.g. screws or nuts). When the box is empty, the worker puts the box on a defined area on the gravity-shelf and a logistic worker replaces the box when he comes by during his next milk run.

Figure 44: Shelf with 2Bin Boxes[128]

[127] Own picture photographed at CNH Industrial St. Valentin

[128] Own picture photographed at CNH Industrial St. Valentin

- Pre-mounted assemblies are delivered with a special trolley. The trolley can be used for support reasons during the pre-mounting (steering-assembly APL, see Figure 58), assists the assembly operator installing the parts in the cabin (APH main harness, see Figure 59) or just functions as a shelve on the assembly line (steering-assembly APH, see Figure 60).

Identification of the connection between manufacturing and logistics

The connection between manufacturing and logistics the material transport, happens by three different systems.

- Manually, the logistic worker brings the kitting-boxes stored on a FIFO-gravity trolley or the special trolley, directly to the workstation.

Figure 45: FIFO Gravity Trolley[129]

- With an electric tractor, a logistic worker drives with a defined route and brings the parts from the logistic zone to the assembly line.
- With an Automated Guided Vehicle, which collects the kitting-boxes in the logistic zone automatically, delivers them to the workstation, and unloads them autonomous or gives an acoustic signal which tells the

[129] Own picture photographed at CNH Industrial St. Valentin

assemblyman to grab up the part or a special trolley. After hooking up the empty, trolley he confirms the process and the AGV resumes his round.

Figure 46: Automated Guided Vehicle[130]

Analysis of the work step positioning

For the re-planning of the layout it is necessary to shift, outsource, and combine some work steps. Therefore, it is important to have a solid overview of the standalone and linked work steps.

- Shifting work steps means to reposition a work step to another position in the assembly sequence where it can be performed more effective or achieve a better material supply.
- To outsource a work step or a group of connected work steps means to collect work steps in a pre-assembly station where the worker has better conditions for assembling. This is reached by an optimal positioning of the parts, which leads to less walking, the best possible position of the work area in the Golden Zone on a special trolley or special mounting box.

[130] Own picture photographed at CNH Industrial St. Valentin

- To combine work steps or work stations if the assembling of these stations can be done simultaneously.

3.2 Planning of the I-Shape

After the analysis of the current state of the cabin assembly line, the planning of the new layout, based on the generated data, was done. The first step in this phase was to build group-work-steps which can be relocated into a pre-assembly. The second step was to combine work stations to save assembly area and decrease the amount of walking between the stations. After this, the re-planning of the I-shape layout was done and refined in some iterations.

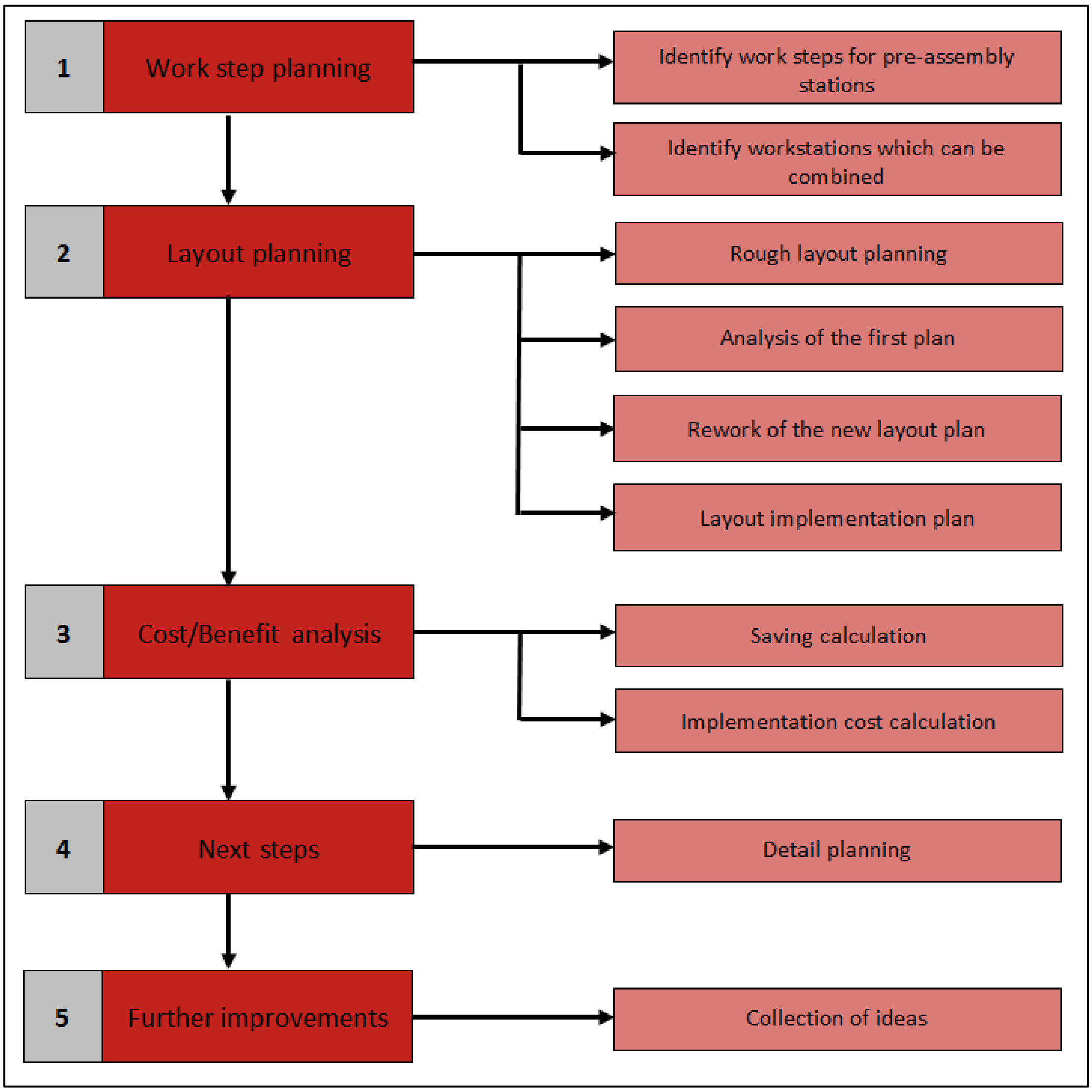

Figure 47: Practical Approach Procedure[131]

3.2.1 Work step planning

Within this project phase, work steps which can be shifted to a pre-assembly station and workstations which can be combined have been identified.

Work step groups for pre-assembly stations

During the analysis, a list of work steps which can be shifted to pre-assembly stations was generated. Based on this list, groups of work steps which can be summarized in pre-assembly stations had been created. The group with the

131 Own figure based on practical approach procedure

highest potential contains the work steps for the steering column assembly for the APH-series. Currently, there exists a pre-assembly station for the APL-series steering column assembly. It is pre-mounted on special trolleys and carried with these trolleys directly to the assembly line. The mounting of the pre-assembled steering column in the cabin is done with a special lifting device. With small modifications, this device also can be used for the APH-series steering column assembly. For the APH-series, it would be useful to develop a separate pre-assembly station with customized trolleys.

Workstation combining

When the work steps which are listed in Table 6 are shifted to a pre-assembly station, there will be a lot of free area on the left side of the station of CAB 05 and CAB 06. At CAB 05, the main activity is to install the handbrake in the cabin. At CAB 06, primarily the PTO-lever (Power Take-Off shaft) and the levers for the remote valves unit are mounted. These two work steps are located on the opposite on the left and right side of the cabin. Therefore, it is possible to combine the workstations CAB 05 and CAB 06 and perform these operations simultaneously. In this case, the material shelves of CAB 05 have to be located on the left side of the assembly line what has a positive effect on the material supply as well, because the parts of CAB 05 could be delivered directly form the logistic zone without an AGV. (see Figure 48)

Work steps pre-assembly Steering assembly group			
Station	**AGA**	**Description**	**Time** [min]
CAB05	00002363	mounting steering post	1,63
	00003665	pre-assembling switch bracket	1,23
	00000475	mounting clutch sensor	1,30
	00000465	mounting pedals	3,14
	00000415	adjusting pedals	1,82
	00000492	mounting switch bracket	2,20
CAB06	00006674	mounting edge protection	0,10
	00000455	mounting ignition lock	2,42
	00000499	mounting upper column cover	1,10
VM 2		pre-assembling steering post	10,63
		∑	25,57 min

Table 6: Work steps for APH-Steering pre-assembly[132]

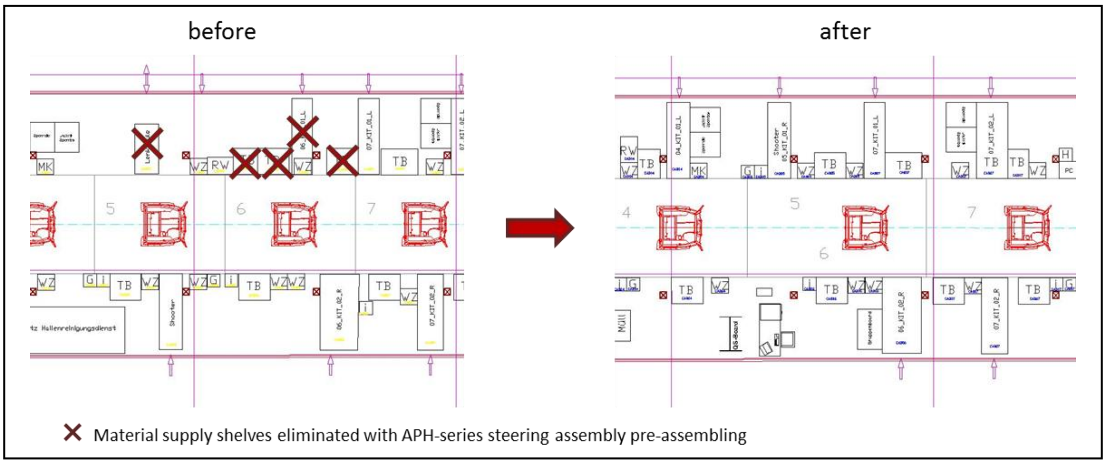

Figure 48: Material Shelve arrangement of CAB 05-CAB06[133]

3.2.2 Layout planning

For the planning of the new layout the most important goals are to improve the walking distances, to shorten the throughput time, and enhance the material supply. The first step with the focus on these aims was a rough planning of the layout with the knowledge and developments of the analysis and the planning of the prior steps in the planning phase.

[132] Own table based on work step analysis

[133] Own figure based on workstation analysis

Rough layout planning

For the APL-series cabin, the main harness and the ventilation conduit have to be mounted on the outside of the cabin floor, what is done at the stations CAB 001 till CAB 003. On these three stations only cabins from the APL-series are mounted. Therefore, the cabin is lifted up and swivelled to the side by a special lifting and swivelling device, (see Figure 49) to enable a save and qualitative working. The manipulating and the mounting of the parts takes about 30 minutes per cabin. By this fact, it is not reasonable to integrate this station in the main assembly line since only about every fourth cabin is from the APL-series and the extra 30 minutes would cause a heavy unbalancing of the line. For this reason, it was decided to keep the stations CAB 001 till CAB 003 as an external assembly area which should be located as close to the elevator as possible, which brings the cabins back to the ground floor after the quality check, to minimize the cabin transport during production.

Figure 49: Lifting Device[134]

[134] Own picture photographed at CNH Industrial St. Valentin

The analysis has shown that at these three APL-series stations generally one worker is operating and there is also a lot of unused space. As part of the assembly line optimization, the APL-series should be downsized to two stations and the material supply updated to the latest standard according to the WCM-program. For reducing the transport of the cabin before assembling, what is done by manually pulling and takes therefore a lot of time, the whole pre-mounting stations for the APL-series should be located as close as possible to the elevator. In the first layout plan, the area for the roof pre-assembly commission zone and the APL-series pre-assembling stations are swapped. The material supply for the APL-series pre-assembly station can be done directly from the commissioning zone U14 what ensures short material transport. For the main assembly line, the work steps for the APH-series steering column are shifted to a pre-assembly station and as mentioned before the stations CAB 05 and CAB 06 are combined. The station CAB 7Q had been a quality check station and is currently not in use and therefore has been removed from the line. By eliminating these two stations it is already possible to plan a straight layout of the assembly line with the CAD-software (AutoCAD). The APH-steering column pre-assembly station should be located on the free area, where the station CAB 01 and CAB 02 of the main assembly line had been before. Also the pre-mounting of the remote valves and the gear shift lever finds place in this area. For a satisfactory material transport from the pre-assembly station to the assembly line, new kitting boxes are necessary; moreover, updating the station to the latest WCM standard should be considered. On the remaining free area between the new located roof pre-assembly commission zone and the APH-series steering column pre-assembly station a new rack for logistic activities is planned. Another logistic zone is planned on the previous location of the remote valves pre-assembly station. (coordinates A3 at the blueprint)

Analysis of the first layout plan

After this first rough planning of the layout (see Figure 50) the blueprint had been sent to the logistic department to get a feedback about the advantages and disadvantages of the new layout regarding to logistic needs.[135] The main

[135] Based on interview with Christina Wurm - Logistic engineer at CNH Industrial Österreich GmbH

content of the feedback had been the new disposal of the parts within the logistic zones and some suggestions to improve the new layout further.

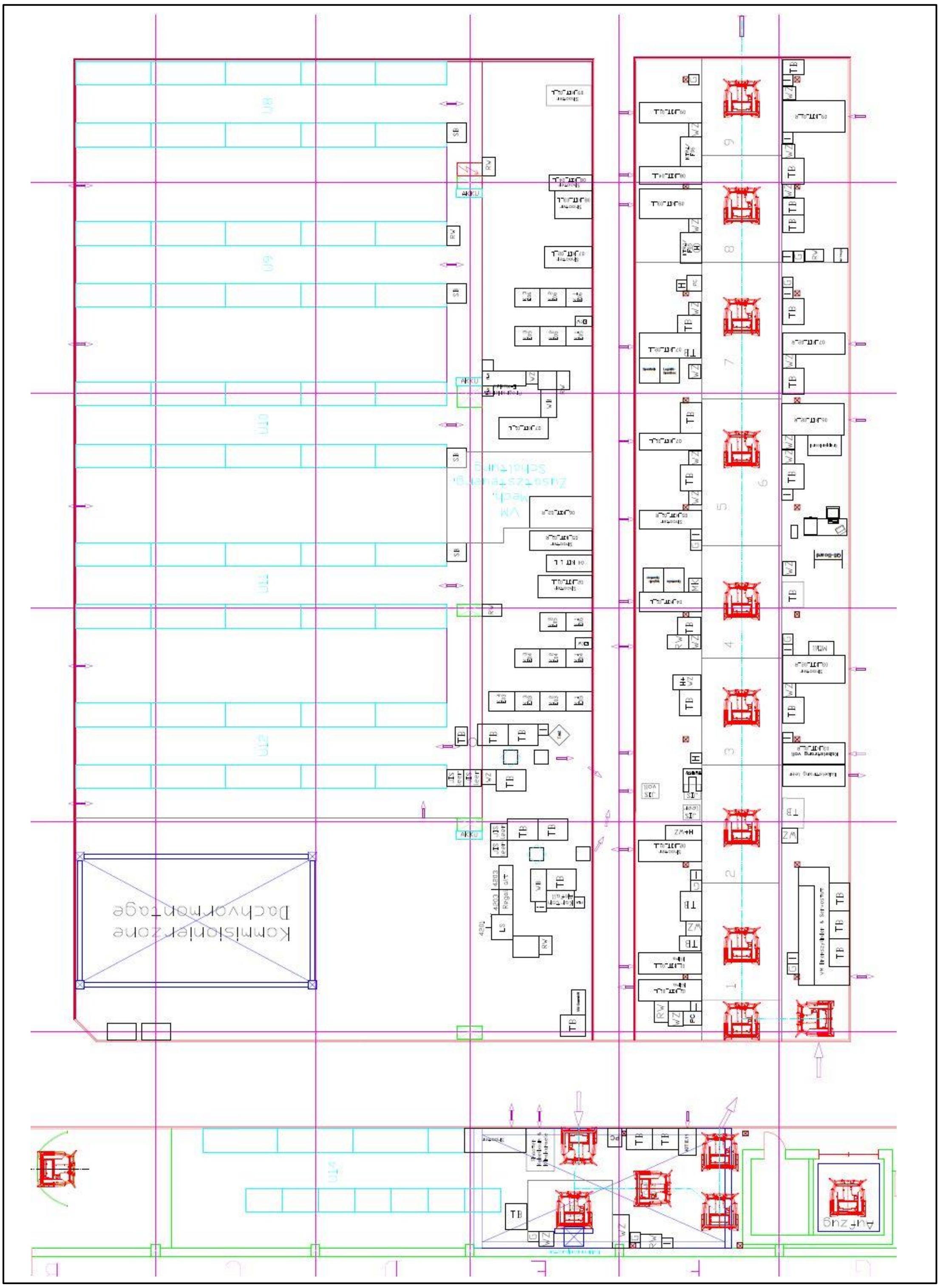

Figure 50: First Layout Blueprint[136]

[136] Own figure based on layout replanning

Rework of the new layout

With the knowledge of the analysis and the feedback of the logistic department, the new layout had been reworked to fit the requirements the best possible way. The roof pre-assembly commissioning zone was shifted to the area A3 of the hall to make a bigger logistic zone in the previous position possible. By this activity, it is possible to ensure a short and flexible material transport to the APH steering column pre-assembly station and the remote valves pre-assembly station without the need of any transport vehicle. The main wiring harness is delivered to the assembly line on the left side. By this it is possible to supply the trolley directly from the logistic zone what saves every APH-series cabin about 0,53 minutes for changing the trolley of the AGV. Besides, it is easier to overrun the guide rail which is mounted on the floor from the left, side because it is lower and therefore as a consequence the process gets more stable.

Implementation plan

With the refined layout, the planning of the implementation had been started. For a smooth changeover from L-Shape to the I-Shape, the assembly process should not be influenced by the transformation activities. Therefore, it was the target to develop an implementation plan which can be executed after the working shifts, respectively on weekends step by step. The most time-consuming activities are the relocating of the crane for the roof pre-assembly commissioning, the transfer of the lifting and turning device for the APL-cabin and similar activities what are realized by external contractors. These activities are the most challenging and limiting activities for a transformation to the new layout. For that reason, the time assessment regarding to this was created with the factory planning specialist of CNH Industrial. The outcome was an implementation plan with five main phases what can be realized within three weeks. Important for the successful outworking is a detailed planning of each of the five main phases in advance.

The five implementation phases:

- Phase one mainly contains the straightening of the assembly line. This requires that the pre-assembly station for the APH-series steering column is developed and useable. Then the main assembly line could be arranged in the straight I-Shape and the APH-series steering column pre-assembly station will be located in its final position. With the corresponding preparation this could be done on Friday afternoon and on Saturday of the first transformation week.
- Phase two deals with the relocation of the commissioning zone for the roof pre-assembling. This could be done when area A3 is free. The prime activity in this phase is the transfer of the crane from E1 and F1 to A3 what is planned in the second week on Friday afternoon and on Saturday.
- Phase three includes the moving of the APL-series pre-mounting stations CAB 001 and CAB 002 including the lifting up and swivelling device. Some preparation can be done directly after phase 2 is finished. The rest is done on the first three days of week three in the transformation process.
- Phase four contains the dismounting of the unused crane at B2 and C2 area and installing new shelves for the logistics in this previously cleared area. This activity is planned on Thursday and Friday of the third week.
- Phase five is the final phase in the third week on Friday and Saturday, where the remote valves pre-assembly station starts operating on the new position next to the assembly line. The final state of the transformation can be seen in Figure 51.

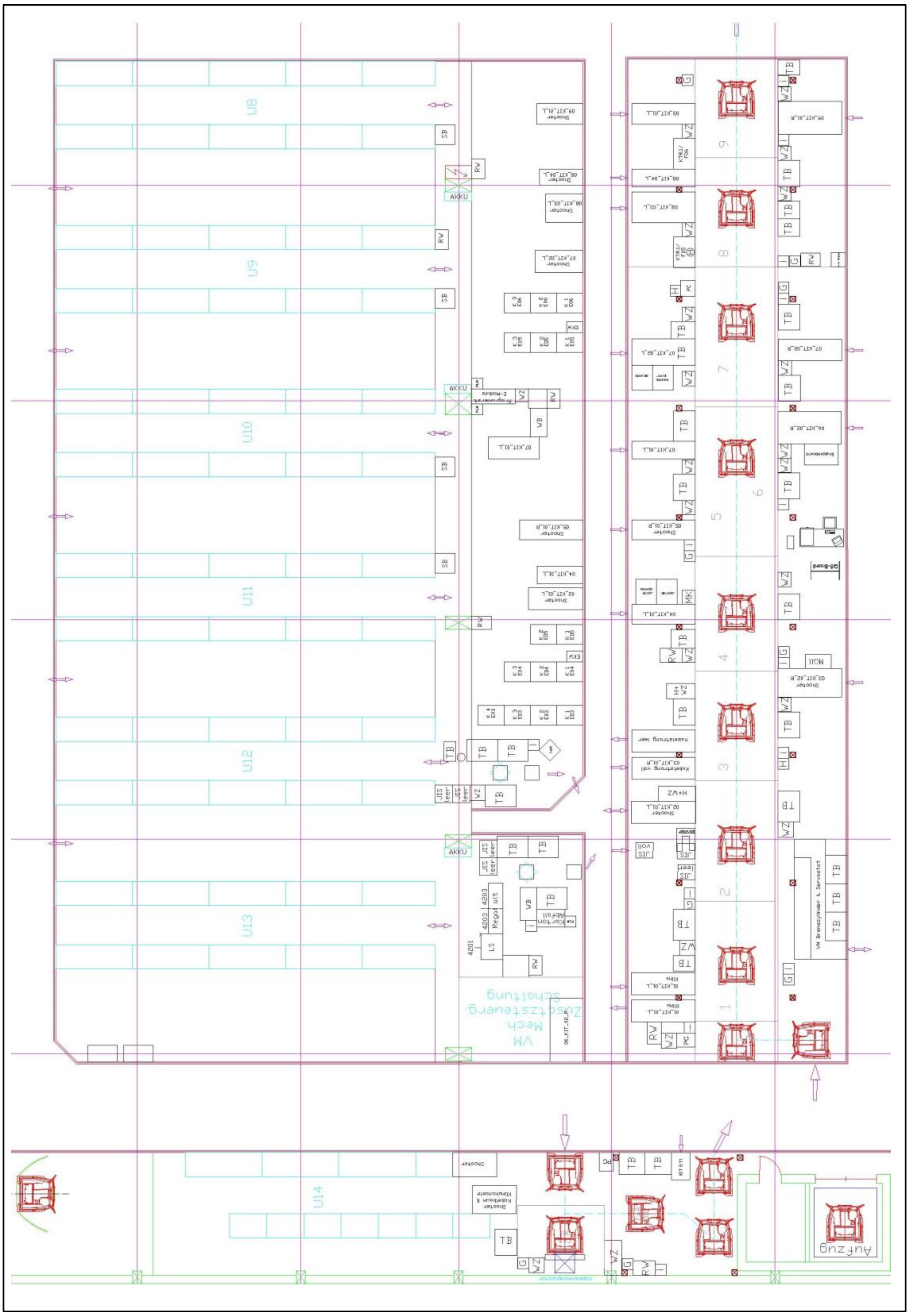

Figure 51: Final Shape of the Assembly Line after Phase 5[137]

[137] Own figure based on layout replanning

Phase	description	Week 1							Week 2							Week 3						
		Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
1	straighten assembly line					•	•															
2	relocate roof commissioning												•	•								
3	relocate lifting up and swivelling device															•	•	•				
4	install logistic zone U13																		•	•		
5	relocate remote valves pre-assembly station																			•	•	

Figure 52: Implementation Plan[138]

[138] Own figure based on implementation planning

3.3 Cost/Benefit Analysis

To rate the developed layout and changes in the next step, the benefit and the costs has been evaluated. For comparability reasons within the company, the Cost/Benefit ratio was calculated according to CNH Industrial guidelines with the accuracy to get a first overview about the profitability of the project. The Cost/Benefit ratio is calculated with the onetime costs of the changeover divided by the savings the change will bring during one year.

Benefit

The main improvement aimed by the new layout is the reduction of walking during assembling and transporting the cabin inside the assembly hall. By locating the start of the main assembly line and the pre-assembly stations for the APL-series closer to the elevator, a lot of walking and transport distance is axed. By reducing the number of assembly stations, the walking distance between the stations is also decreased decisively. With the centralization of the pre-assembly stations, the distances among these stations are shortened strongly. The reduction of the walking distances causes on the one hand a big saving on time which is lost for walking. And on the other hand it has a good influence on work force planning and utilization, because it is easier to change the workplace in a short time without long walking. This second saving of time is not quantified by numbers because it would have exceeded the framework of this project, but there is definitely a positive influence on the assembly process.

- Walking
  As mentioned in the literature review, unnecessary movement like walking or material transport is a source of Muda within a production process. The savings of walked distance were measured directly on the assembly line and with the CAD-program. Afterwards, the distances were added up in a table multiplied with the repetitions (produced units per year) to get the saved distance per year. An accurate listing of the saved distance can be seen in Table 7: Saving WalkingTable 7.

description	saved distance [m]	time [min]	time per year [min]	time per year [h]	distance per year [m]
APH Kabine von Aufzug zu Pufferzone schieben	23,5	0,35	2741,75	45,70	182783
APH Kabine von Pufferzone in CAB01 schieben	2,5	0,04	291,68	4,86	19445
Kabine von CAB02 nach CAB03 schieben	4,2	0,06	557,80	9,30	37186,8
2 Stationen weniger		0,74	6551,96	109,20	177080
APL Kabine von Aufzug zu Pufferzone und CAB001 schieben	10,3	0,15	166,24	2,77	11082,8
1 Station in CAB00x Zone weniger		0,37	398,12	6,64	10760
Gehen zwischen Dachvormontage und VM 7	22	0,33	355,08	5,92	23672
CAB 05 Lenksäule	10,8	0,16	1260,04	21,00	84002,4
CAB 06 Schalterleiste	3,55	0,05	414,18	6,90	27611,9
CAB 06 Brems. & Kupplungspedal	5,15	0,08	600,85	10,01	40056,7
Zündschloss	4,5	0,07	525,02	8,75	35001
VM Servostat zu VM Zusatzsteuerung	47,3	0,71	709,50	11,83	47300
CAB 03 Transportwagen Kabelstrang FTS wechseln		0,53	4106,78	68,45	77780
			∑	311,32 h/year	773761,6 meters/year

Table 7: Saving Walking[139]

- Optimization of the work steps
  The benefit of the work step optimization has been estimated by experts of the manufacturing department based on experience values from former optimization projects. By combining work steps in pre-assembly stations and eliminating unnecessary or non-value adding work steps, an expected saving of 1441,40 hours per year could be reached (see Table 8).

description	saved time [TMU]	time [min]	time/year [min]	time/year [h]
VM Lenksäule APH	1/3 h by optimization			1104,85
Shooter APL Luftkanal & Kabelbaum	10	0,15	161,40	2,69
VM mech. Zusatzsteuerung & Schaltung	1/3 h by optimization			233,33
CAB 001 Gewindenachschneiden APL		3,12	3357,12	55,95
Blindstopfen APH Rahmen		0,30	2333,40	38,89
CAB 001 Kabelstrang mit offener Schelle befestigen 00002781		0,07	71,73	1,20
CAB 001 Auftrennen des Kabelbaums (richtig anliefern)		0,25	269,00	4,48
			∑	1441,40 h/year

Table 8: Expected Saving by Optimization[140]

- Area usage
  The area usage was defined as the total provided area for assembling, according to the marks on the hall floor, divided by the total used area for assembling. The repositioning of the workstations increased the area usage from 56,92 percent up to 67,25 percent (see Table 9).

[139] Own table based on walking analysis

[140] Own table based on work step optimization

L-Shape	
Total area CAB 001 - CAB 09	Total used area CAB 001 - CAB 09
723,7 m²	411,91 m²
100 %	56,92 %

I-Shape	
Total area CAB 001 - CAB 09	Total used area CAB 001 - CAB 09
517,51 m²	348,00 m²
100 %	67,25 %

Table 9: Area Usage[141]

- Productivity
  Altogether, the walking savings and work step optimization and the replanning of the assembly line layout leads to a saving of 1752,71 assembling hours per year, assumed that there is no change of produced units. This leads to an average assembly time of 2,8 hours per cab for the treated area, which means a reduction of 0,2 hours of the initial status. In other words, through this project the productivity could be increased by 7 percent as can be seen in Table 10.

	Assambly hours		avg. Time per cab	Productivity cab/h	Productivity %
Total per year	1593082,53 26551,3755	min h	179,93 3,00	0,33	100,00 %
Total per year after optimization	1502073,63 25034,5604	min h	169,65 2,80	0,36	107,07 %

Table 10: Productivity[142]

Summarized, the saving of walking time, transport time, and assembly time reduction multiplied by the internal hourly wage leads to a saving of 66.883€ per year through the new layout.

Costs

The cost estimation of implementation was carried out in cooperation with employees of CNH Industrial Österreich GmbH. For the costs of the logistic changeover, experts form the logistics department estimated the time exposure by two workers for 10 working days. The costs for the new

[141] Own table based on area analysis

[142] Own table based on time analysis

infrastructure, rearrangement of the workstations and additional operation were estimated by an expert of the plant engineering department. On the following table a summation of the costs assigned to the correlated implementation phase can be found. For the extended transport of the roof from the roof commissioning zone to the roof pre-assembling zone, the logistic department estimates additional costs of 25.000€ per year.

Phase	Description	Requirements	Operations	Costs	Time exposure [days]
1	straighten assembly line	APH steering column pre-assembly station	relocation of workstation lighting CAB 01 & CAB 02	€ 2.500	2 days
			PC network connection + electricity supply	€ 1.500	
			relocation of cab floor guidence, floor renovation	€ 1.000	
			relocation compressed air	€ 6.000	
2	relocate roof commissioning		temporary relocation of remote valves pre-assembly station		2 days
		area A3 free	crane relocation from E1-F1 to A3	€ 3.000	
3	relocate lifting up and swivelling device		protection cover for gas pipeat F1	€ 500	1 day, preperation the days before
			compressed air and electricity supply for lifting up and swivel	€ 2.000	
			relocation lifting up and swivelling device	€ 3.000	
			remove of workstation lighting CAB 001 & CAB 003 (old) installation of workstation lighting CAB 001 & CAB 002 (new)	€ 2.500	
			PC network connection + electricity supply	€ 1.500	
			relocation of cab floor guidence, floor renovation	€ 2.000	
			relocation compressed air	€ 6.000	
4	install logistic zone U13		remove cranefrom B2 & C2	€ 1.000	evening
			installation logistic shelves		
5	relocate remote valves pre-assembly station	pre-assembly station ready for use	relocation pre-assembly from A to E2		evening
	additional operations		floor marking, protection cover installation	€ 1.000	
			rearrange assembly line ca. 40h	€ 1.526	
			logistic changeover ca 10 days à 2 workers	€ 6.487	
				∑ € 41.514	

Table 11: Costs Implementation[143]

143 Own table based on cost analysis

Description	Implementation costs
Transformation to I-Shape	41.514 €

Description	Savings per year
Savings through I-Shape	66.883 €
Additional costs logistics	- 25.000 €
Savings first year	41.883 €

Table 12: Savings first Year[144]

With the savings of 41.883€ in the first year and implementation costs of 41.514€, the project fulfils the company's requirement of an amortisation after one year.

3.4 Next steps

Before the implementation of the new layout can start there should be a detail planning of the five implementation phases with a detailed schedule. As mentioned in the implementation plan, the new pre-assembly stations for the APH steering column and the pre-assembly station for the remote valves have to be ready for use. The new logistic shelves for the logistic zone U13 have to be planned and ordered. Beforehand, new kitting boxes for the APL pre-assembly station CAB 001-CAB002 have to be designed. Also the positioning of the work steps on the assembly line should be checked and if needed, updated and relocated to ensure the best possible work flow during the assembly process.

3.5 Further improvements and ideas

During this project some further improvements for the I-shape assembly line have been made. These improvements can be accomplished after the implementation of the I-shape concept of this master thesis had been realized. Below these ideas and improvements are documented.

[144] Own table cost analysis

- Currently, the pre-assembling of the APL rear windows is located at the end of the assembly line. After pre-assembling, the rear windows are delivered by an AGV to the area where the lifting device for the APL cabs is located, stored, and if necessary delivered to the workstation where needed at the end of the assembly line. By locating the pre-assembly station next to the door where the cabs enter the hall (red highlighted in Figure 53), this unnecessary transportation could be eliminated. Also the utilization of the worker who dismounts the doors, at the cab input, could be improved with the short distance of the rear window pre-assembly station.

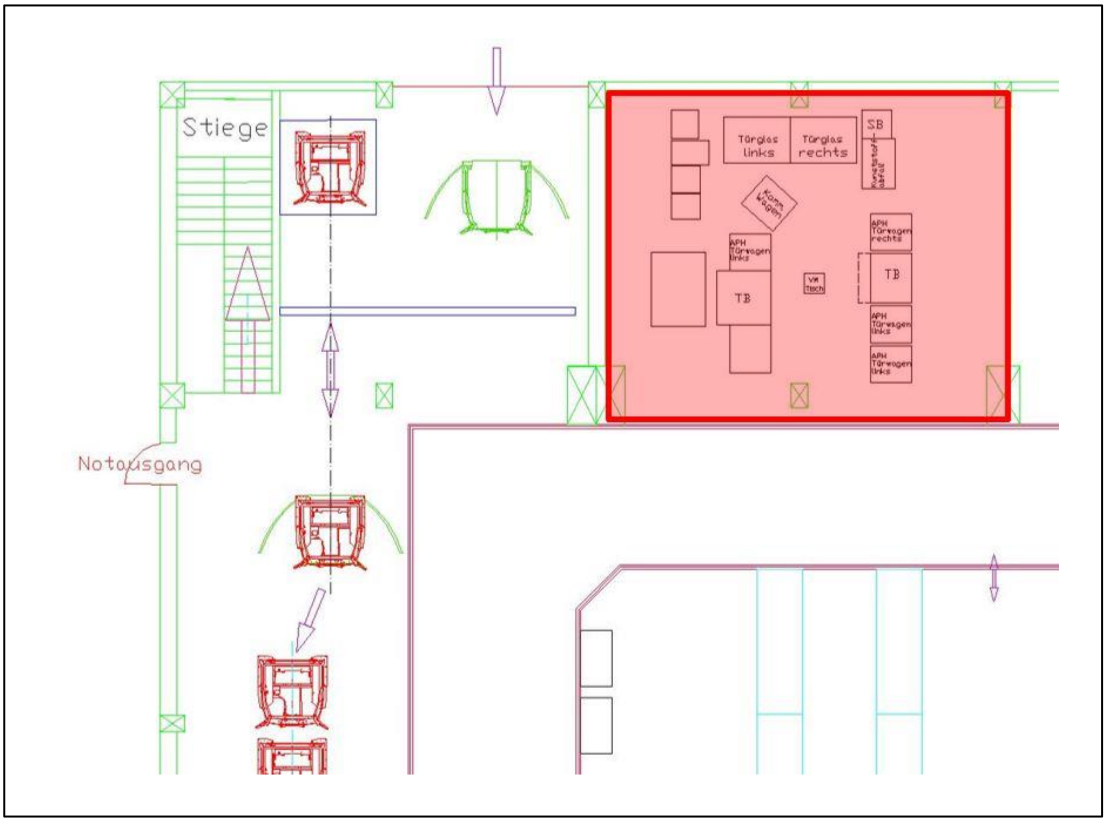

Figure 53: Rear Window pre-assembling[145]

- At the moment, all cabs have to pass a quality control when entering the hall and nearly all cabs need some rework. This happens at the first floor of the building at four welding workplaces. When it is achieved that the supplier delivers at a higher quality standard there would be no need for four welding work places. If it is possible to do the rework on two workplaces and the rework does not take more time than one takt, the

[145] Own figure based on layout planning

workplaces could be located at the ground floor (red highlighted in Figure 54). The work in progress and the transport of the cabs within the hall would be significantly reduced.

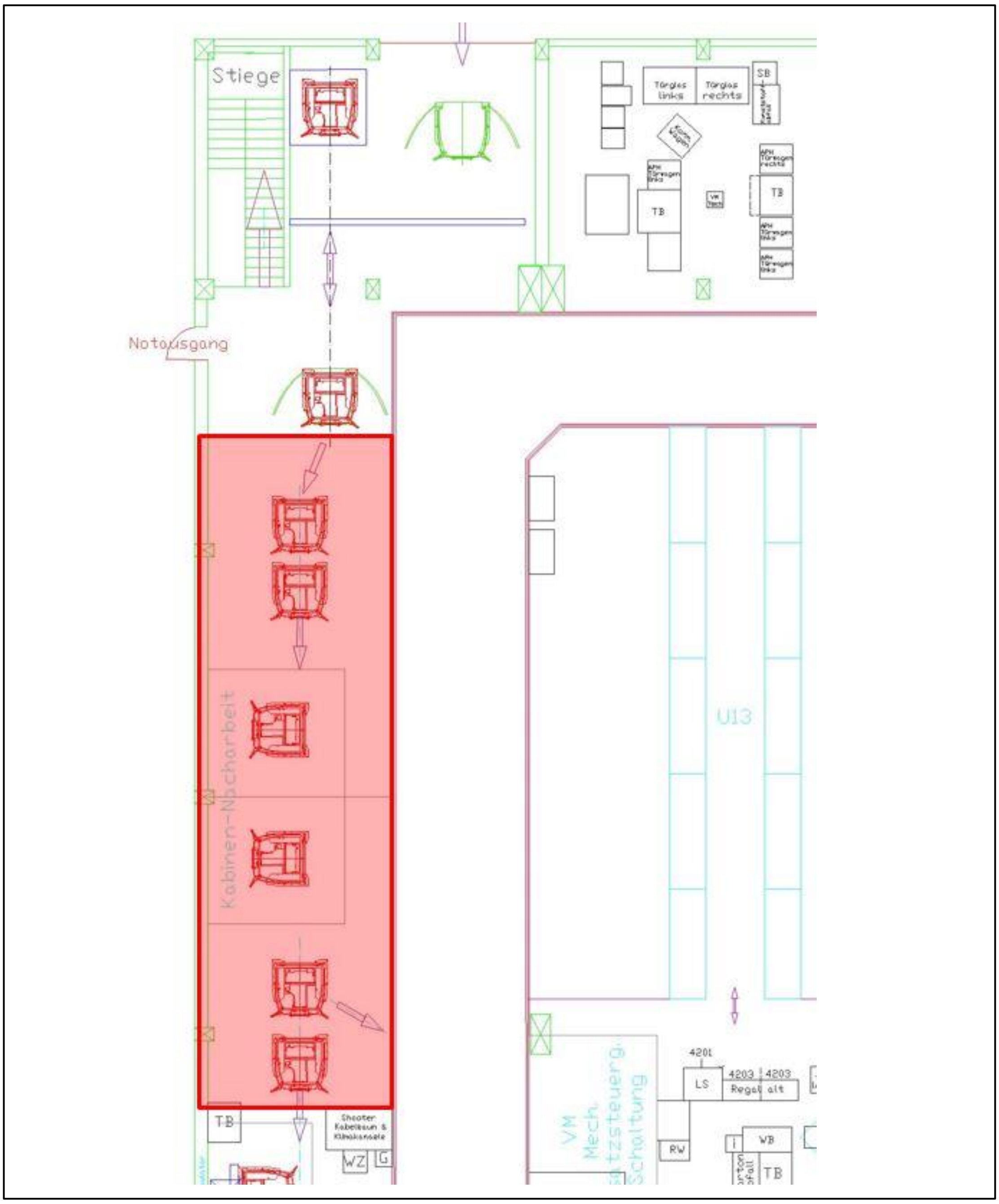

Figure 54: Rework Area[146]

- To minimize the transport of the cab roof between roof commissioning and roof pre-assembling, the two stations should be located as close to

146 Own figure based on layout planning

each other as possible. Therefore, the storage room and the common room have to be relocated and the roof pre-assembling occupies this area. This makes the placement of the roof commissioning next to the pre-assembling possible. For a simple supply with roofs, the roof-shelves could be transported and stored on a new special trolley which can be moved by hand. The exchange of the roof-shelves takes place by a new gate (green highlighted in Figure 55) just before the roof commissioning zone. Since there is a lot of AGV traffic in the hall, even if it is against the WCM principle, an overhead transportation by an overhead conveyer (yellow highlighted in Figure 55) to the main assembly line would be reasonable.

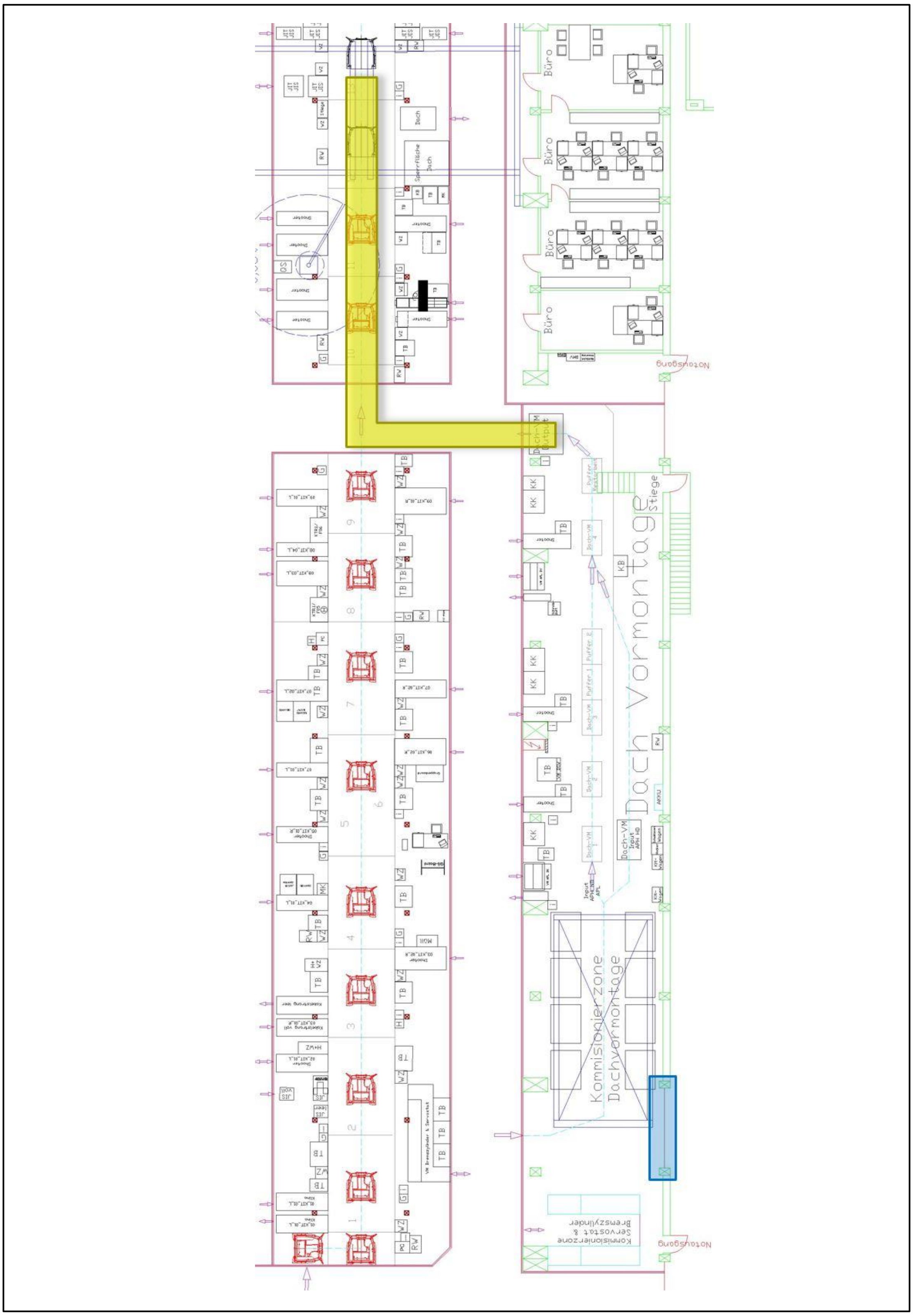

Figure 55: Roof pre-assembling[147]

[147] Own figure based on layout planning

4 Conclusion

Within this project, the cab assembly line for agricultural tractors at CNH Industrial GmbH at St. Valentin was analysed to subsequently, with special emphasis on Lean production principles, plan an I-Shape assembly line layout concept. The first part of the project was to define the areas to be examined, which was done in cooperation with employees of CNH Industrial. Because of the varying state of development, the least optimized segment, the first part of the assembly line, was chosen. Following, the analysis of the products, started with the overall product mix, classified with an ABC-analysis according to assembly time per year, was carried out. Based on this classification, several analyses have been performed until the level of the single work step. The aim of this process was to find the work steps with the highest non-value adding time rate and, therefore, the highest optimization potential. This analysis basically has been done with the manufacturing data and work-step-time-analysis of CNH Industrial GmbH. Afterwards, the analysis of the assembly line started with a blue print update to have a defined starting condition. With various hours on the assembly line, the position of the work steps during the assembly process has been recorded. With the knowledge of the high potential work steps for improving determination from the previous analyses, these work steps have been evaluated directly on the assembly line. The outcome of this evaluation was that the potential of time saving due to various optimizations in the past is relatively small. Therefore, the decision to reach the goal was to set the focus mainly on the replanning of the layout by optimizing the arrangement of the work stations, combining related work steps in pre-assembly stations, and improving the material supply. With the input of the analysis, the replanning of the layout has been started with the use of a computer aid design software. The interim findings have been discussed with the logistic and the manufacturing experts of the company, in order to find the best solution for both departments. With the final layout plan as a basis, the savings of the new layout has been calculated, an implementation time schedule has been worked out, and the costs for the transformation have been calculated in cooperation with the plant engineering department. The results of the transformation cost calculation were expected to be 41.514€ for the rearrangement of the stations, the new infrastructure, and the relocation of the logistic zones. By a reduction of two workstations within the investigated area, the throughput time for the whole cab assembly line decreases form 3,6h to 3,2h, which means that the productivity is increased by 7 percent and the area usage of the assembly line would be improved from 56,92 percent up to 67,25 percent. This can be reached through assembly time saving by the optimized assembly conditions within the new pre-assembly stations and the shortening of walking during production. In cooperation with manufacturing experts of CNH Industrial, the savings of assembly time by the new pre-assembly stations and the rearrangement of the workstations were calculated. The outcome of these calculation was an assembly time saving of 1441,40h per year. The optimized straight layout promises a reduction of the operator movement by 773.761m per year, which corresponds 311,32h of walking according to the MTM-UAS time. Added up, the new layout leads to a time saving of 1752,72h per year, which corresponds a saving of 66.883€. For the additional logistic afford by the new layout. the logistic experts estimated extra costs of 25.000€ per year. Final, the savings have been confronted with the transformation costs and the additional cost for logistics to give a statement about the profitability of the new layout. Summarizing, the implementation of the new layout has a payback period of one year. The next steps for implementing the layout are a detail planning of the assembly line with a work step balancing, the development of the new pre-assembly workstations, a logistic zone detail plan, and the development of a detailed implementation schedule.

Concluding there were collected multiple ideas for the further improvement of the assembly line after the I-shape is implemented. One of this ideas is to relocate the roof pre-assembling so that the roof commissioning finds place in an area close to the pre-assembling. By this change, the flow of the roofs could be heavily enhanced and the transport of the roofs reduced to a minimum. Furthermore, it would be reasonable to change the transport of the pre-assembled roofs between the pre-assembly station and the main assembly line to an overhead device in order to gain flexibility on the currently overloaded AGV transport way.

5 Glossary

AGV Automated Guided Vehicle

APH All Purpose Heavy. Tractor classification at CHN Industrial Österreich GmbH.

APL All Purpose Light. Tractor classification at CHN Industrial Österreich GmbH.

Bottleneck The process or machine within an assembly process which limits the throughput.

Changeover time The time it takes to change the setup of a machine or a process to produce a different model or a different product.

FIFO First in- First out is a material storage system. The material which is stored first leaves the storage before the material which was stored afterwards.

I-Shape Shape of the straight assembly line from the bird's-eye view

JIT Just in Time. The needed material is delivered in the right quantity at the right time to right place. This avoids the waste of too much inventory.

KPI - Key Performance Indicator Is a simple to understand classification number to rate a process, a team, a department, an assembly line or something else. For example: manufactured units per day can be an KPI.

L-Shape Shape of the one cornered assembly line from the bird's-eye view

LIFO Last in- First out is a material storage system. The material which is stored last is leaving the storage first.

Macro Automated repetition of a defined collection of tasks in Microsoft Excel.

Make-to-Order Products are only produced when there is an order for the customer. This avoids the inventory of finished goods.

Make-to-stock Products are produced in advance and stored until they are sold.

Milk run A logistic worker drives a fixed route at the production floor collects the empty material containers and replaces them with refilled. The same principle can be done with finished products.

NVAA - Non-value added activity Any activity that costs resources but does not add value to the product form the customer point of view. Often also called NVA – Non-value added. For example, walking, waiting, searching, …

Super market Small cheap parts are stored beside the assembly line on shelves. When the assembly worker runs out of parts he refills his storage by himself.

SVAA – Semi-value added activity Any activity that costs resources, does not add value to the product but cannot be removed from the process. For example, picking, holding, positioning, …

Takt time Is the available assembly time divided by the customer demand.

Upstream Against the material flow, for example from the finish product to the raw-material.

VAA – Value added activity Any activity that increases the value of the product.

WIP Work In Process. All materials which are in the production process. Before the production process the materials are called raw-material and afterwards they a stored as finished goods.

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Appendix

Overall	NVA	SVA	VA	Σ	# per Year	NVA per Year	SVA per Year	VA per Year	Σ	Σ kumuliert	Σ in %	Σ in % kumuliert	
									0	0	0	0	0
APL32	96,61	123,60	35,28	255,49	1076	103955,62	132994,78	37960,96	274911,36	274911	17,26%	17,26%	A APL32 (274911)
CCM T4B	46,45	101,26	27,47	175,18	1487	69066,61	150576,52	40842,77	260485,91	535397	16,35%	33,61%	A CCM T4B (535397)
SWBCV T4B	47,60	101,10	27,67	176,37	1378	65590,94	139320,14	38131,41	243042,49	778440	15,26%	48,86%	A SWBCV T4B (778440)
APHG4	44,60	98,34	26,03	168,97	1000	44597,20	98340,40	26031,26	168968,86	947409	10,61%	59,47%	A APHG4 (947409)
APHCV	44,43	94,71	25,46	164,60	983	43677,25	93101,90	25026,75	161805,89	1109215	10,16%	69,63%	A APHCV (1109215)
SWBG T4B	46,33	95,59	26,34	168,26	744	34465,91	71119,96	19598,86	125184,74	1234399	7,86%	77,48%	A SWBG T4B (1234399)
CCM HD	46,95	98,44	27,45	172,84	539	25306,06	53059,12	14792,97	93158,15	1327557	5,85%	83,33%	A CCM HD (1327557)
APH4	42,79	103,24	25,71	171,73	523	22376,97	53994,60	13445,34	89816,91	1417374	5,64%	88,97%	B APH4 (1417374)
PUMA T4B	46,52	98,19	26,86	171,56	381	17723,22	37408,81	10233,11	65365,14	1482739	4,10%	93,07%	B PUMA T4B (1482739)
APH3	36,33	90,68	22,34	149,35	300	10900,02	27205,07	6700,98	44806,07	1527546	2,81%	95,89%	B APH3 (1527546)
PUMAG	37,99	84,34	22,17	144,50	164	6229,88	13831,28	3636,51	23697,68	1551243	1,49%	97,37%	C PUMAG (1551243)
SWBG	39,13	85,78	22,77	147,69	108	4226,45	9264,49	2459,39	15950,33	1567194	1,00%	98,37%	C SWBG (1567194)
APHCV T4B	44,20	91,98	25,48	161,66	94	4154,84	8646,34	2395,12	15196,30	1582390	0,95%	99,33%	C APHCV T4B (1582390)
CCM	36,02	81,28	21,56	138,87	77	2773,52	6258,88	1660,29	10692,69	1593083	0,67%	100,00%	C CCM (1593083)
	655,94	1348,55	362,59	2367,07	8854	455044,51	895122,29	242915,73	1593082,53		100,00%		

No.	Type	NVAA per Year [min]	SVAA per Year [min]	VAA per Year [min]	Σ [min]	Classification	Percentage of total number of cabin types
1	APL32	103956	132995	37961	274911	A	42,86%
2	CCM T4B	69067	150577	40843	260486	A	
3	SWBCV T4B	65591	139320	38131	243042	A	
4	APHG4	44597	98340	26031	168969	A	
5	APHCV	43677	93102	25027	161806	A	
6	SWBG T4B	34466	71120	19599	125185	A	
7	CCM HD	25306	53059	14793	93158	B	21,43%
8	APH4	22377	53995	13445	89817	B	
9	PUMA T4B	17723	37409	10233	65365	B	
10	APH3	10900	27205	6701	44806	C	35,71%
11	PUMAG	6230	13831	3637	23698	C	
12	SWBG	4226	9264	2459	15950	C	
13	APHCV T4B	4155	8646	2395	15196	C	
14	CCM	2774	6259	1660	10693	C	
	Σ	455045	895122	242916	1593083		

Table 13: Data Elevation ABC-Analysis

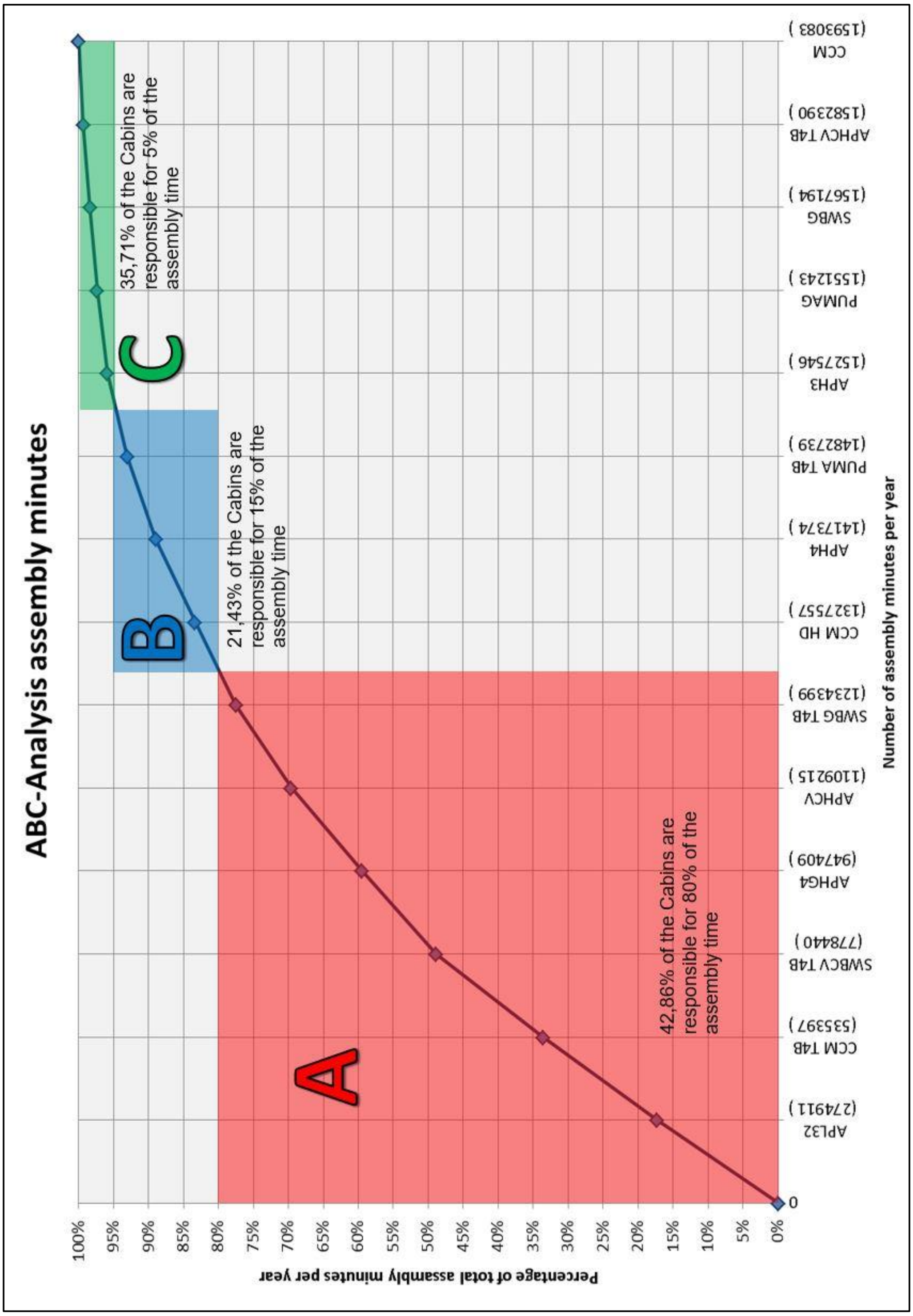

Figure 56: ABC-Analysis

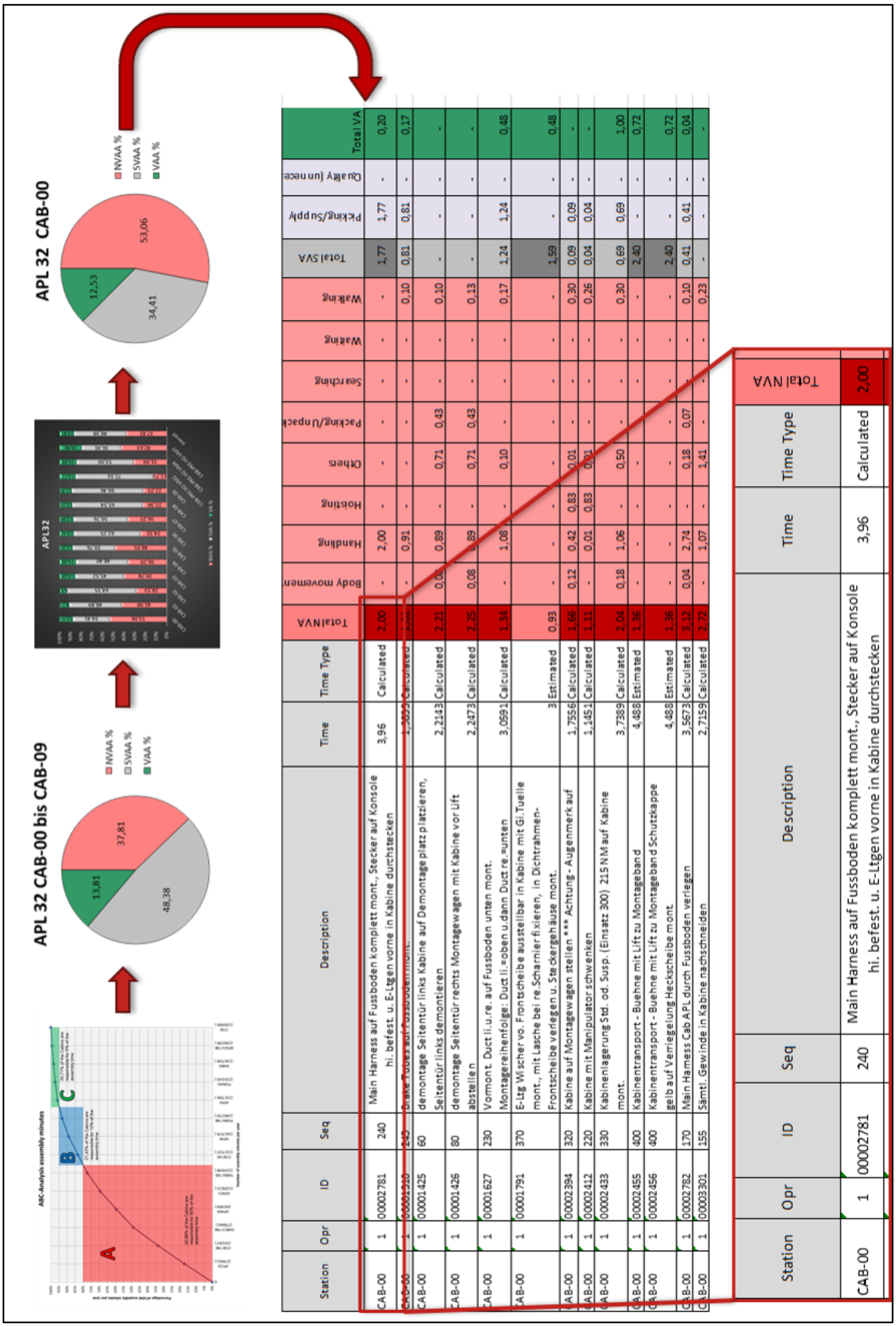

Figure 57: Work Step Identification

Figure 58: Special Trolley for APL steering pre-assembly[148]

[148] Own picture

Figure 59: APH Main Harness Trolley[149]

Figure 60: Steering Assembly APH Trolley

149 Own picture

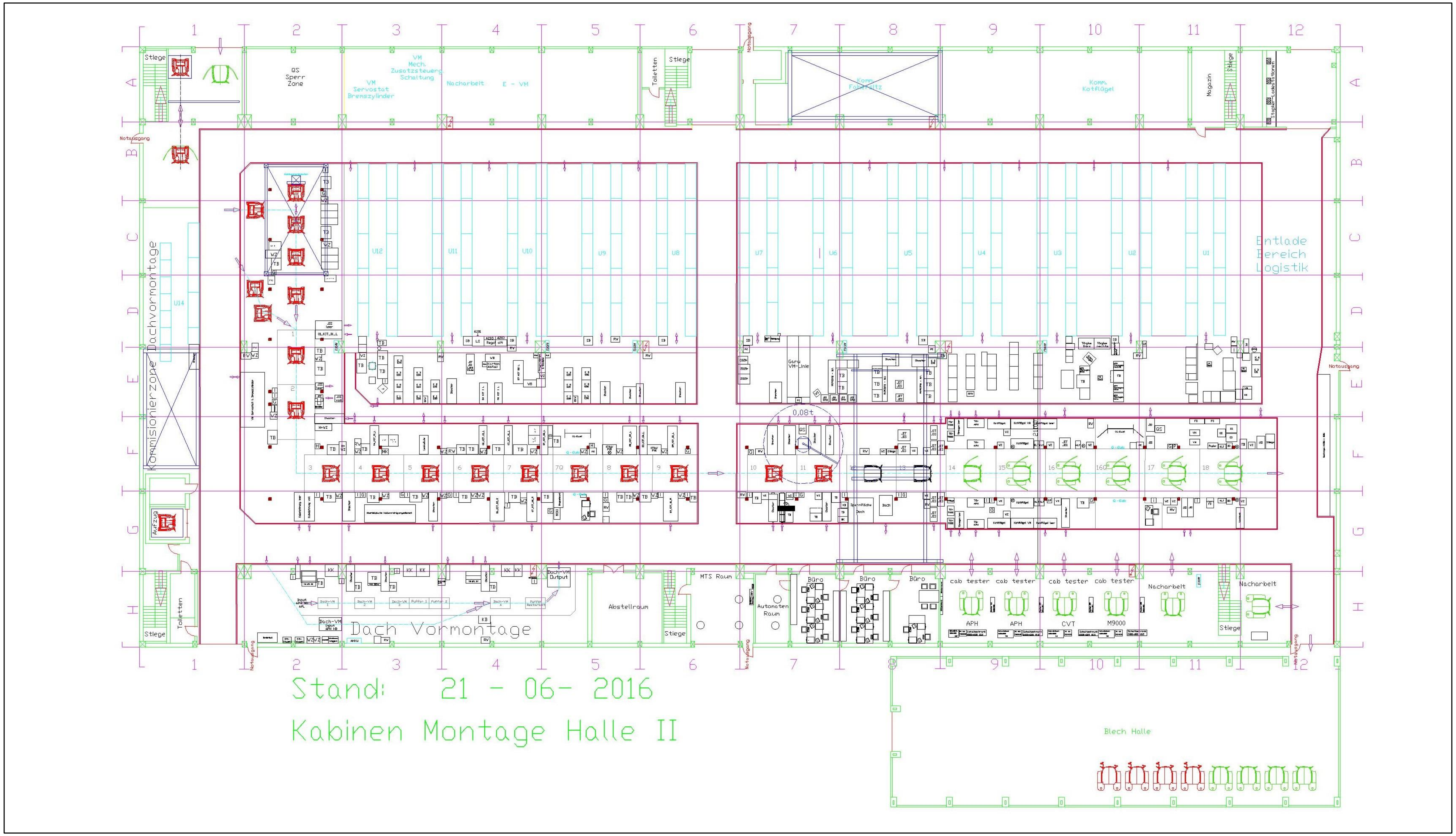

Figure 61: Initial State of the Assembly Line[150]

[150] Own figure based on layout analysis

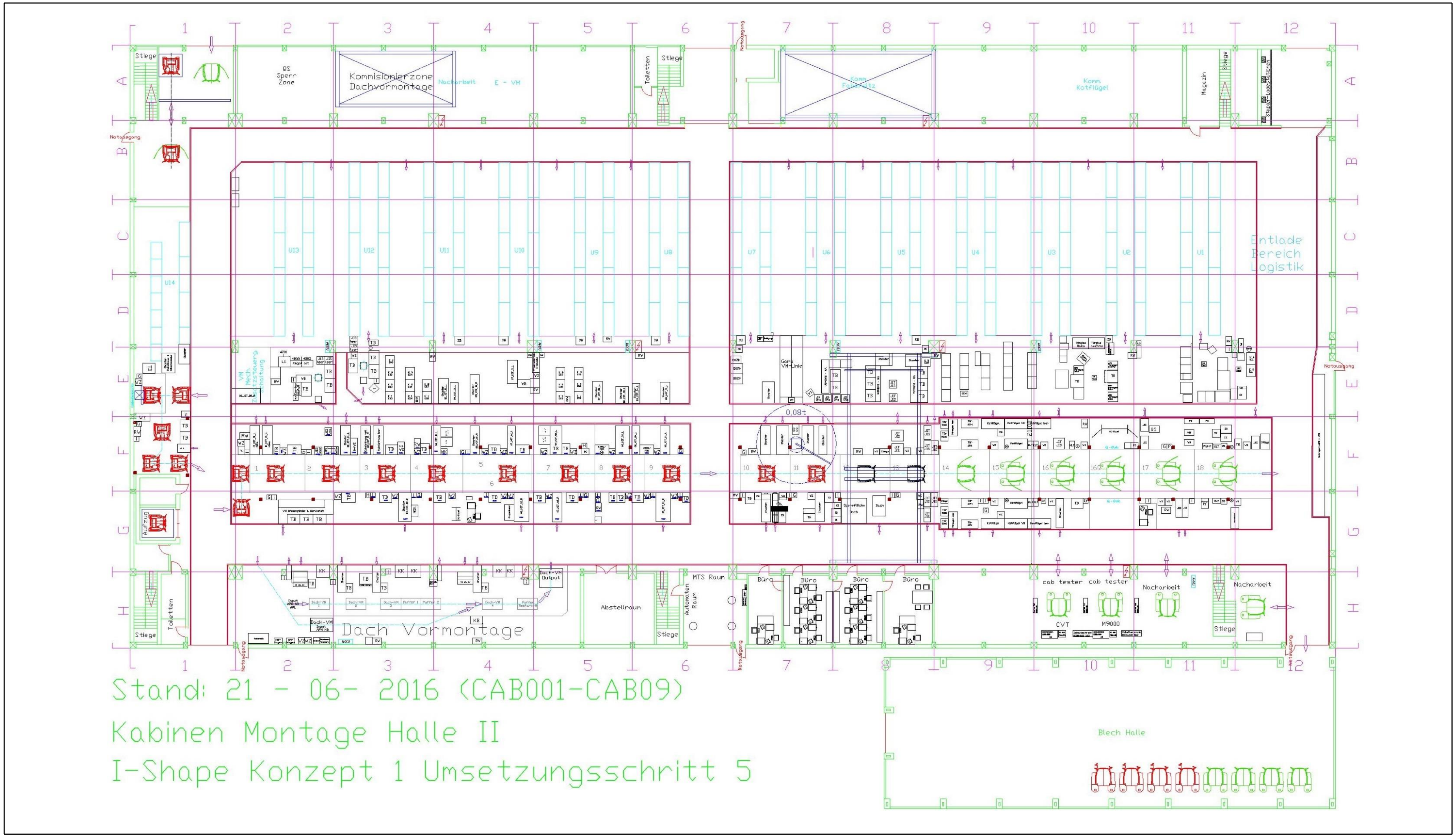

Figure 62: I-Shape Assembly Line[151]

[151] Own figure based on layout planning

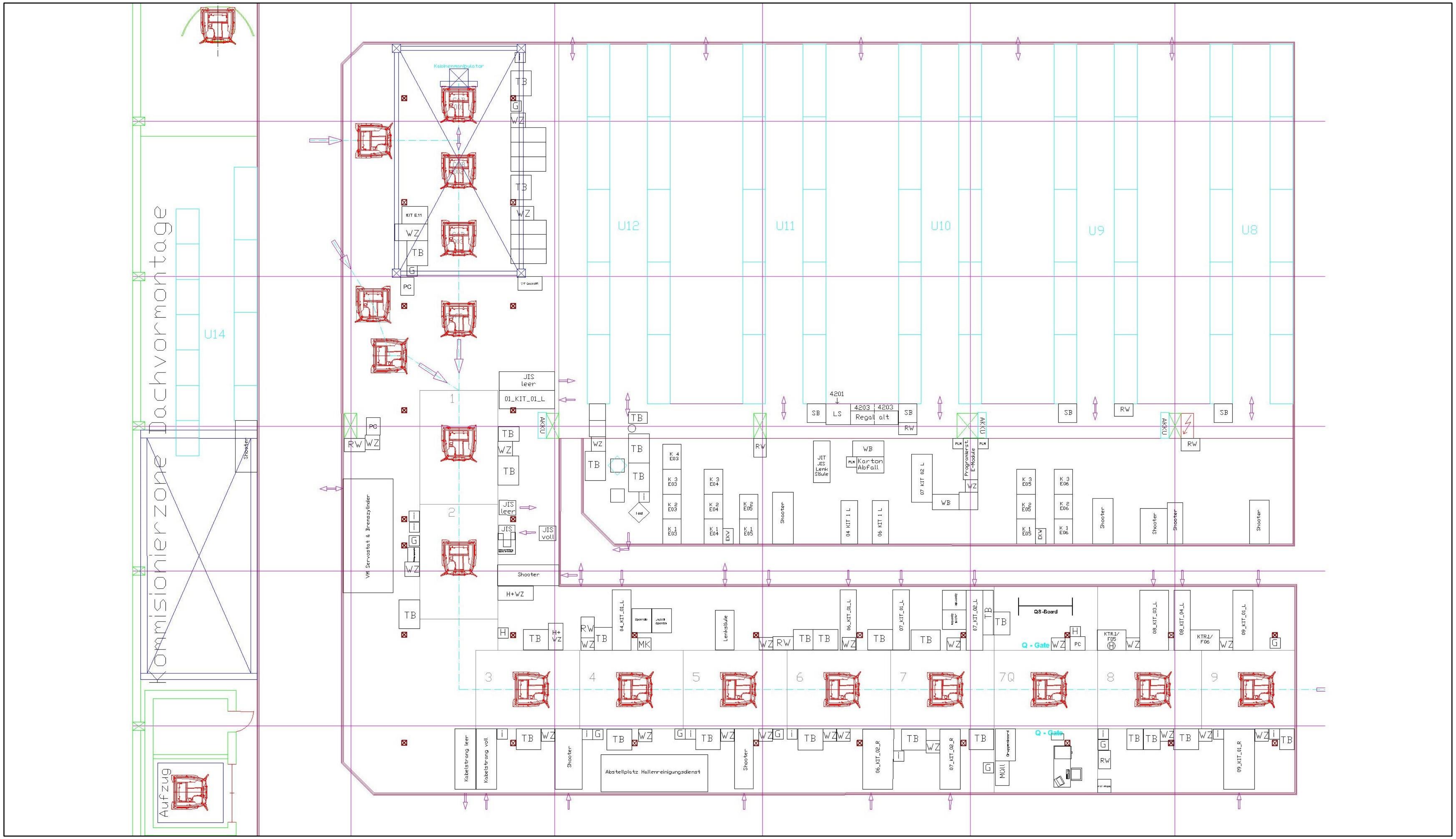

Figure 63: Initial State of the Assembly Line - Detail[152]

[152] Own figure based on layout planning

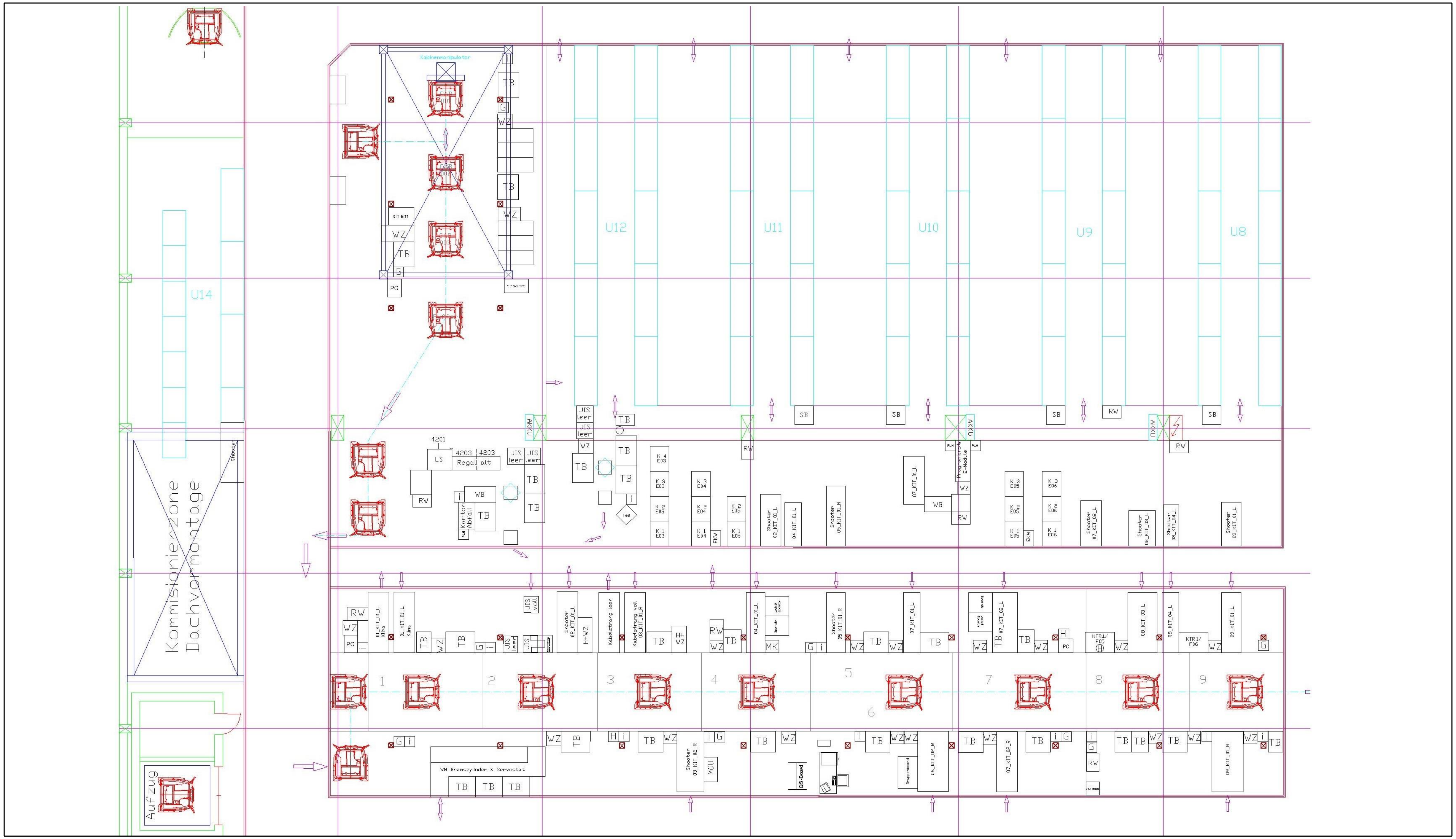

Figure 64: Assembly Line after Phase 1 - Detail[153]

153 Own figure based on layout planning

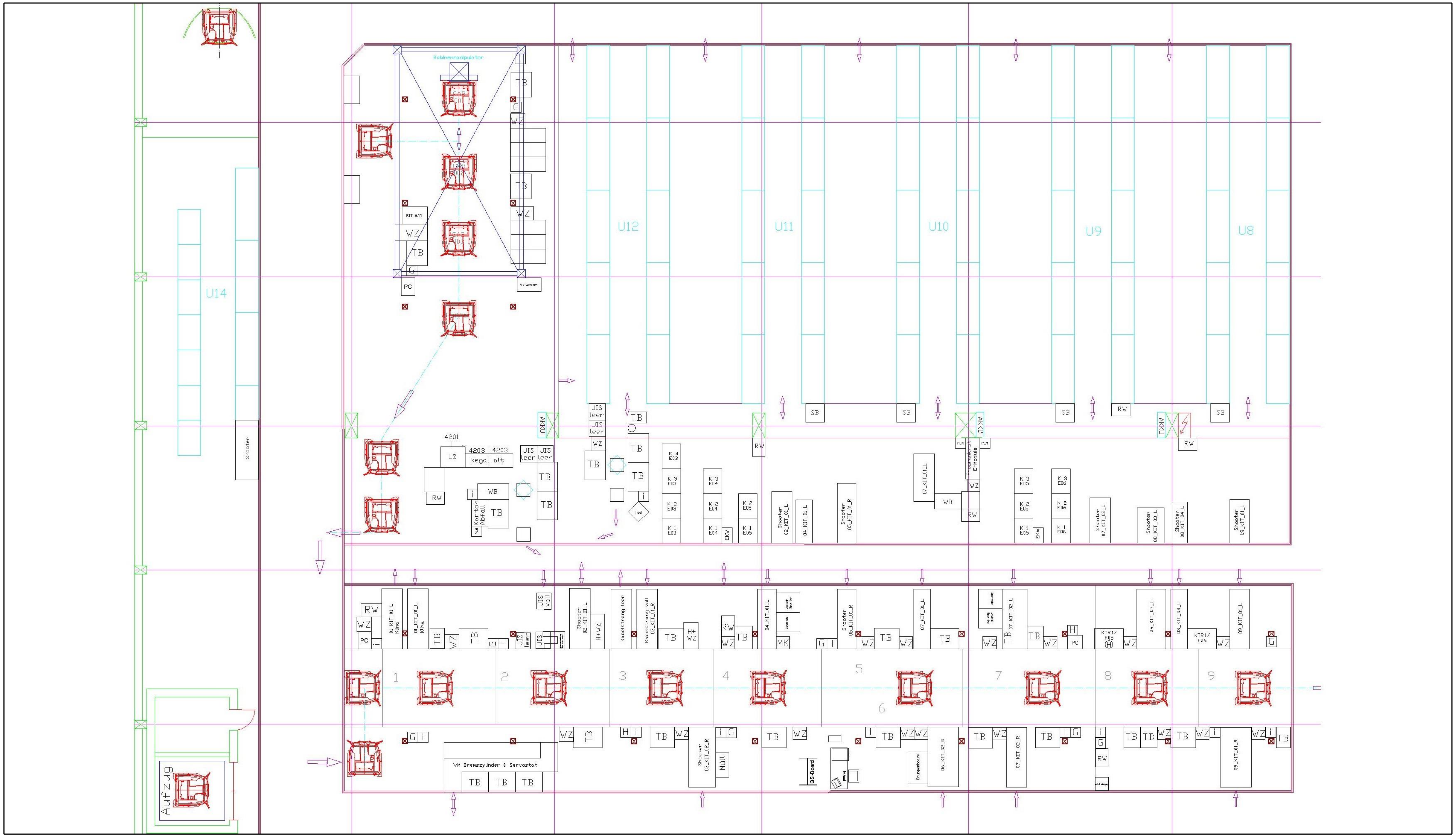

Figure 65: Assembly Line after Phase 2 - Detail[154]

[154] Own figure based on layout planning

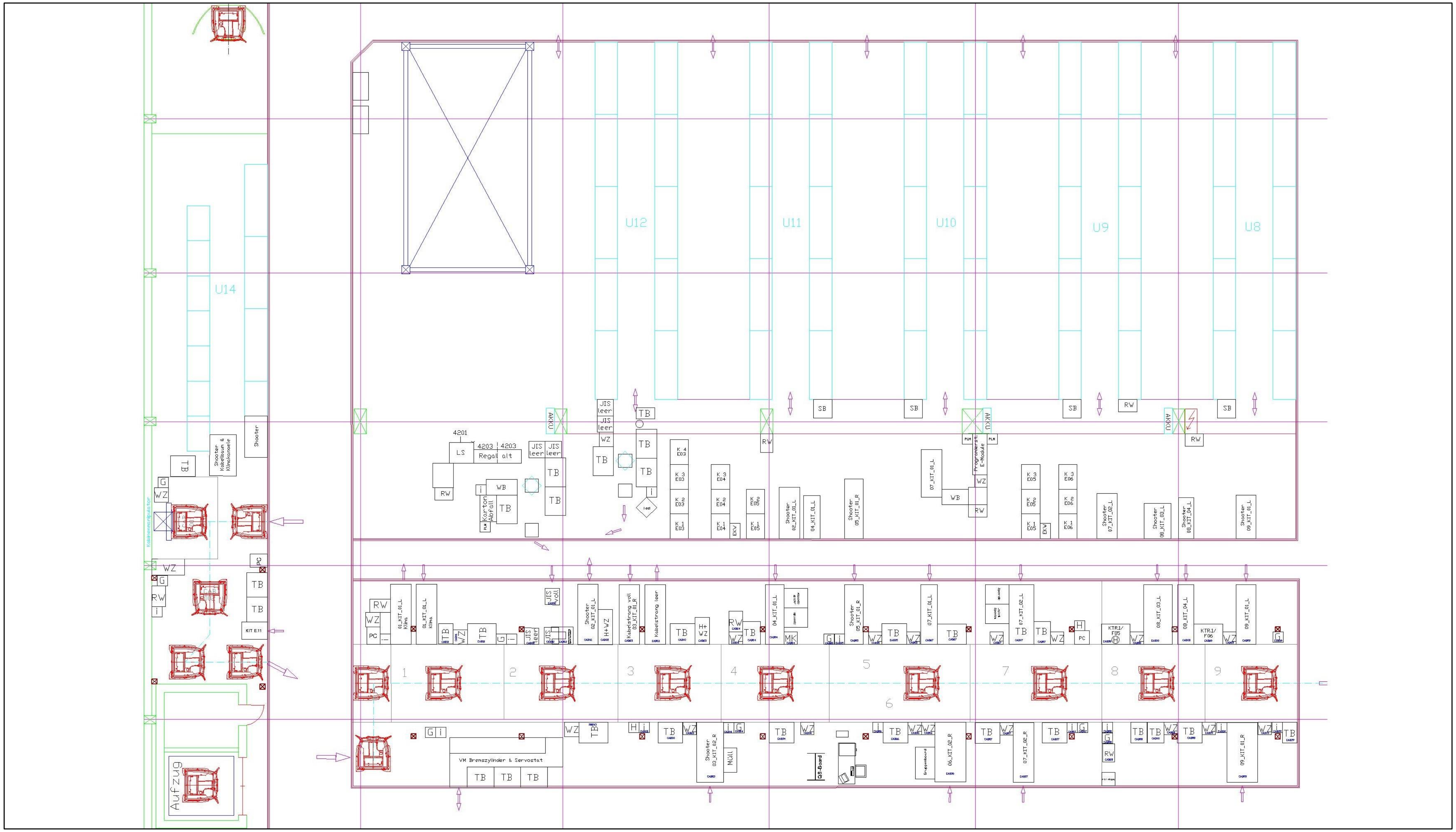

Figure 66: Assembly Line after Phase 3 - Detail[155]

[155] Own figure based on layout planning

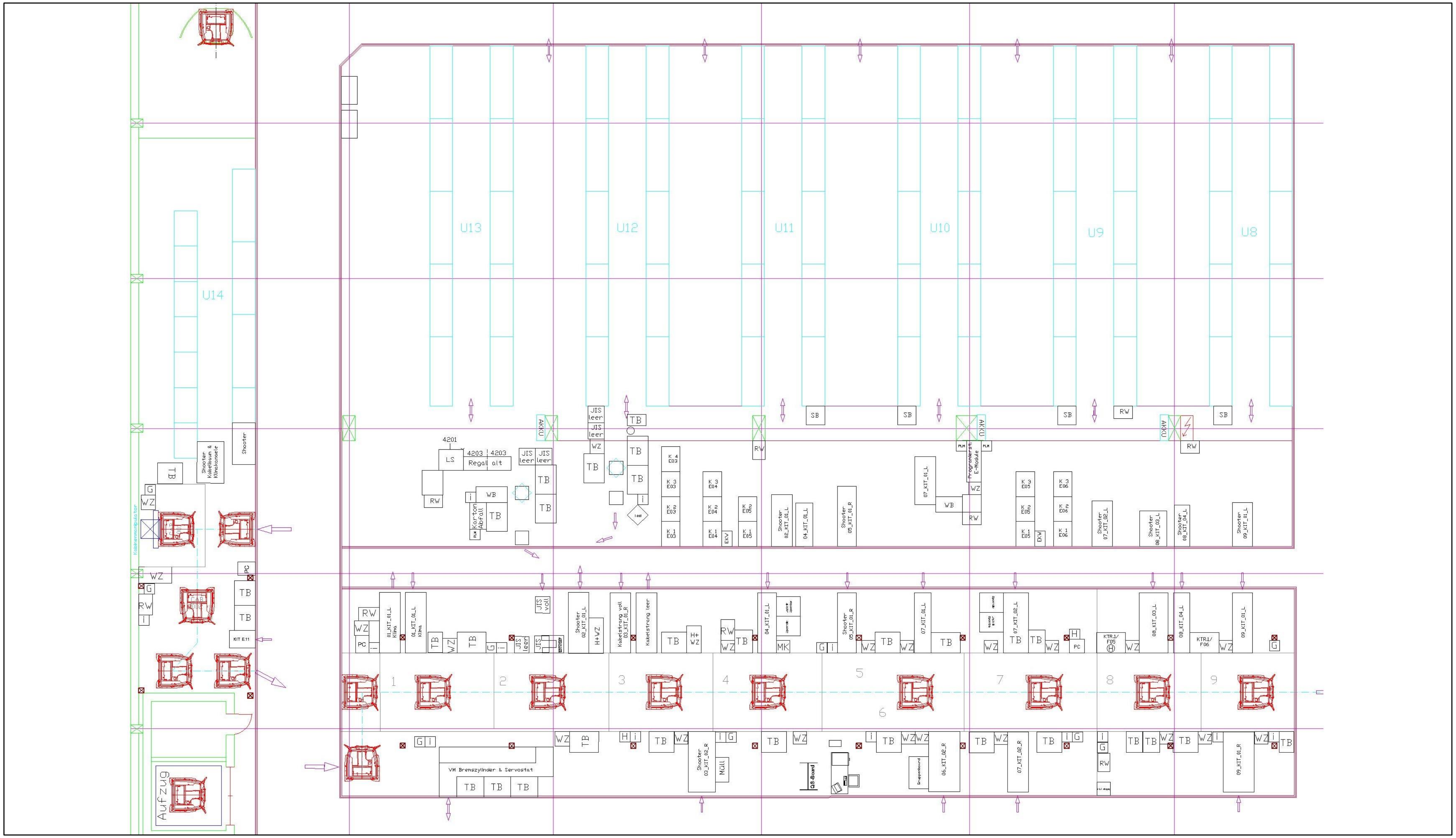

Figure 67: Assembly Line after Phase 4 - Detail[156]

[156] Own figure based on layout planning

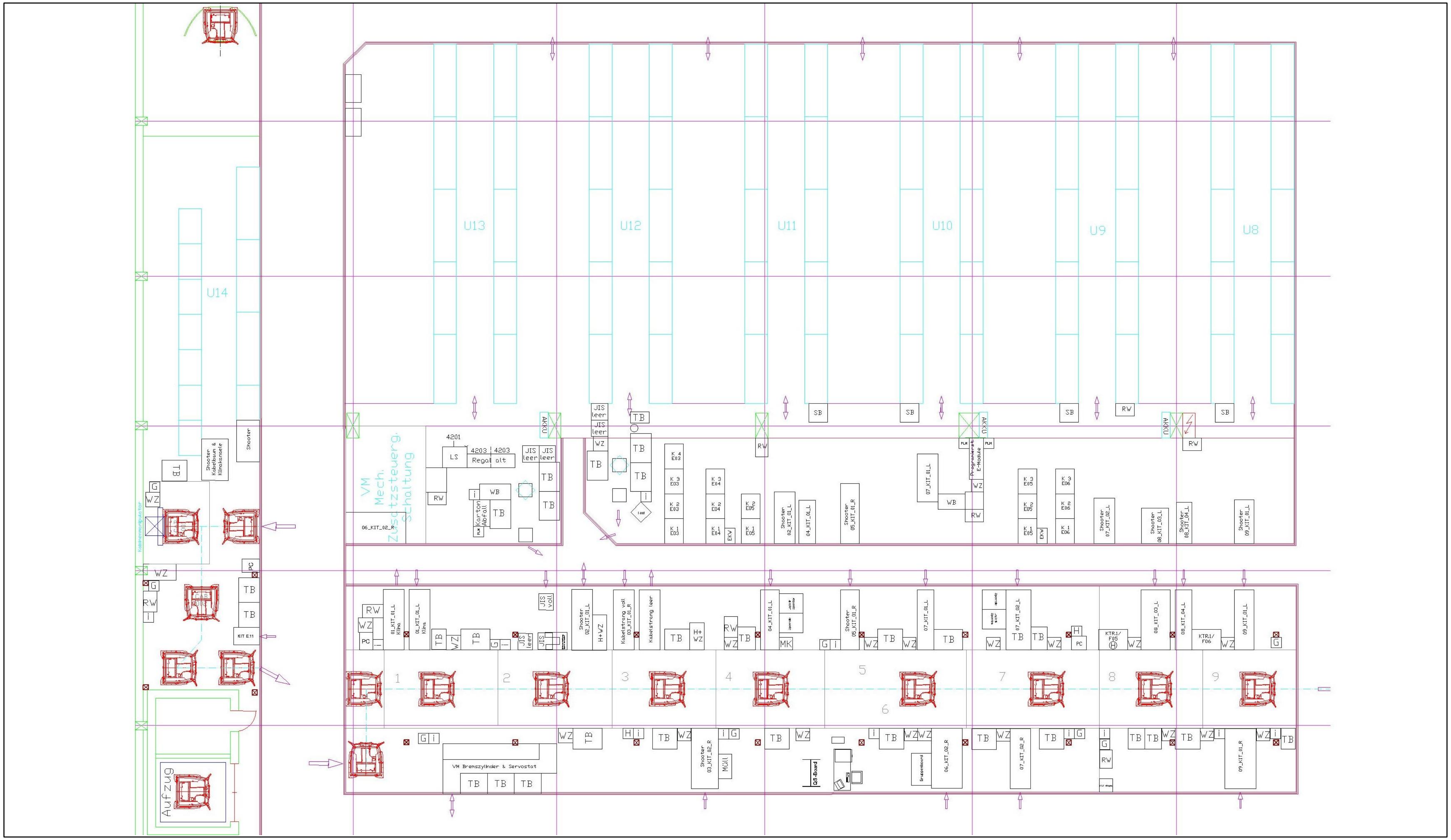

Figure 68: Assembly Line after Phase 5 - Detail[157]

[157] Own figure based on layout planning

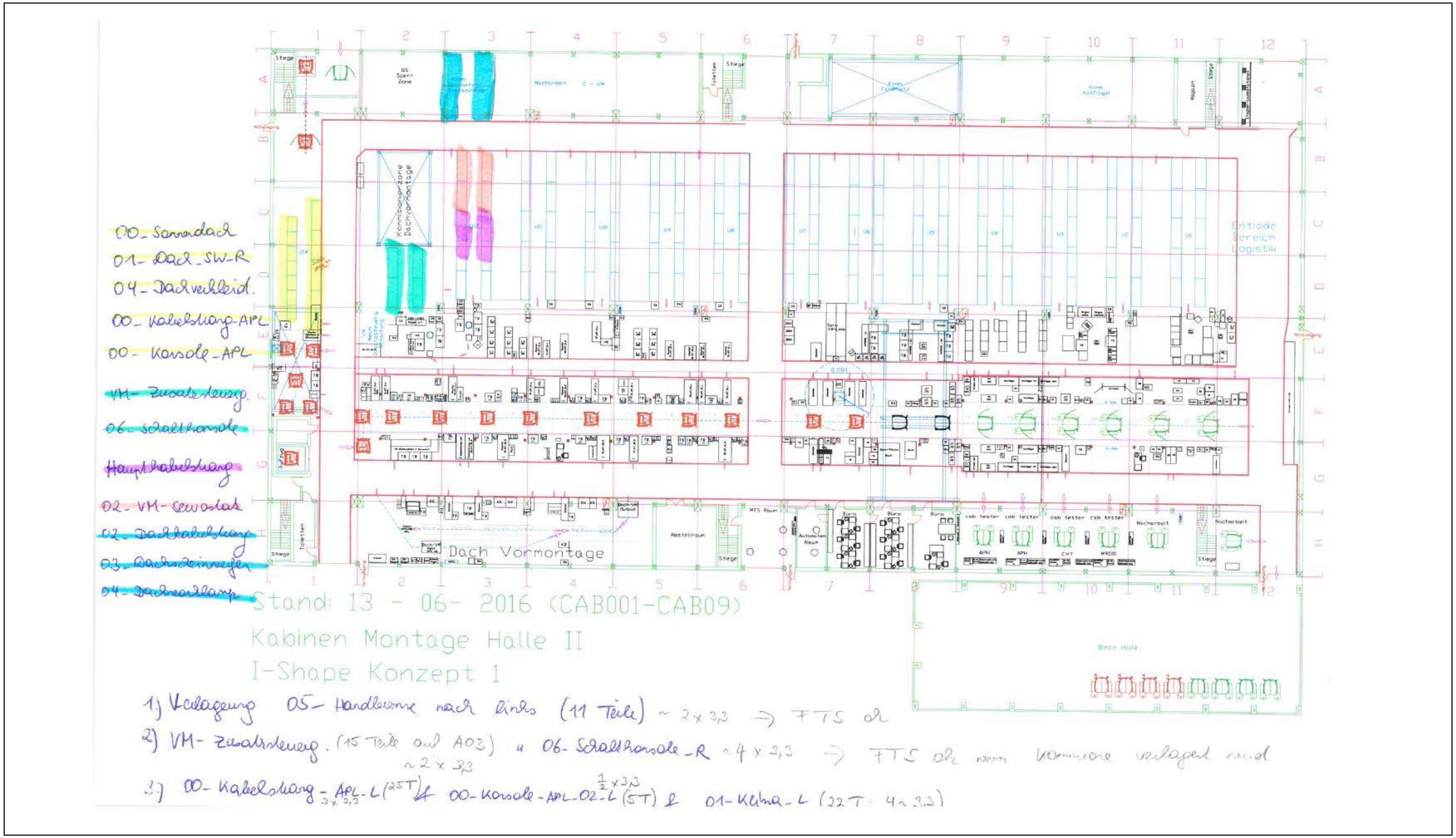

Figure 69: First Feedback Logistic Department[158]

158 Own figure based on logistic feedback

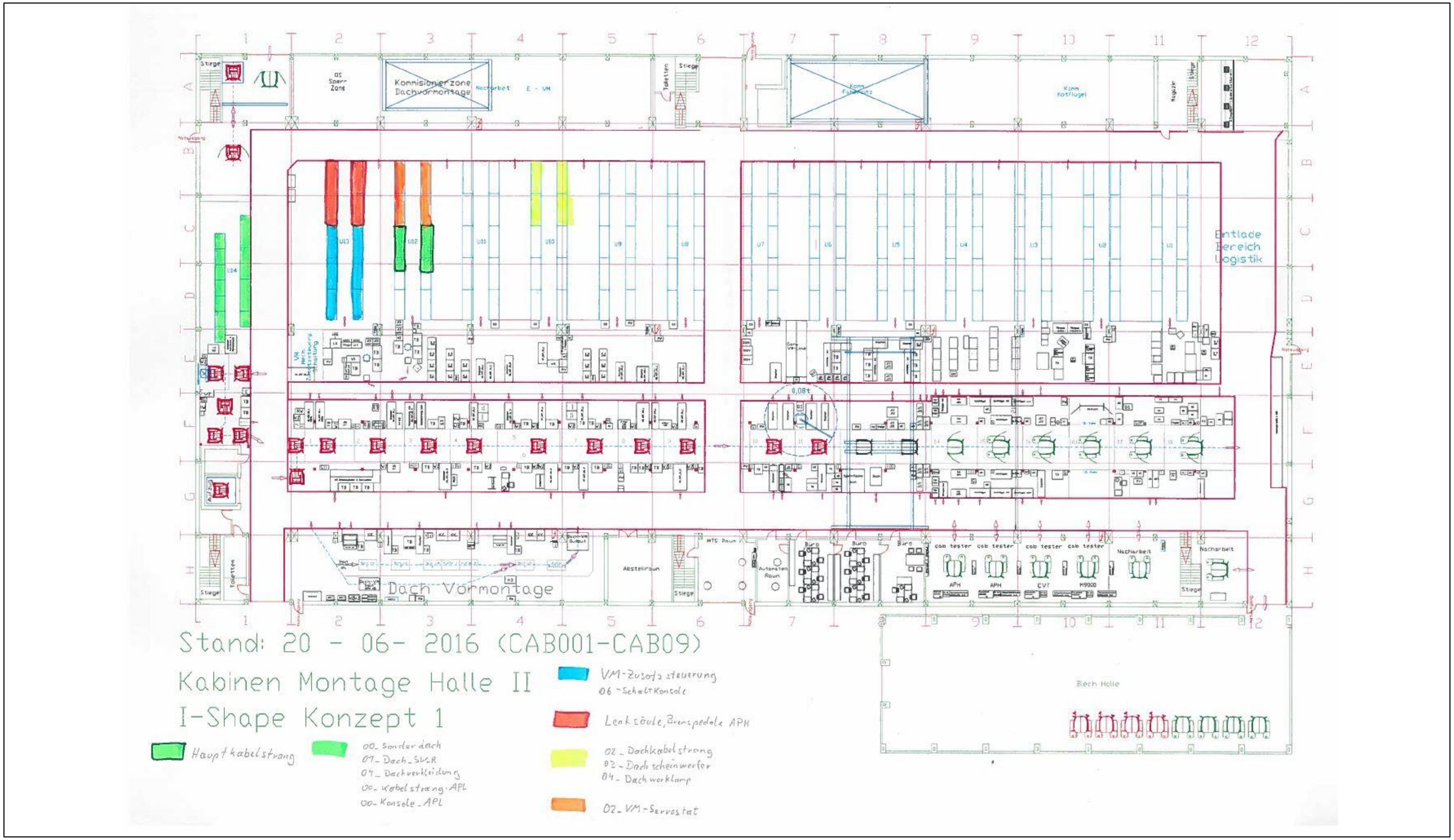

Figure 70: Improved Layout after Logistic Feedback[159]

[159] Own figure based on layout planning

Phase	Description	Requirements	Operations	Costs	Time exposure [days]	Woche 1							Woche 2							Woche 3						
						Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So
1	straighten assembly line	APH steering column pre-assembly station	relocation of workstation lighting CAB 01 & CAB 02	€ 2.500	2 days					•	•															
			PC network connection + electricity supply	€ 1.500						•	•															
			relocation of cab floor guidence, floor renovation	€ 1.000						•	•															
			relocation compressed air	€ 6.000						•	•															
2	relocate roof commissioning		temporary relocation of remote valves pre-assembly station		2 days												•	•								
		area A3 free	crane relocation from E1-F1 to A3	€ 3.000													•	•								
3	relocate lifting up and swivelling device		protection cover for gas pipeat F1	€ 500	1 day, preperation the days before															•						
			n compressed air and electricity supply for lifting up and swivellin	€ 2.000																•						
			relocation lifting up and swivelling device	€ 3.000																		•				
			remove of workstation lighting CAB 001 & CAB 003 (old) installation of workstation lighting CAB 001 & CAB 002 (new)	€ 2.500																		•				
			PC network connection + electricity supply	€ 1.500																•						
			relocation of cab floor guidence, floor renovation	€ 2.000																		•				
			relocation compressed air	€ 6.000																	•					
4	install logistic zone U13		remove cranefrom B2 & C2	€ 1.000	evening																		•			
			installation logistic shelves																					•		
5	relocate remote valves pre-assembly station	pre-assembly station ready for use	relocation pre-assembly from A to E2		evening																			•	•	
	additional operations		floor marking, protection cover installation	€ 1.000																						
			rearrange assembly line ca. 40h	€ 1.526																						
			logistic changeover ca 10 days à 2 workers	€ 6.487																						

Figure 71: Implementation Phases[160]

[160] Own figure based on implementation planning

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