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Application of Lean Methodologies in the Improvement of a CNC Spindle Manufacturer's Operation

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Institute of Production Engineering

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Foreword

This thesis was carried out as a part of my master's studies at Graz University of Technology and the study was conducted in Franz Kessler GmbH (Abbr.: FK), a German computer numerically controlled (Abbr.: CNC) spindle manufacturer, to improve its efficiency by deploying lean methodologies.

First and foremost, I thank God Almighty, for his abundant bounties. I am greatly indebted to everyone who had guided and supported me throughout this thesis. I would like to express my sincere gratitude to Univ.-Prof. Dipl.-Ing. Dr.techn. Franz Haas, for trusting, advising and supervising me throughout. His guidance has been of great value in developing this thesis. I would like to thank Mr. Dirk Sloof wholeheartedly for the opportunity to perform this study in the Service Department of Franz Kessler GmbH, for mentoring me over the entire development of this thesis and for the unconditional support extended to me.

I would like to extend my gratitude to managers and colleagues in various departments of Franz Kessler GmbH for their cooperation and assistance through various means. A token of appreciation to the staff members of Institute of Production Engineering at the University for their continuous help and support.

I am deeply grateful to my family, for all love and support through thick and thin. Finally, yet importantly, I cannot thank enough my friends for the incessant motivation all along.

Saeed Ahmad

Graz, September 2020

Kurzfassung

Die deutsche Werkzeugmaschinenindustrie ist ein Teil des starken globalisierten Fertigungssektors, der sowohl technisch als auch organisatorisch komplex ist. Namhafte Hersteller, die dem Wettbewerb ausgesetzt sind, sind auf dem Weg, ihre Abläufe zu optimieren. Lean Manufacturing mit seiner Erfolgsgeschichte in einer Vielzahl von Branchen auf der ganzen Welt ist unabdingbar, um dieses Ziel zu erreichen.

Diese Studie konzentriert sich auf die Serviceabteilung der Franz Kessler GmbH, einem CNC-Spindelhersteller in Deutschland, und die Notwendigkeit, die Effizienz durch Lean Implementierung zu steigern. Dies geschieht durch Beobachtung und Analyse des Status Quo, um einen Rahmen für die Erzielung von Prozessverbesserungen zu entwickeln.

Die Untersuchung des Betriebs in der Serviceabteilung auf Lean-Methode ergab die Konstruktion von drei Wertströmungskarten, nämlich Spindeln für normale Reparaturen, Spindeln für Gewährleistungsreparaturen und Systemreparaturen. Verbesserungspotenziale wurden durch den Einsatz von Lean-Tools und die Analyse aktuelle Wertströmungskarten identifiziert. Die Verbesserungsmöglichkeiten flossen dann in die Erstellung zukünftige Wertströmungskarten ein, die bei der Analyse unter anderem zweistellige Verbesserungen der Vorlaufzeit, der Betriebskosten und des Platzbedarfs aufwiesen.

Abstract

The German machine tool industry is a part of highly globalized manufacturing sector, which is complex both in terms of technical and organisational perspective. Subjected to competition, notable manufacturers are on the way to optimize their operations. Lean manufacturing, with its history of success in a multitude of industries around the globe is inevitable in leading the way to realise the goal.

This study focuses on the service department of Franz Kessler GmbH, a CNC spindle manufacturer in Germany and the necessity by which increasing efficiency through lean implementation is imperative. This is done by observing and analysing the status quo to devise a framework for attaining process improvements.

The study of operations in the service department in the lean way yielded design of three value stream maps, namely, spindles for normal repairs, spindles for warranty repairs, and system repairs. Opportunities for improvement were identified due to deployment of lean tools and analyses of current state value stream maps. The improvement opportunities were then instilled in the creation of future state value stream maps, which when analysed revealed double-digit improvements in the lead-time, operating costs and space requirement among others.

List of abbreviations and acronyms

BOM	Bill of materials
CNC	Computer numerically controlled
COF	Customer order form
CSR	Customer service representative
DCN	Design change notification
FK	Franz Kessler GmbH
NVA	Non-value added time
PDCA	Plan-Do-Check-Act cycle, an approach for continuous improvement
SAP	Systems, Applications, and Products in data processing, an ERP software
SD	Service department
TCSR	Technical customer service representative
TPS	Toyota production system
VA	Value added time
VSM	Value stream map
WIP	Work in progress

Table of contents

1. Introduction

This chapter provides an introduction to this thesis with brief discussions on the context in which it was built on, its objectives, research methodology deployed, thesis structure and limitations faced along its development.

1.1. Background overview

Businesses around the world are being compelled to undertake initiatives to transform their processes to be able to remain globally competitive due to intensifying competition in the manufacturing sector. Such initiatives deploy lean manufacturing as their key strategy.[1] It is obvious that due to this surging competition, dwindling resources and fluctuating economies, lean manufacturing has become quintessential to the survival of contemporary manufacturing establishments in the long run.[2]

A leading German spindle manufacturer, Franz Kessler GmbH, in this respect, resolved on implementing principles of lean manufacturing in all departments of their facility. This thesis is aimed to back their service department by employing lean philosophies. This is done by waste elimination and identification of activities that create value along the value stream of their two main product ranges, namely, spindles and systems, and wherefore an internship was carried out for a period of 6 months.

1.2. Thesis objectives

The major goal behind this thesis is to optimize the processes in the service department, which can be broken down into specific sub goals as follows:

- Perform a thorough analysis of operations in the service department (Abbr.: SD).
- Develop improvement proposals to reduce lead-times, cost and space.
- Envision the future state and perform a results analysis.

1.3. Methodology

The science which studies how a research can be conducted in a scientific manner is known as methodology. It is a systematic analysis of principles and methods applied to solve a research problem.[3] This section discusses the research methodology followed in this thesis, highlighting research approach, research strategy, case study design and quality of study.

1.3.1. Research approach

There are two main research approaches; quantitative approach, known as deductive approach and qualitative approach, which is known as inductive approach. Inductive approach is used when the issue was not previously known. This is done by, first collecting all relevant data, followed by theoretically depicting it and then forming a substantive theory to formulate the issue. Hence, it can be said that inductive research process begins with an issue and develops a theory to explain it. Deductive approach, on the other hand, begins with reviewing related literature, followed by a theoretical frame of reference on this and then applying it in the field.

[1] Cf. Vinodh/Somanathan/Aravind. (2013), P. 130; de-Arbulo-Lopez/ Fortuny-Santos/ Cuatrecasas-Arbos (2013), P. 113.

[2] Cf. Scherrer-Rathje/Boyle/Deflorin (2009), P. 80.

[3] Cf. Achari (2014), P. 21.

These two approaches are also combined to form what is known as balanced research approach.[4]

Based on the above and the fact that lean manufacturing is a well-researched subject, it can be stated that the research approach followed in this study is deductive approach, as it begins with literature review, followed by a developing a theoretical frame of reference and then applying it on the field.

1.3.2. Research strategy

There are two main research strategies, case studies and rationalist studies. Case studies, to study current state, use various data collection methods without impacting the study result. Whereas in rationalist studies, the researcher can separate pre-determined variables and relationships from their explanatory theories without dissenting the theories[5].

Since this study is devoid of such pre-defined variables and relationships, but rather tries to depict the current situation quantitatively and qualitatively, the strategy to be used is of case studies.

1.3.3. Case study design

There are a multitude of ways of designing a case study. Different designs are proposed by Stuart et al. (2002) and Vinodh et al. (2013). However, Yin (2009) supports an iterative process in case study methods. Although the design followed in this case study as shown in Figure 1.1 contain more detailed steps, it is quite similar to the ones put forward by Stuart et al. (2002) and Yin (2009)[6].

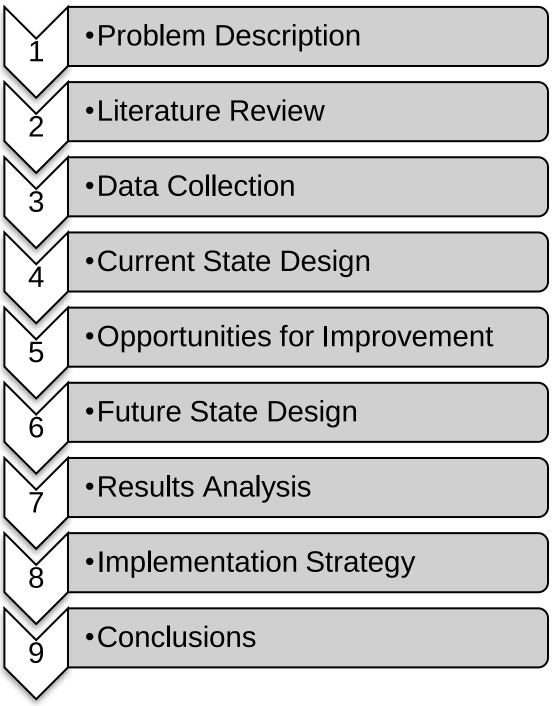


Figure 1.1: Design of case study, Source: Own Illustration.

[4] Cf. Golicic/ Davis/ McCarthy (2005), P. 17 ff.

[5] Cf. Meredith (1998), P. 441 ff.

[6] Cf. Stuart et al. (2002), P. 420; Yin. (2009) P. 28 ff.

The first stage is aimed to provide a basic understandings of the company, its operations and its limitations. To reason the problem solving approach in this study, a solid theoretical base is grounded in the second stage. This is done by conducting a literature review to revise pertinent philosophies, concepts and tools.

The third stage aims at data collection of the two main product ranges. Primary data and secondary data are two classifications based on source of data. Observations and interviews are commonly classified as primary data, whereas data extracted from a company's database is termed as secondary data.[7]

A few skills worthy of mention while collecting data, which can increase the quality are: being meticulous, a good listener, a good interpreter, unbiased and focused.[8]

Additionally, gathering the same kind of data by using different means is also known as triangulation.[9] Employing three methods, observations, interviews and data extracted from databases has led to enhancement of validity of this study. These data are then used to design the current state by means of value stream maps (Abbr.: VSM) in the fourth stage.

The fifth stage identifies optimisation potentials by analysing current state value stream maps, and consequently in the next stage future state VSMs are conceived. Besides individual work, development of improvement proposals instilled in the future state VSMs included cross-collaborations in the form of meetings with persons from various departments and hierarchies with appropriate knowledge to verify the analysed data and to note suggestions from their perspective. In the seventh stage, the results are scrutinized, followed by an implementation strategy proposition in the eighth stage. Finally, the ninth stage concludes the study and devises future work.

1.3.4. Quality of study

The quality of a study can be evaluated by three criteria: construct validity, external validity and reliability.[10] Constructive validity asks the question if the right factors were studied and right measurements were taken. In this study, the same type of data has been gathered from multiple sources as mentioned before, which results in providing high constructive validity.

External validity evaluates the quality of the study by assessing the extent to which it can be generalised. In a single-case studies, using similar theories can increase the generalisability. In this case, theoretical base is derived from lean methodologies, which are well tried and tested in such operational environments. Nevertheless, to truly generalise the results of a case study, identical multiple case studies have to be done in different environments.[11]

Reliability of a case study is said to be high, if similar results is obtainable by other researchers as well. Yin (2009) says that it can be enhanced by creating a structured case study database or a case study protocol.[12] Reliability for this study is high, as a database of data collected is formed and additionally a clear case study methodology is designed and followed throughout.

[7] Cf. Stuart et al. (2002), P. 427; Voss/ Tsikriktsis/ Frohlich (2002), P. 205.

[8] Cf. Yin (2009). P. 105 f.

[9] Cf. Voss/ Tsikriktsis/ Frohlich (2002), P. 205.

[10] Cf. Stuart et al. (2002), P. 430; Voss/ Tsikriktsis/ Frohlich (2002), P. 211; Yin (2009), P. 135 ff.

[11] Cf. Yin (2009), P. 136.

[12] Cf. Yin. (2009), P. 136.

1.4. Disposition

This thesis consists of seven chapters, structured as follows:

Chapter 1 constitutes a brief introduction of the subject, followed by objectives of this thesis, methodology, outline and limitations. An overview of spindle technology, including its history, spindle structure, spindle design, and causes and ways to mitigate failure are provided in the Chapter 2. Chapter 3 consists of an apercu of FK, layout and process in SD, concluding with the problem description. Chapter 4 presents the literature review to reason the deployed lean tools in this thesis. It starts with the history of lean manufacturing, followed by its philosophies and relevant key tools.

Current state is unveiled in Chapter 4. Value stream maps and Spaghetti diagrams are designed by means of data collection and flow determination, followed by lead-time analysis. In Chapter 5 an improvement proposal is laid out, which consists of optimization potentials, Yamazumi charts, future state value stream maps, flow and lead-time analyses, final result analysis and implementation strategy. Chapter 6 draws the thesis to a close with a conclusion and a proposal for future work.

1.5. Delimitations

The process times for this study are taken from SAP (Systems, Applications, and Products in data processing, an ERP software) database, since it was not possible to obtain permission from the workers' union to carry a stopwatch and measure the working time, this being against the company policy of protecting employees' privacy. After each process, employees feedback its duration, start date and end date. This data has been extracted from SAP database and analysed for this study.

2. Spindle technology

This chapter explains spindle technology in detail, including spindle structure with explanation on various constituents, different parameters and trends in spindle design, and spindle failure modes and preventive measures.

2.1. Introduction

Metal cutting processes are in the forefront of metal working industry, despite the influx of new production processes in recent times. Technological advancements in the machine tool industry have made products and processes faster, cheaper and more reliable. Nevertheless, the backbone of machine tools remains the same i.e. spindle, moving axes and cutting tool; of which the spindle is of utmost importance. Spindles play the same role in cutting process by rotating the tool or work piece with appropriate speed and torque against the other one that is fixed, although they differ in their design for various machine tools.[13]

Spindles were powered by steam engines in early industrial ages and consequently pneumatic and hydraulic power were used.[14] This has now culminated to being mostly powered by electric motors these days. If the motor is outside the spindle housing, it is known as externally driven spindle and if it is coupled with spindle shaft inside the housing, it is referred to as internally driven spindle. Companies catering to the high-end market prefer internally driven spindles due to their superior performance and space advantage in small and medium size segments. However, externally driven spindles find more prominence in the large size segments, since motor integration becomes difficult at this level.[15]

2.2. Spindle structure

As mentioned earlier, due to higher performance and efficiency, most of today's spindles are internally driven type. Due to practical reasons, externally driven design is adopted for spindles with bearing inner diameter higher than 150 mm. Basic structure of a typical spindle includes spindle housing, spindle motor, spindle shaft, and spindle bearings.

2.2.1. Spindle housing

Functional parts of a spindle like spindle shaft, bearings etc. are built inside the housing, which is the unit that holds spindle structure its components together. Its main duty is to support and station the bearings and it must be robust because forces generated on the spindle during operation will be transmitted to machine body along it.[16] Spindle housing can be designed as part of the machine tool body, or as cartridge housing type. Nowadays, cartridge type spindles are more popular due to better serviceability and they require extra housing to mount the complete cartridge unit.[17]

2.2.2. Spindle bearings

Bearings act as an interface between spindle and its housing. Since housing itself is purposed to withstand the reaction forces, bearings greatly determine the life of a spindle due to stresses induced by cutting forces.

[13] Cf. McNeil (2002), P. 389.

[14] Cf. McNeil (2002), P. 389.

[15] Cf. de Lacalle/ Mentxaka (2008), P. 80.

[16] Cf. de Lacalle/ Mentxaka (2008), P. 104.

[17] Cf. Popoli (1998), online source [01.09.2020].

To withhold the spindle and bear those forces, a minimum of two sets of bearing, one each on the front and on the back are provided depending on the technical and design specifications. Internal motor is usually placed between the two bearing sets on the shaft.[18]

2.2.3. Spindle motor

Spindle motors are of two types, external and internal, as mentioned before. External motor is independent from the spindle system and drives the spindle by either direct coupling or by means of a belt, chain or gear. Their main drawbacks are loading on bearings due to such transmission systems, lower speeds and lower efficiency.

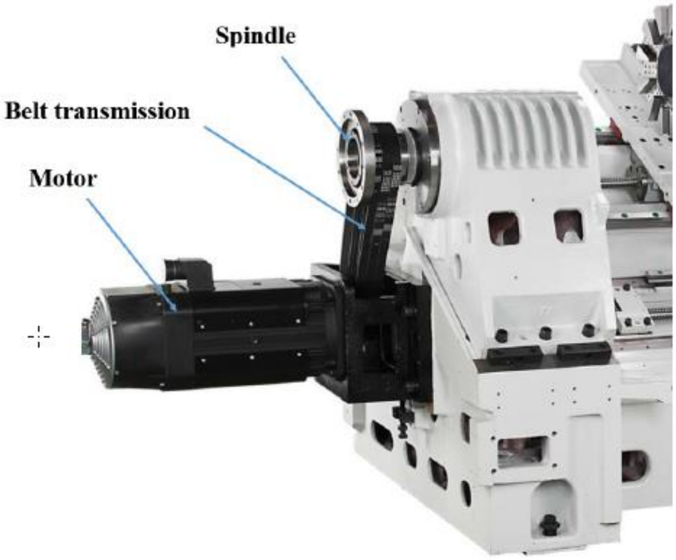


Figure 2.1: Externally driven motor with belt transmission, Source: Hurco (2014), online source [01.09.2020].

In internally driven spindles, motors are an integral part of the spindle system. Unlike external motors loading on the bearing and vibrations or losses due to transmission systems can be completely avoided. However, heating and complex structure calls for cooling system and specifically, active cooling due to high power to volume ratio. Liquid based cooling, where coolant flows along a cooling sleeve around the stator of motor and outer bearings. The need for cooling results in making it more expensive and hence a main drawback.[19]

Based on magnets on rotor, material, geometry, and rotation of the rotor, internal spindle motors can be classified into synchronous or asynchronous. Rotors are made of steel and bars of aluminium or copper in asynchronous motors. The rotor rotates in the magnetic field due to the current and voltage flows through the laminations induced by the magnetic field generated in the stator. Phase difference between the rotor and magnetic field rotation, however, has a negative impact on efficiency and accuracy. Synchronous motors overcomes this because slip effect is prevented by their permanent magnet rotors and enhanced thermal properties and power are imparted by phase differences.[20] Soshi, et al. (2011) noted that synchronous motors enables spindles to perform better for heavy cutting operations. Synchronous motors though more expensive than their counterparts, are gaining ground due to better performance and smaller size and hence manufacturers have been increasingly adopting them.[21]

[18] Cf. Smith (2016), P. 477.

[19] Cf. Stephenson/Agapiou (2018), P. 129.

[20] Cf. Stephenson/Agapiou (2018), P. 129.

[21] Cf. Soshi et al. (2011), P. 399-402.

2.2.4. Spindle shaft

It is the main rotating part in the spindle system, it holds the components together and bearings sit on it. Robustness of the shaft affects the performance of the spindle as it is plays a major role in withstanding cutting forces.[22]

2.2.5. Other components

Encoders are used to continuously track speed and measure angular position of the spindle to enhance machining quality. Temperature sensors to check motor temperature, proximity sensors to determine position of clamping system, and sensors to monitor bearings and process stability could be additionally integrated.[23]

Based on its application, a tooling system and a drawbar for tool retention along with clamping and unclamping systems could be additionally integrated in the spindle. For milling operations, clamping systems are deployed to secure the tool holders by means of a tool interface such as HSK, SK, etc. to the spindle, whereas for turning and grinding operations, work piece can be clamped or unclamped.[24]

Furthermore, O-rings, seals and protection flanges play an important role in ensuring that the spindle is water-proof since early failure can occur due to water-sensitivity of bearings.[25]

2.2.6. Spindle Bill of Materials

A spindle is assembled by putting together a plethora pf parts. Apart from the major components discussed above, there are many other components, which will be enlisted in this section to give a holistic overview of spindles. The figure below represents a typical spindle. The bill of materials (Abbr.: BOM) can be found in Appendix A.

[22] Cf. de Lacalle/ Mentxaka (2008), P. 103.

[23] Cf. de Lacalle/ Mentxaka (2008), P. 103.

[24] Cf. Abele/Altintas/Brecher (2010), P. 792 ff.

[25] Cf. Abele/Altintas/Brecher (2010), P. 781.

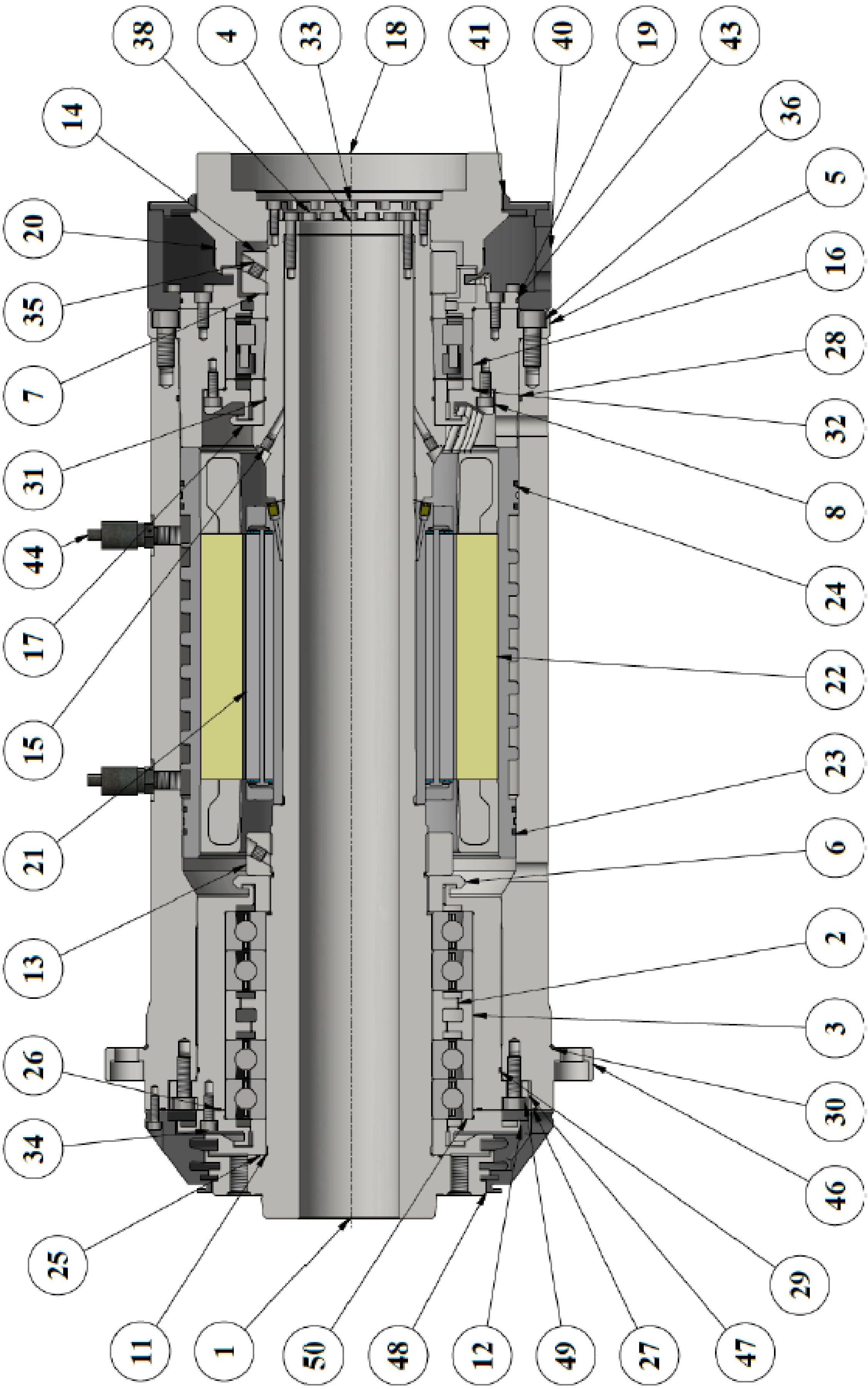


Figure 2.2: A typical spindle assembly, Source: Kutlu (2016), P. 69.

2.3. Spindle design

This section covers various aspects of spindle design, such as spindle properties and performance, design considerations and current industrial trends in spindle design.

2.3.1. Spindle properties and performance

Four major properties determine spindle performance. They are dynamic behaviour, thermal behaviour, stiffness, torque and power:[26]

Dynamic behaviour of spindles is governed by vibrations, which are divided into two types- forced and self-excited. Variable chip thickness and process interruptions are the main causes of forced vibrations, which implies that they are inevitable during normal course of operation and need constant monitoring to avoid spindle damage. Self-excited vibrations are caused due to tool imbalance. Use of inadequate tools can cause a shift of critical speed close to operating speed in high-frequency spindles, resulting in imminent damage.

Thermal behaviour of spindles entails the three types of heat transfer, namely, conduction, convection and radiation. Contact between tool and work piece, for instance, induces heat transfer in the form of conduction. Heat transfer by means of convection takes place when coolants come in contact with the rotating tool. Radiation, which is quite inconspicuous, occurs due to the high surrounding temperature affecting a component. To improve performance of spindles with respect to temperature changes, all three modes of heat transfer should be considered.

By using power and torque versus speed curve, the characteristics of a spindle can be defined. This is shown in Figure 2.4. Two types of curves can be found, constant torque curve and knee curve. Although in constant torque spindles, the power increases along with speed, Maximum torque achieved is less than “knee-type” spindles. In “knee-type” spindles, torque stays constant till “the knee” and then lowers down, whereas power raises linearly till the knee and then stays constant. Both small diameter tools that require high speed and large diameter tools that require high torque are deployable in such spindles. Factors like spindle’s speed range, shape and precision degrees, nature of cutting tools and work piece material need to be considered in evaluating power and torque requirement.

[26] Cf. de Lacalle/Mentxaka (2008), P. 105-115.

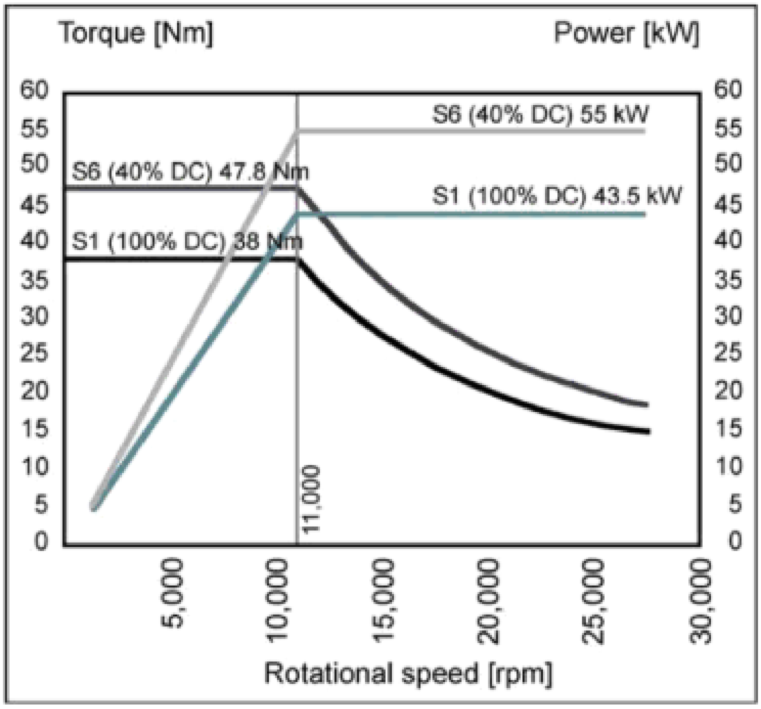


Figure 2.3: Spindle power and torque curves of a typical spindle, Source: de Lacalle/Mentxaka (2008), P. 106.

Deflection of tool tip due to impact of cutting tools affects static behaviour of the spindle. A spindle can be considered as a beam supported on front and rear bearings. However, stiffness of spindle depends on its housing, because bearings are inserted in it. Deflection from bearings, beam and deflection derived from flexibility of bearing accommodation into housing are added to give the total deflection of spindle.

2.3.2. Design considerations

Spindles are often designed with consideration of the following constraints: spindle type (externally or internally driven), size, power, speed, maximum load, tooling style, part availability and cost.

Spindles are demanded with different specifications based on their application. For instance, high speed cutting of aluminium can be done with high-speed spindles of low stiffness, whereas machining nickel based alloys demand low speed, high load enduring spindles.[27] Design specifications vary according to the following: work piece material, cutting conditions, and tooling. With consideration of these factors, Maeda, Cao and Altintas (2004) developed a design methodology using fuzzy logic.[28]

Many factors affect spindle life. Although bearings play a major role in it, overall performance depends on shaft, preload and spacing of the bearings, centrifugal forces, stiffness, and material properties. Machining efficiency and quality is affected by static and dynamic stiffness of the spindle. Speed of a spindle is set considering factors like friction, thermal stresses and load carrying capacity of bearings.[29] Altintas and Cao (2005) developed a FEM model to achieve better stiffness and material removal rate by simulating spindle size.[30]

[27] Cf. Abele/Altintas/Brecher (2010), P. 783.

[28] Cf. Maeda/Cao/Altintas (2004), P. 543.

[29] Cf. Sawamoto/Konishi (1982), P. 200 ff.

[30] Cf. Altintas/Cao (2005), P. 380.

2.3.3. Design trends

Three major trends of spindle configuration that has become popular recently are enlisted below:[31]

1. Low-cost, high-torque spindles: These are used for heavy-duty purposes, where cost is the major factor in spindle selection. Such spindles usually are externally driven type, with a belt transmission. They are very common in heavy-duty CNC turning centres.
2. Flexible, general purpose with automatic spindle change: Spindles of this type are well suited for manufacturing environments that demand high flexibility, productivity, serviceability and dynamic performance. They are usually equipped with asynchronous motors that possess high-speed and high-torque characteristics. The spindle units are coupled with motors, which saves space requirements and imparts aforementioned characteristics of flexibility, serviceability etc.
3. High-speed, high-power, medium and high performance spindles: As mentioned before, internally driven spindles has become the norm these days. The synchronous or asynchronous motors incorporated into the spindles are capable of speed well beyond 20,000 rev/min and up to 80,000 rev/min. Spindles with synchronous motors have the advantage of better performance and quality are commonplace for CNC milling, coaxial mill/turn centres, grinding and for pick up and high performance CNC lathes.

2.4. Spindle failure and preventive measures

A spindle is prone to a number of vulnerabilities, as is obvious from the previous sections. These vulnerabilities can possibly lead to failures. Spindle failures are mostly unpredictable. This section deals with causes of failure and preventive measures:[32]

A major cause is collision, which results in severe physical damage. Rolling contact bearings are most affected among other components of spindle. The contact area between the races is small and on being impacted with huge collision forces, causes an increase in interface pressure above desired level, resulting in deformation of rolling elements. Permanent denting of a shaft can occur due to axial or radial impact to it, which too causes rapid deterioration of bearings. Damage to tooling and clamping systems are also obvious. Since spindles are very sensitive, vibration impacts on them should be limited and appropriate handling be ensured to keep up their performance.

Over time, gradual wear and tear of parts can cause the spindle to breakdown. Parts usually prone to wear include stator, rotor, shaft, front, rear, and main housings, bearings, encoder, drawbar springs, and front shaft nut. A part replacement has to be done if any of the aforementioned parts show signs of wear.

[31] Cf. Smith (2016), P. 475-476.

[32] Cf. Smith (2016), P. 478-485.

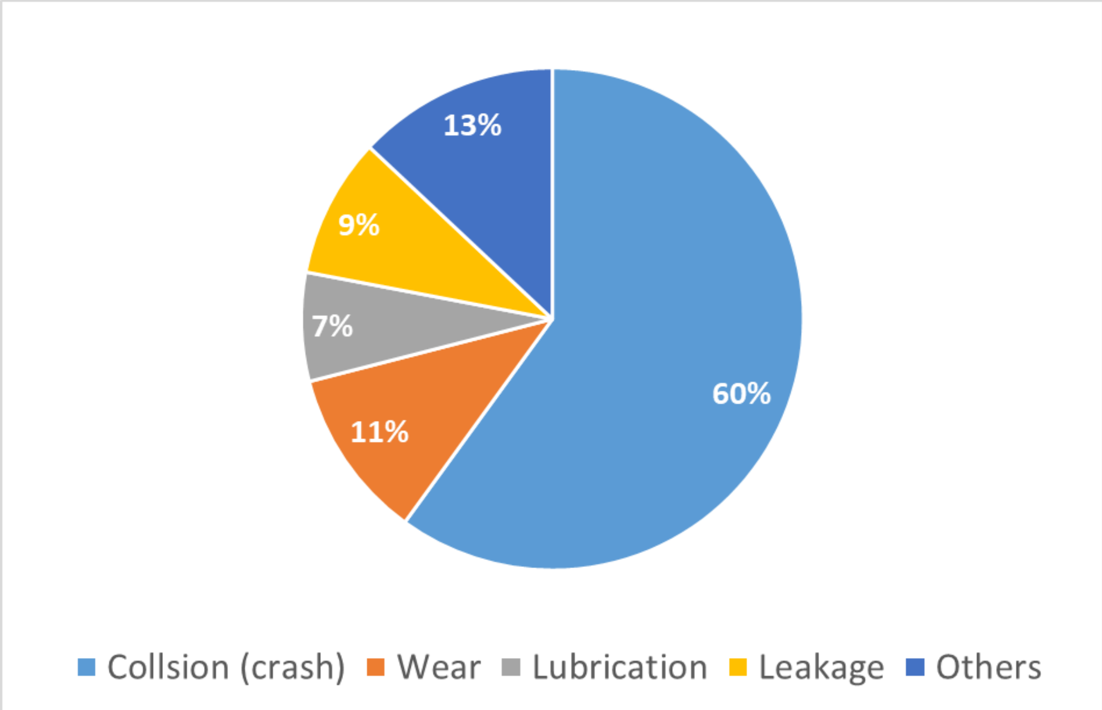


Figure 2.4: Causes of spindles failure, Source: Based on Design world (2012), online source [01.09.2020].

Overheating due to excessive heat generated by improper lubrication can cause drastic reductions in efficiency, power and speed. Proper amount of the right lubricant supply at the right time is to be ensured. While replenishing, pockets and pathways of lubrication must be inspected to ensure that foreign substances did not contaminate them. Quality, integrity and conformity of lubricants must be always ensured and should be stored in an environment free from any contaminants.

External agents like condensed coolant, chips and debris can have unprecedented impacts on bearings, shafts and electronics. Such risks can be avoided by ensuring proper sealing. Coolants should be directed straight to the tool or work piece and distant from spindle as much as possible. Other causes of failure include, but not limited to bearing overload, tool-change errors, improper repair, etc.

Longer life of spindles can be ensured by several measures, including but not limited to the following:[33]

- Balancing of tool holders should be done properly, which can help prevent vibration and mitigate failures like collision. This should be meticulously done in case of high-speed spindles.
- For spindle and its bearings, an ample supply of clean oil should be guaranteed.
- To monitor quality of air a regular maintenance check for lubrication system is to be scheduled.
- Blowing compressed air into the seals must be avoided as this enables entry of contaminants. This is commonplace when cleaning and can result in spindle failure.
- To prevent washing out of grease in bearings, and entry of chips and contaminants, coolants should be directed straight to the tool or work piece and distant from spindle as much as possible.
- Monitoring speeds and feeds, cooling system, temperatures and noticing unusual noises help to detect failures before they occur.

[33] Cf. Smith (2016), P. 483 f.

3. The case study

This chapter begins with a short description of the company's evolution to add context to the case study. This is followed by an introduction to their product range and a portrayal of processes and operations of their service department.

3.1. Introduction to the company

Franz Kessler GmbH was established in Chemnitz in 1923 as a special motors factory to serve machine tool and textile machine industries. After the Second World War, the company was moved to its present location in Bad Buchau. Through constant development of their product range, they attained an outstanding reputation as a motor manufacturer and years on with their experience in producing motors for main drives in machine tools industry, they have now garnered a respectable position in the field of motor spindles.

Figure 3.1: Locations across the globe, Source: Franz Kessler GmbH (2019), online source [01.09.2020].

Currently Europe's biggest spindle manufacturer, the company has become the leading supplier of motor spindles as well as directly driven 2-axis heads and rotary tilt tables (to be collectively referred to as systems henceforth) for the machine tool industry. The product range caters to various industrial sectors, processes and applications. Their main clients include DMG MORI, GROB, and SW etc. The company is present in Europe, Asia and North America employing over 850 people worldwide.[34]

3.1.1. Product range

The product range, divided into Spindles and Systems along with their subsequent product lines are illustrated in Table 3.1 below:

Spindles	H line, V line, MT line, PC line
Systems	Head line (1-axis, 2-axis), Table line (1-axis, 2-axis, multi-axis)

Table 3.1: Product range, Source: Own Illustration.

[34] Cf. Franz Kessler GmbH (2019), online source [01.09.2020]

3.2. The service department

Over the course of operation, it is quite natural for the spindles to break down due to gradual wear and hence a repair or a replacement is imperative to avert operational disruptions. The SD therefore caters to these frequent repair requirements. It operates on normal shift five days a week (40 hours per week). The company provides warranty for its newly sold spindles as well as repaired spindles and it covers periods of one or two years based on agreement with respective customers.

To provide a quantitative outlook, yearly and monthly demand since 2016 in the SD were derived from the SAP system and are presented below in Figure 3.2 and Figure 3.3 respectively. While the annual figures show constant rates of incoming repairs except for a slight dip in 2018, monthly figures show high degrees of fluctuation throughout the years.

In addition to the product range, the incoming repairs in the SD are further divided based on the kind of maintenance required into normal repairs, repairs on warranty, minor repairs, test run and products that are likely to be scrapped due to extensive wear and tear. Table 3.2 illustrates the data for the last 12-month period, i.e. May 2018 to April 2019, on which this study is based on, divided into product ranges and type of maintenance required.

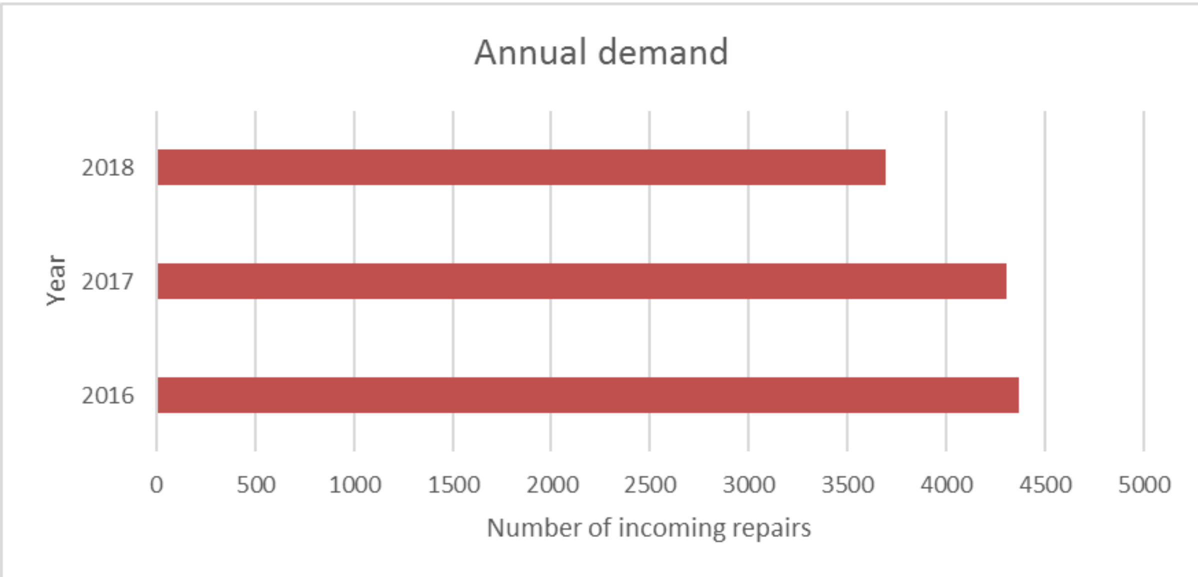


Figure 3.2: Annual repair demand, Source: Own Illustration.

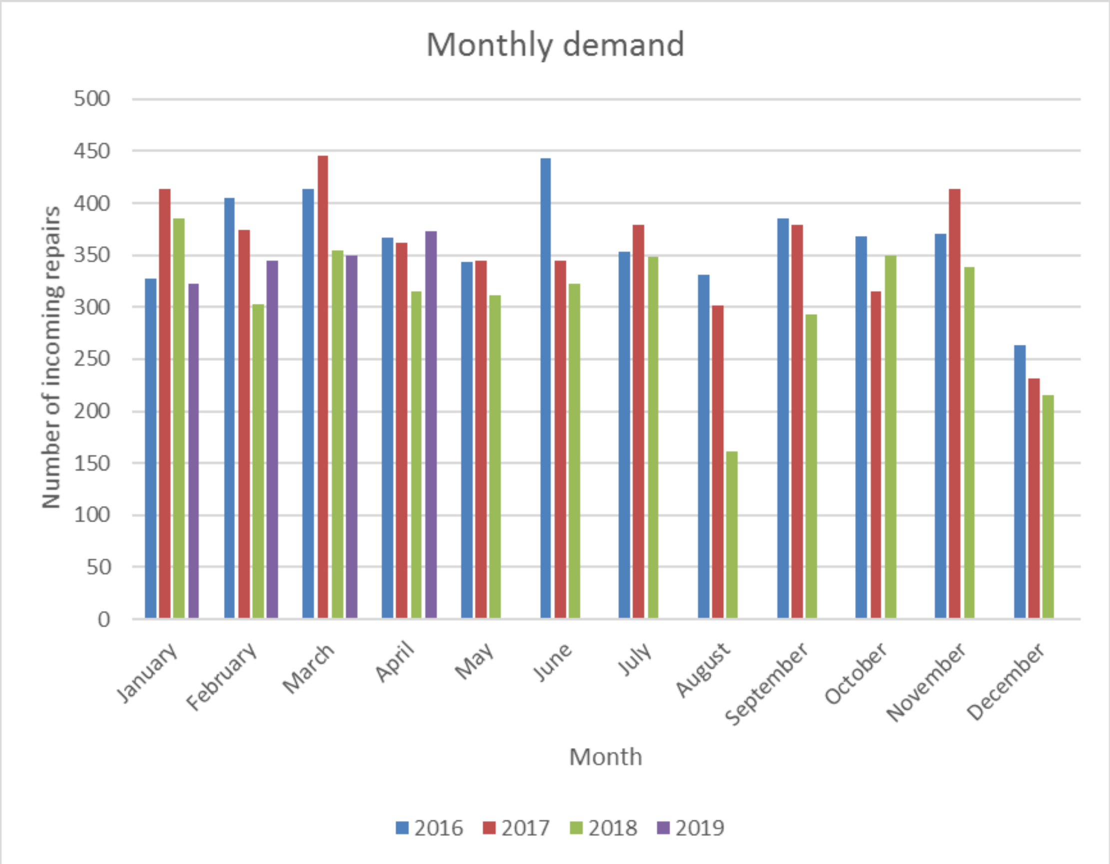


Figure 3.3: Average monthly repair demand, Source: Own Illustration.

Product range and type of maintenance	Demand
Normal repairs (Spindles)	2403
Warranty repairs (Spindles)	620
Systems	85
Test run	100
Minor repairs	180
To be scrapped	380
Total	3768

Table 3.2: Demand for the last 12-month period, Source: Own Illustration.

The SD’s core activities take place in the shop floor, which is divided into eight main areas: the unpacking area, the incoming inspection area, the normal and warranty disassembly area, the pre-cleaning area and cleaning area, the minor repairs area, the electrical inspection area, and the final inspection area. In addition, there is a system disassembly area in a different section of the plant due to lack of space in this hall. To achieve its operational goals and therefore maximum customer satisfaction, a high degree of coordination between the operational areas is required. For a better understanding of the SD’s needs and specifications, an overview of the shop floor is provided in the following section.

3.2.1. Shop floor overview

This section describes the service area and its operational areas in the plant layout. It is shown in Figure 3.5 in order to visualise each area more clearly. The description of the areas is structured in the following sequence: unpacking area (marked in light turquois), incoming inspection area (marked in gold), normal disassembly area (marked in lavender), warranty disassembly area (marked in red), pre-cleaning and cleaning area (marked in turquois), minor repairs (marked in rose), electrical inspection area (marked in brown), final inspection area (marked in sea green), and system disassembly area (highlighted with light blue in Figure 3.4). Each area is described in more detail as follows:

Unpacking area: It consists of a workbench, a pallet dispenser and two waiting zones-one for the wooden crates that are transported from warehouse to the unpacking area and the other one for the unpacked products, which have been subsequently placed on pallets and are waiting for incoming inspection.

Incoming inspection area: It comprises of three test benches each operated by an incoming inspector. Each test bench is equipped with necessary mechanical, hydraulic, pneumatic and electrical testing equipment along with a computer and a workbench. After the incoming inspection, spindles that are to be disassembled are directly loader to the conveyor belts on either sides of the hall, whereas systems are transported to the system disassembly area.

Normal disassembly area: It is divided into six work benches each operated by a disassembler. Each workbench consists of necessary tools and fixtures for the operation. Computers, cranes, presses, tool racks and concentricity measurement apparatuses are shared with one or two other workbenches.

After disassembly, the disassembled components are transferred to the pallet and moved to the main conveyor belt.

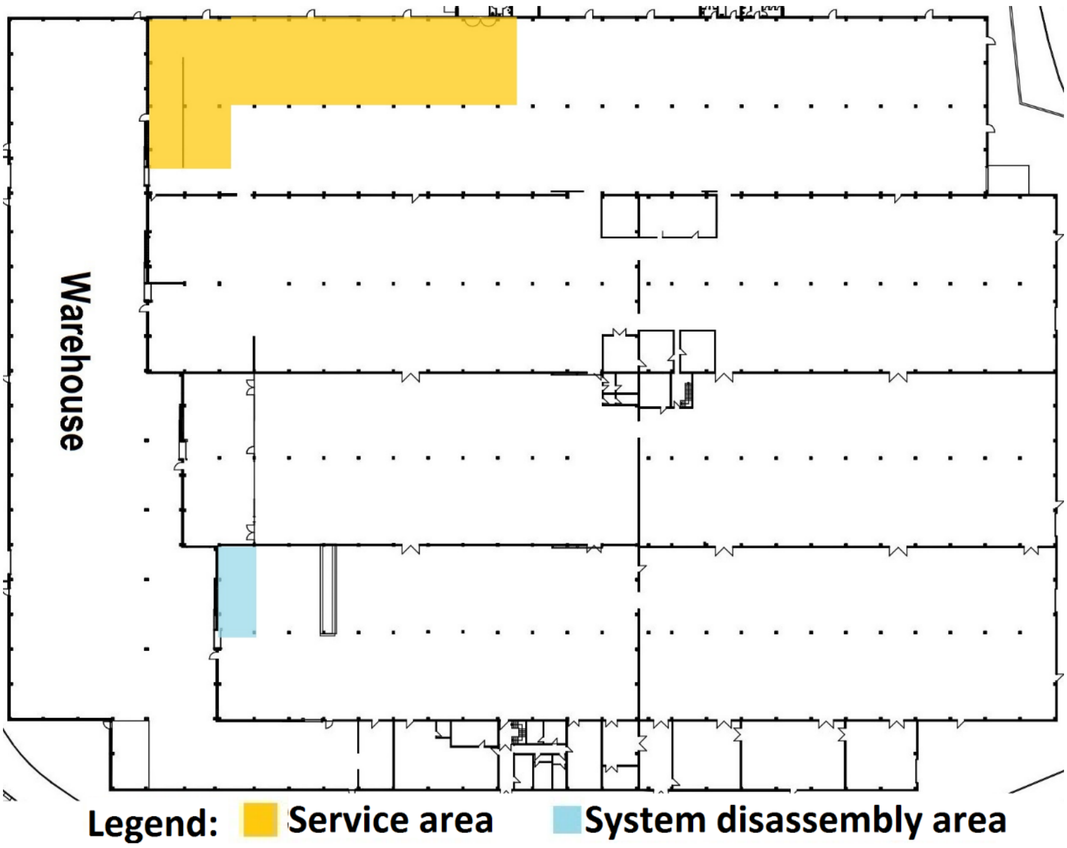


Figure 3.4: Plant layout highlighting service area and system disassembly area, Source: Own Illustration.

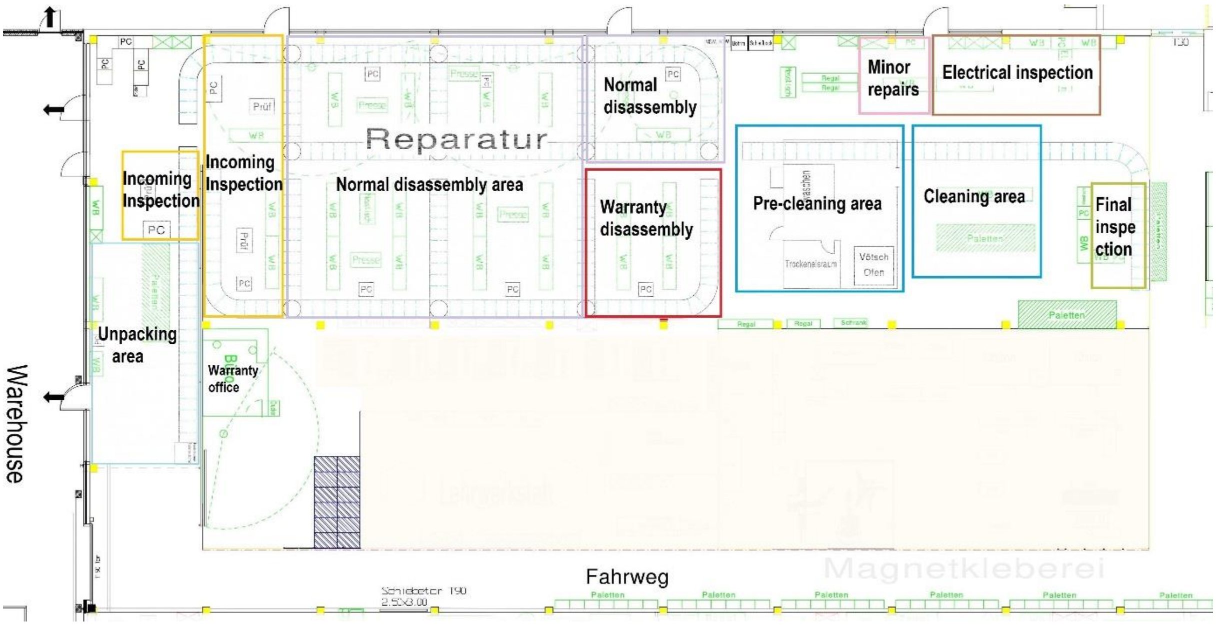


Figure 3.5: Service area in the plant layout, Source: Own Illustration.

Warranty disassembly area: It is divided into three workbenches each operated by a disassembler. Similar to the normal disassembly area, each workbench consists of necessary tools and fixtures for the operation. Computers, cranes, presses, tool racks, imaging setup and concentricity measurement apparatuses are shared with other workbenches. After disassembly, the disassembled components are transferred to the pallet and moved to the main conveyor belt.

Pre-cleaning and cleaning area: Spindles and systems after disassembled head towards pre-cleaning area. It consists of a large washing machine, dry ice blast cleaning room and an industrial oven. After pre-cleaning the pallets head to the cleaning area, where each component is cleaned again manually. It has two waiting areas, one, where pallets of disassembled systems are waiting to be cleaned and another for washed stators waiting to be placed in the oven for drying overnight.

Electric inspection area: After cleaning, stators are picked from each pallet by crane to the electrical inspection area. It is equipped with multiple electrical testing equipment and a computer. It has a waiting area, where stators that were not able to be electrically inspected on time are queued together, transported to the warehouse and placed on corresponding pallets.

Final inspection area: After cleaning and stator inspection, the pallet on the conveyor belt arrives at the final inspection area. A single inspector performs 100% quality check on components in the pallet. Parts for rework are moved into the rework entry station and the pallet is transported to the warehouse by means of a forklift.

Minor repairs: Products with minor part replacements need not go through the entire process. Instead, after incoming inspection, they are transported to the minor repairs area. It is equipped with necessary tools, spare components and fittings to prepare the product for test run. It also has a waiting area, where the product waits either to be operated or to be sent for test run.

System disassembly: As mentioned before, due to bigger space requirement for disassembly of systems, which are significantly larger than spindles, they are therefore disassembled in another hall within the same facility. It consists of a work bench equipped with necessary tools, a crane, a computer and a waiting area, where systems wait either to be disassembled or to be sent for cleaning in the other hall.

In order to discuss issues and progress, a general meeting is held twice a week with department manager and supervisors. The main focus point of the meeting is to provide an overview of weekly situation and discuss recent problems and measures taken. A similar meeting termed as “shop floor meeting” is held with supervisors and workers when required.

3.2.2. Process overview

This section depicts the operational scenario in SD, which includes information flow followed by material flow.

3.2.2.1. Information flow

Information flow starts when the customer contacts the technical customer service representative (Abbr.: TCSR) via phone or email and subsequently informs him of dispatching the spindle to FK. Products are to be dispatched by customers with an error checklist provided by FK (shown in Appendix B), which when filled can give an overview of the defect that has occurred. After the product is arrived and unpacked, the unpacker enters the details of the product and information from error checklist into SAP, followed by scanning and e-mailing of the customer delivery note addressed to the respective customer service representative (Abbr.: CSR). An SAP registration number for the product is automatically generated at the end.

The email scanned by the unpacker reaches a central email pool in the service office. One CSR and one TCRS are designated for each customer by FK.

If the customer has made a warranty claim, the designated TCSR checks it and categorises the emails into normal repair or warranty repair. Now, CSR creates a link between the customer’s delivery reference number found on the delivery note and the SAP registration number in the SAP system. This is followed by a series of operations in SAP to generate a customer order form (Abbr.: COF) containing a repair number, which is then transferred downstairs to the shop floor. The COF is placed in a yellow folder in case of warranty repair and blue folder if it is a normal repair. By the time incoming inspection is done, the supervisor attaches the COF indicated by the folder colour to the product and it is then transferred to normal or warranty disassembly accordingly. After each process, the operator gives a feedback into the SAP system, so that the progress is tracked. The information flow in SD is as illustrated in Figure 5.3.

3.2.2.2. Material flow

As depicted in Figure 3.6, material flow starts with customer delivery. The product is then unpacked and the incoming inspection is done. After incoming inspection arise various situations:

Case 1: If only minor parts replacements are required, the product is transferred to the minor parts replacement workbench, where the parts are replaced and the product sent for test run. Test run is a set up where the product is run continuously in ideal operating conditions for eight hours or more in order to simulate its performance. If the results are within desired limits, the product is sent to warehouse, where it waits until customer clearance for dispatch is received.

Case 2: If the product has damages or a few parameters that are out of range, which could be rectified by rework, then the product could be disassembled. Here too arises three different scenarios. Now, if it is a spindle out of warranty period or not complacent to warranty criteria, then it goes to the normal disassembly area. If it is within the warranty period and fulfils warranty criteria, it is sent to the warranty office. The warranty officer inspects the spindle and decides whether to take it to the test run or proceed to partial or full disassembly, in which case the spindle is transferred to warranty disassembly.

Now, if the product is a system, it goes to the system disassembly area in other hall as shown in Figure 3.4, it comes back to the main service area after disassembly and follows the normal course like other disassembled spindles, i.e. cleaning, electrical inspection, final inspection and is finally stored in warehouse, where it waits until it is taken to assembly department for re-assembly.

Case 3: If the product is found to be heavily damaged or parameters irreparably out of range, then the product is sent to be scrapped. This is, however, a total loss for the customer.

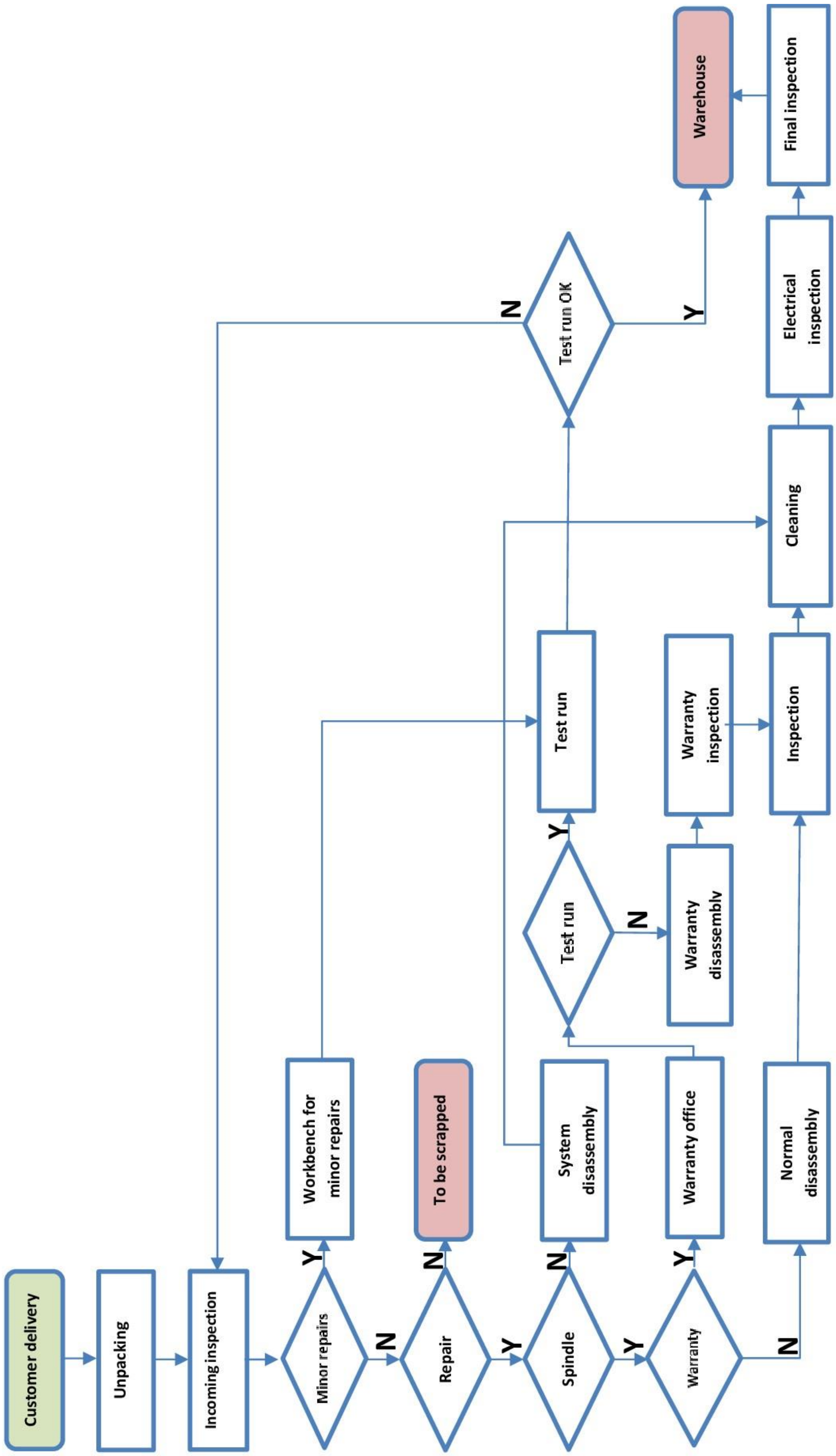


Figure 3.6: Flowchart illustrating material flow, Source: Own Illustration.

3.3. Problem description

A spindle or system repair passes through multiple stages, from analysing its components in the present condition to performing tests on the newly rebuilt spindle. The flow throughout the service area is generally not continuous during working hours and is struggling with high amounts of work in progress (Abbr.: WIP) between workstations.

The SD does not find its performance to be up to the mark; the operational costs and lead-times being too high. Both the company and the customers deem the lead-times to be several days too high and it is imperative to be reduced. More precisely, in the last 12 months, lead-times averaged up to eleven working days. The goal is to lower it by more than 50 %.

In brief, the SD is in great need of improving its operations and in particular, areas to be discussed later on that presently hinder efficient operations. The development of this thesis aims to support the SD's objectives for leaner operations, and therefore, it is crucial to take several lean tools and methodologies into consideration.

4. Literature review

This study is based on lean methodologies, a prominent manufacturing archetype these days.[35] By spotting and eliminating waste and employing lean tools, companies can boost their productivity, enhance quality and achieve better cost effectiveness.[36]

Although lean methodologies come with great benefits, ensuring its effectiveness require tedious jobs of reaching higher levels of organizational commitment, employee autonomy, and information transparency.[37]

This chapter is dedicated for a literature review on lean methodologies-its history, principles and tools that are to be used in this study.

4.1. History

The very idea pf mass production by Henry Ford brought about a revolution at the dawn of last century, in which different components are assembled in an assembly line, where each worker along the line has a single task and resulted in a complete car at the end of the line. Results of this idea were, in 1928, Ford cars were priced at a quarter of what it used to be before twenty years and one in two cars sold in the US was a Ford, each manufactured with a takt time of one minute.[38] These impressive figures are results of employing principles of economies of scale, whereby, the more you produce, the lesser it costs.[39]

It was around these times, that the Toyota Motor Corporation was established, in the year 1935 to be exact. Met with little success in the beginning, managers visited the US to be acquainted with production systems of automotive giants there. However, they realized that they had to adapt those production systems to suit the Japanese market, as it was much smaller and rather disjoint even before the onset of World War II.[40]

On the aftermath of the war and with a near devastated economy, Taichi Ohno, who would later define the Toyota Production System (Abbr.: TPS), sets out once again to the US. This time he was taken aback as he observed the principles of mass production were still deployed without any innovation, which accrued inventory levels. Then again, Toyota would not be able to replicate their success due to low volumes and lack of financial means, space and warehouses.[41]

Toyota realized that only a fraction of the total lead-time added value to the end customer.[42] They then chose to renovate the American model by eliminating wastes of all kinds, enhancing throughput and empowering employees to suggest improvements to problems that came along, and hence TPS came into existence in 1949.[43]

35 Cf. Holweg (2007), P. 420.

36 Cf. Imai (1997), P. 8.

37 Cf. Scherrer-Rathje/Boyle/Deflorin (2009), P. 81.

38 Cf. Womack/Jones/Roos (1990), P. 25.

39 Cf. Hindle (2008), P. 71.

40 Cf. Liker (2004), P. 20.

41 Cf. Liker (2004), P. 20.

42 Cf. Melton (2005), P. 662.

43 Cf. Womack/Jones/Roos (1990), P. 48.

Two well-known works, The Machine That Changed the World by Womack et al. (1990) and Lean Thinking by Womack and Jones (2003) referred TPS to as lean production, which made the term 'lean production' more popular.[44]

4.2. Definition

"The machine that changed the World" by Womack et al. (1990), which became one of the most cited books on operations management introduced the term Lean Production and compared the Japanese and American models.[45]

The socio-economic conditions prevailed in Japan after World War II contextualises the characteristics that define lean manufacturing. This situation of rebuilding its industries from scratch allowed them to instil new values and norms from within and hence, Lean methodologies, which aimed to eliminate waste and ensure that time is spent only on value added activities was a perfect fit for this situation.[46]

Value is what the customer wishes to pay for and value is added when an activity unequivocally creates value. In pragmatic terms, lean involves an array of tools shaped to eliminate wastes of all kind.[47]

4.3. Lean thinking

Lean methodologies aim at diminished and efficient usage of all resources i.e. man, material, space etc. However, it should be noted that rather than merely reducing resource utilization, lean methodologies aims at their efficient use. More than just in shop floor, lean methodologies can be deployed anywhere labour, capital and energy interact to improve time, cost and quality.[48]

Lean perceives a process as a medium to deliver value to customer.[49] It devises means to identify value, arranges value-adding process together, and executes them efficiently on demand. According to a study, companies who deploy lean tools are quite ahead of others producing according to principles of mass production in terms of cost and quality. Incorporating lean demands for a culture to improve, a pull system and achieving continuous flow.[50]

4.3.1. Lean principles

There are five guiding principles for successful implementation of lean.[51] This is illustrated in the figure bellow.

[44] Cf. Melton (2005), P. 662.

[45] Cf. Holweg (2007), P. 420.

[46] Cf. Womack/Jones/Roos (1990), P. 50.

[47] Cf. Shah/Ward (2007), P. 9.

[48] Cf. Di Dio (2018), P. 122.

[49] Cf. Melton (2005), P. 663.

[50] Cf. Womack/Jones (2003), P. 17.

[51] Cf. Womack/Jones (2003), P. 6.

Figure 4.1: 5-step thought process for guiding lean implementation, Source: Lean Enterprise Institute (2019), online source [01.09.2020].

The first step in the cycle starts with identifying value from end customer's perspective across all product families. Next, track down all process steps in the value streams and eliminate non-value adding steps. Rearrange those value-adding process steps together to create a flow and in the next step, customers pull the product at the right time. This cycle is repeated over and over again until a state of perfection with zero waste is attained.[52]

4.3.2. House of lean

The house of lean symbolises the qualities of TPS and has turned out to be one of the unmistakable images associated with lean methodologies. A house requires a solid framework, whereby, the foundation, columns and rooftop should be equally strong to sustain, and hence selected as symbol.[53] These structures, which together form the house of lean are detailed as follows:[54]

A strong foundation sets up a fruitful execution of lean, bringing about improved quality, deliverability, and consumer loyalty. This is quite significant in light of the fact that it is nearly impossible to retain changes without stable processes. For standardized work, 5S framework can be deployed, which imparts a strategy for eliminating waste and is the foundation of many lean frameworks.

[52] Cf. Womack/Jones (2003), P. 6-14.

[53] Cf. Liker (2004), P. 7.

[54] Cf. Bicheno/Holweg (2016), P. 4-5.

Figure 4.2: House of lean, Source: United States Environmental Protection Agency (2017), online source [01.09.2020].

Pillars enhance production and quality. Lean tools used to form the columns incorporate Just-in-Time (JIT), and Jidoka. Pull system and Heijunka together form the pillar of JIT. It minimizes inventory to the bare minimum so that costs and flexibility are enhanced. Pull system is where a customer pulls products from the last upstream process at the right time. Raw material is purchased when production is needed and production takes place only on behest of the customer. This ensures that orders are finished as demanded, disposing of waste brought about by excess WIP and overproduction. Heijunka enables to produce across different product mixes, while ensuring pull by analysing and planning through product and order fluctuations.

The next pillar is Jidoka, by which defect-free products are ensured to customers enhances quality. Processes, which are equipped to autonomously identify defects, stop until the cause is spotted and eliminated, using tools like Five Whys. Hence, Jidoka is often referred to as “automation with a human touch”. Tools used are 5 Whys and Poka-yoke. “Why” is asked multiple times until root cause of the issue is found and eliminated. Poka-yoke designs mistake-proof processes or makes the mistakes discoverable on the course of processes. 100% quality is hence assured without any inspection.

The roof symbolises customer orientation: to provide right quality of product, at right price, and on right time. With customer orientation, processes are better designed to meet their demands by eliminating processes that do not create value for them.

4.3.3. Lean Wastes

A waste is anything that is not being paid for by the customer, neither does it create value to the product nor does the production system need it. The Japanese term “muda” meaning futile is associated with waste, as it consumes resources without adding value.[55] James Womack added one more waste to the seven deadly wastes defined by Taiichi Ohno, mentioned below:[56]

- Overproduction: Contrary to JIT, producing more than customer’s demand.
- Transportation: It is not being paid for by the customers as it does not create value for them. Risks associated with transportation include damage, loss, and delay.
- Inventory: Inventory come in different types: WIP, raw materials or finished goods. Excessive inventory adds up costs in form of handling and labour.
- Motion: It includes unnecessary movement of workers and transmission of documents in electronic form or otherwise that are not required to fulfil a task, which might be caused by mediocre layouts, or process designs leading to excessive movement of man, material or information.
- Waiting: It is the time waited by man, machine or document for a previous process to end before starting the next, in which it remains idle.
- Over-processing: it occurs when unnecessary steps are performed, tried to impart characteristics that does not create value for the customer or when the process consumes more resources than needed.
- Defects: Waste from a product or service failure to meet customer expectations. This adds up costs on the course of identifying the cause, reworking or rescheduling.
- Skill of employees: Not tapping on people’s talents, skills and knowledge, which should otherwise be extracted to the maximum, leads to waste.

4.3.4. Nemawashi

Nemawashi refers to the idea of making decisions in slow-pace instead of making rash decisions. This involves studying all possible alternatives and reaching a consensus. When all stakeholders accept a carefully analysed decision, higher success rates can be guaranteed.[57]

Taking enough time to plan saves time later while implementing it. Problems can be identified in the planning phase, if it is meticulous and long enough. Shorter planning duration makes quicker plans, but implementing it could savour time. Well-thought plans reduce complexities and enable simple and faultless implementation, which makes it more appropriate as the ultimate aim is to reduce the time between planning and start of defect-free process.[58]

4.4. Lean tools

Tools that execute lean methodologies to reduce lead-times, waste, cost and inventory and enhance quality are referred to as lean tools. They can be adopted by any industry with ease.[59]

As mentioned before, cultural change is key to sustain lean methodologies implemented. Without that the initial impact would be watered down over time resulting in a failed lean implementation program.

[55] Cf. Womack/Jones (2003), P. 5.

[56] Cf. Bicheno/Holweg (2016), P. 17-23.

[57] Cf. Bicheno/Holweg (2016), P. 113 f.

[58] Cf. Bicheno/Holweg (2016), P. 113 f.

[59] Cf. Bicheno/Holweg (2016), P. 307.

It is a fact that the way change is managed within the company along with its corporate culture are two important deciding factors for the success of lean implementation.[60]

Tools	Description
5S	It is five-step process structured to evolve and maintain order in a workplace.
Cellular manufacturing	It is a method, where workstations are equipped with all tools or machines required to produce a particular product or a product family items, in contrast to grouping workstations based on similar equipment whereby material need to be transported to different workplaces for processing.
JIT	Just in time production is a planning methods in which material arrives or is delivered the exact time it is needed.
Kaizen	It is a philosophy which focuses on regular, incremental but small changes to be applied and maintained over a long time span to bring out large results. Lean implementation is done by means of kaizen events which are rapid action plans ranging between two to five days.
Standard work	Improvements achieved throughout kaizen events are documented to form a new standardized work. The processes and sequences are structured in such a way to ensure all employees implement it in the same manner later on.
VSM	Value stream mapping is used to map processes to identify current state and envision future state of material and information flows from supplier to customer for a value stream.
Yamazumi	It is a stacked bar chart used to represent value added, necessary and non-value added activities in a colour coded manner.
Spaghetti diagram	It is a representation of the flow of man and material for every processes. Improvements of flow, distance and waiting time can be envisaged.
Kanban	They are cards or signals used to control inventory and WIP.

Table 4.1: Selected lean tools, Source: Based on United States Environmental Protection Agency (2017), online source [01.09.2020].

4.4.1. Value stream mapping

The idea of VSM, though derived from TPS, was popularised when the book ‘Learning to See– Value Stream Mapping to Create Value and Eliminate Muda’ was published by Rother and Shook.[61] VSM has then on gained prominence as one of the most important lean tools.[62]

[60] Cf. Bhasin (2012), P. 356.

[61] Cf. Singh et al. (2010), P. 158.

[62] Cf. Vinodh/Somanaathan/Arvind (2013), P. 130.

All processes, value added or otherwise, starting from raw material from the supplier to final product to customer constitutes a value stream. A VSM illustrates material and information flows in the current state and helps to develop an improved future state.[63] It clearly defines what processes will be paid for by the customer.[64] Rother and Shook (1999) defines VSM as a tool which brings about improvement apart from pinpointing operational inefficiencies.[65]

Rother and Shook (1999) put forward four steps to be deployed for value stream mapping.[66] VSM is done for a particular product or product family. For that first a product is selected, its data collected, analysed and the results are generalised over remaining product variants that belong to the same family.[67]

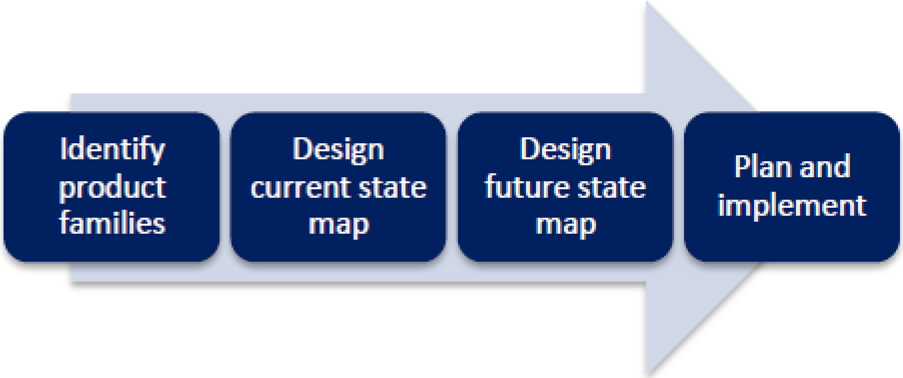


Figure 4.3: 4 steps to perform value stream mapping, Source: Based on Rother/Shook (1999), P. 19.

To design a VSM, a backwards walk along the value stream of the selected product or product family from last point of customer delivery to the first point of raw material supply has to be done. In this walk, actual processes are observed, understood and represented graphically on paper, questions are asked and process data collected.

This leads to a sketch on the paper denoting processes, with information on information flow, WIP, availability, cycle times and lead-times.[68] This sketch is the current state VSM, which is followed by designing future state VSM, and implementing and achieving an action plan to attain future state.[69] Future state VSM can either function as a manual for the company to reach an ideal state or as a guide for short-term implementation.[70] Care should be taken while designing to address the underlying issues rather than merely treating the symptoms. Another aspect to care about when designing future VSM is to ensure continuous flow and using supermarkets with a pull effect where it is not possible.[71]

[63] Cf. Womack/Jones (2003), P. 9.

[64] Cf. Tapping/Shuker (2003), P. 7.

[65] Cf. Rother/Shook (1999), P. 13.

[66] Cf. Rother/Shook (1999), P. 19.

[67] Cf. Rother/Shook (1999), P. 16.

[68] Cf. Singh/Sharma (2009), P. 60-61.

[69] Cf. Lasa et al. (2008), P. 44.

[70] Cf. Rother/Shook (1999), P. 13.

[71] Cf. Rother/Shook (1999), P. 65.

Finally, it comes to the implementation stage. Many companies, however, lack resource to implement all proposals at one go. This can be solved by implementing in small steps and gradually connecting them all together.[72]

Terminology	Description
Takt time	It is the output rate of a product to fulfil customer demand. Total working hours in a day divided over by required output by customer per day gives takt time.
Lead-time	It is the total time elapsed from the time of material input until it is shipped to customer after processing.
Value added time	Time spent on processing that truly adds value to the product is known as value added time (Abbr.: VA) and it is it that the customer pays for.
Cycle time	It is the time elapsed between start and finish of a process.

Table 4.2: Terminology in VSM, Source: Based on Rother/Shook (1999), P. 31.

4.4.2. 5S

Enabling clear vision of all processes, tools, parts, and performance indicators counts as a lean tool known as visual management.[73] The well-known 5S methodology is an essential component of visual management and a key lean tool by which shop floor can be controlled with ease. As mentioned earlier, 5S is required for stability, which forms the foundation of house of lean. It also eliminates waste, as it segregates items required to add value from unwanted items. However, to sustain 5S regular audits are to be carried out.[74]

It comprises of five Japanese terms beginning with S. They are translated into English as follows:[75]

Terminology	Description
Seiri (Sort)	Sort items in the workstation; segregate wanted or value adding items from unwanted ones.
Seiton (Order)	Arrange everything in the workstation in their appropriate place.
Seiso (Shine)	Clean everything exposes blemishes that could potentially affect quality or cause failures.
Seiketsu (Standardize)	Develop a structure to ensure that the first three S's are maintained.
Shitsuke (Sustain)	Maintain stability of workstation by continually improving it.

Table 4.3: Terminology of 5S, Source: Based on Omogbai/Salonitis (2017), P. 380.

[72] Cf. Rother/Shook (1999), P. 94.

[73] Cf. Bicheno/Holweg (2016), P. 140.

[74] Cf. Bicheno/Holweg (2016), P. 136-139.

[75] Cf. Omogbai/Salonitis (2017), P. 380.

4.4.3. Spaghetti diagram

Opportunities for improvement can be found in large numbers when a flow analysis is done. This can be done for man, material or administrative issues. Analysis leads to realization of most critical processes and their interdependencies.[76]

Spaghetti diagram, also known as Spaghetti chart or Spaghetti plot is a tool used to analyse movement of man or material in a context by a simple sketch consisting of lines. The context can be a shop floor, an office, or a segment in a building. The ensuing sketch often looks similar to a spaghetti and hence the name.[77]

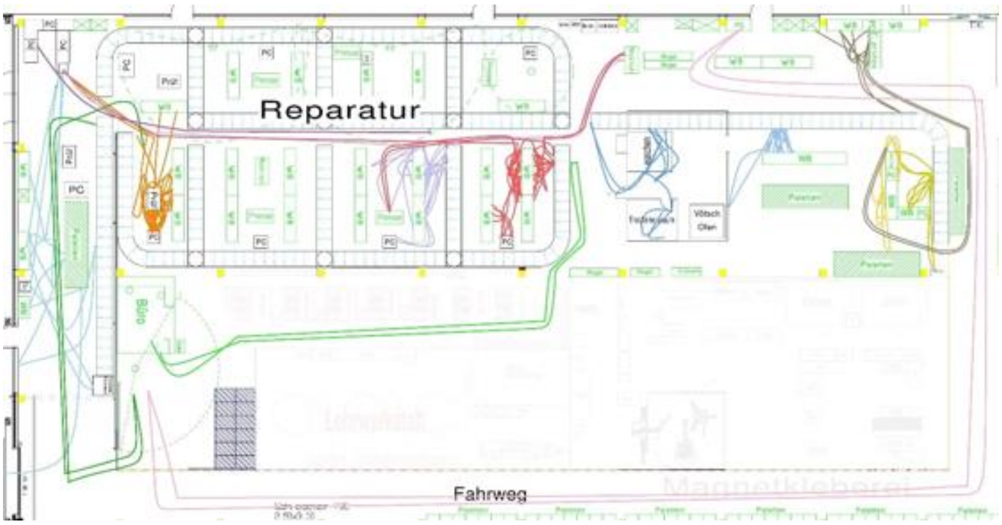


Figure 4.4: A spaghetti diagram, Source: Own Illustration.

Man or material can be colour coded distinctively and tracked. Analysis of spaghetti diagram enables to quantify the distance and number of movements, along with other characterizations such as crossing or overlapping etc., which lead to identification of aspects that could be improved. From this possible actions of process redesign, layout redesign or labour reduction could be taken.[78]

4.4.4. Yamazumi chart

Yamazumi is a term in Japanese which means ‘to stack up’.[79] Yamazumi charts provide quick and easy identification of value added non-value added and non-value-added but necessary types of work and depicted in the form of a stacked bar chart. The horizontal axis represents process steps or operators, whereas, the vertical axis represents process times. Process steps are stacked one by one to finally form the Yamazumi chart for the whole process.[80] It is thus a great visual tool, which could be used for either waste reduction or line balancing or both.[81]

[76] Cf. Hys/Domagała (2018), P. 65.

[77] Cf. Senderská/Mareš/Václav (2017), P. 141.

[78] Cf. Senderská/Mareš/Václav (2017), P. 141.

[79] Cf. Packianather et al. (2016), P. 3.

[80] Cf. Sheth/Swaroop/Henry (2012), P. 21.

[81] Cf. Sabadka et al. (2017), P. 175-178.

	Value added
	Necessary work
	Non-value added

Figure 4.5: Colour codes of Yamazumi charts, Source: Based on Cava (2015), P.11.

4.5. Conclusion

Lean methodologies is at the core of this thesis and constitutes of the literature review done in this chapter. Lean tools such as VSM, 5S, Spaghetti diagram and Yamazumi charts, which enabled to perform in-depth analysis of the problem and helped to evolve solutions, were explained with additional detail.

Among various literature reviewed, there were a plethora of cases, where huge savings were attained through application of lean methodologies. Nevertheless, only regular, small and incremental improvements can lead to big results in the long run.[82] The case study done in chapter 3 clearly supports the need to improve the processes in SD and as such, it was realized that lean methodologies proved to be the most appropriate for this.

[82] Cf. George (2002), P. 13.

5. The current status

By collecting relevant data and analysing material and information flow along the shop floor, the current state is conceived in this chapter. This is done by means of VSMs, and Spaghetti diagrams.

Data required to calculate lead-times along each product range and repair type was extracted from the SAP database. Information on each incoming repair comprises of its product range, repair type, and start and end dates of each process, which the employees after each process feed back into the SAP system. The data was then analysed by means of a spreadsheet. The data, being sensitive and confidential is not presented in detail in this report.

5.1. Process data

This section provides the process data of two processes-unpacking and incoming inspection- which are common to all cases, followed by spindles with normal repair, warranty repair and finally systems repair. The cycle times were obtained from SAP as mentioned before and is tabulated in Table 5.1, Table 5.2, Table 5.3, and Table 5.4 respectively.

5.1.1. Unpacking and Incoming inspection

Unpacking is the starting point of material and information flow in the service area. The unpacker brings the products by means of a forklift to the unpacking area. He then unpacks and enters the details of the product and information from error checklist into SAP, followed by scanning and e-mailing of the customer delivery note addressed to the respective CSR. If it is a spindle, he pushes a button to dispense a pallet into the conveyor belt and mounts the spindle by means of a crane into the conveyor belt, and if it is a system, it is not mounted on the assembly line, but transported later to the incoming inspection. The SAP registration number mentioned in section 3.2.2.1 is printed on a paper and hanged on the pallet to be identified and tracked.

The spindles move along the conveyor belt and reaches any of the three incoming inspectors. The inspector carries the spindle to the test bench by an overhead crane. He then searches his computer for the last measurement protocol that would serve as a reference to his observations. Photographs are taken from all sides to document the received condition. This is followed by hydraulic test, insulation test, sensor test, geometry test, concentricity test and power check. The results from each testing device is entered simultaneously in to an incoming inspection report, created as a Microsoft excel sheet. A printout of inspection report is placed in the folder along with COF and the spindle is mounted back into the conveyor belt. In case of systems, only insulation and sensor tests are conducted and the system is transported by a pallet jack to the waiting area at the entry of the hall, until the system disassembler picks it up.

Process	Cycle times (min)	
	Spindles	Systems
Unpacking	15	15
Incoming inspection	80	60

Table 5.1: Process data for unpacking and incoming inspection, Source: Own Illustration.

5.1.2. Spindles with normal repair

After incoming inspection, spindles designated to normal repair are moved along either side of the conveyor belt to each disassembly workstation. The disassembler carries the spindle from the conveyor belt over to his workbench using overhead crane.

Photographs are taken to document the condition prior to disassembly. He then starts the disassembly operation by first removing peripheral components such as encoder, proximity sensor, rotary feed union and unclamping unit. O-rings and bolts are put into two different packets to be disposed. Now he uses an impact wrench to detach rear bearing shield, rings, spacers and gripper. After the gripper is unscrewed, the drawbar can now be removed by tapping on the other side of the spindle. The impact wrench is used again to remove shaft nut and several bolts. Special fixtures are used to remove the rotor assembly from the stator, which is placed on the pallet with the help of overhead crane. The rotor assembly consists of several subcomponents. It is first carried over to press down the long spindle shaft, which is then taken for concentricity measurement. This then leaves with bearing housing and after pressing it down and operating on with different fixtures, cooling chamber, bearings and other subcomponents are detached. On the course of disassembly process, the disassembler photographs, checks each component of its originality by comparing its part number to the part number in BOM, writes remarks about the parts on a form, sorts it as to whether it can be reused, reworked or scrapped and places it into separate boxes in the pallet. This classification of parts is done again on the BOM in paper and later on SAP. The disassembler moves on to his computer, fills in disassembly report with details of each component, writes a summary, attaches pictures, classifies parts on SAP BOM as mentioned before and finally, the pallet is moved to the main conveyor. Disassembly is the longest of all processes whereby variabilities within disassembly cause great fluctuations in the total lead-time.

Now, the inspection team consisting of two senior employees comes by the pallet on the conveyor belt and inspects the disassembled parts. They perform a visual inspection of parts and see if any of the scrapped parts could be reused again, check the quality of disassembly report and make edits wherever necessary, and prepare an inspection report to be sent to CSR.

Process	Disassembly	Inspection	Pre-cleaning	Cleaning	Electrical inspection	Final inspection
Cycle times (min)	200	15	15	30	20	25

Table 5.2: Process data for spindles with normal repair, Source: Own Illustration.

After inspection, spindles head to pre-cleaning area. It consists of a large washing machine, dry ice blast cleaning room and an industrial oven. The operator picks all components except stators manually from the pallet and place them in the washing machine. Parts are washed and dried within 10 minutes. If a component shows a very high degree of contamination, it is then cleaned by dry ice blast cleaning method. In individual cases, where stators show high degree of contamination, they are too pre-cleaned in washing machine and left overnight in the oven to dry. After pre-cleaning, components are returned to the pallet and it heads to the cleaning area, where each of the three employees manually cleans every component one after the other and arranges them neatly on the pallet.

Electrical inspector picks up the stator from the pallet and carries over to his workplace, which is equipped with multiple electrical testing equipment. Test leads are attached to stator cables and a specialized software generates results. He then prepares an electrical inspection report adjacent to the disassembly and inspection report.

Meanwhile, the final inspector performs a 100% quality check on the rest of the components in the pallet. He individually inspects each part, verifies it with BOM, cross-checks BOM with design change notification (Abbr.: DCN) and places parts to be reworked on to rework entry desk. He checks all reports and sprays a thin film of grease on the pallet to avoid corrosion while it waits in the warehouse. A forklift driver picks up pallets from the conveyor belt at regular intervals or upon summoning and moves it to the warehouse.

5.1.3. Spindles with warranty repair

Spindles with warranty claim are observed and dismounted meticulously in order to find the reason for malfunction, since if the fault is due to an error from FK, the warranty claim will be accepted and if the fault is due to an error is from the customer's end, the warranty claim will be rejected.

After incoming inspection, spindles claimed warranty are transported by pallet jack to the warranty office. There, the senior warranty officer makes a preliminary assessment and figures out further course of action. If further action can be taken only after the spindle undergoes a test run, it is sent for test run. Otherwise, it is transferred to the warranty disassembly area. In the first case, as illustrated in Figure 3.6, if the test run results is found to be within desirable limits, no further action is taken and is sent to warehouse to be dispatched back to the customer or else, it will be taken for incoming inspection followed by warranty disassembly.

Process	Warranty office	Dis-assembly	Inspecti on	Pre-cleaning	Cleaning	Electrical inspection	Final inspectio n
Cycle times (min)	15	600	15	15	30	20	25

Table 5.3: Process data for spindles with warranty repair, Source: Own Illustration.

The warranty disassembly follows the same steps as detailed under section 5.1.2. However, due to the warranty claim posed by the customer, each component is closely observed, measured when required, close-up photographs of visible abrasions taken, findings analysed with the warranty officers and finally a detailed disassembly report and a warranty inspection report are prepared. All these results in a tripled cycle time for warranty disassembly in comparison to normal disassembly. After disassembly the spindle follows the same course of action as other spindles.

5.1.4. System repair

After incoming inspection, the system disassembler comes to the waiting area and transports the system to the other hall where system disassembly takes place.

Process	Disassembly	Pre-cleaning	Cleaning	Electrical inspection	Final inspection
Cycle times (min)	1440	60	120	30	30

Table 5.4: Process data for systems, Source: Own Illustration.

The sub-assemblies are disassembled in a similar fashion to section 5.1.2. Due to the sheer size of it, numerous components and sub components, systems account for the longest disassembly times. Furthermore, a disassembled system can take up to four pallets for the parts to be laid on. After disassembly, the pallets are brought one after other to the waiting zone in the cleaning area, where each pallet is pre-cleaned and cleaned. After electrical inspection, the disassembler is called upon to perform final inspection.

5.2. Spaghetti diagram

In the following section, spaghetti diagrams of both service area and system disassembly area are showcased. By drawing a spaghetti diagram, a distinct overview of operators' movement throughout the shop floor is obtained. Each operator is colour coded in the spaghetti diagrams.

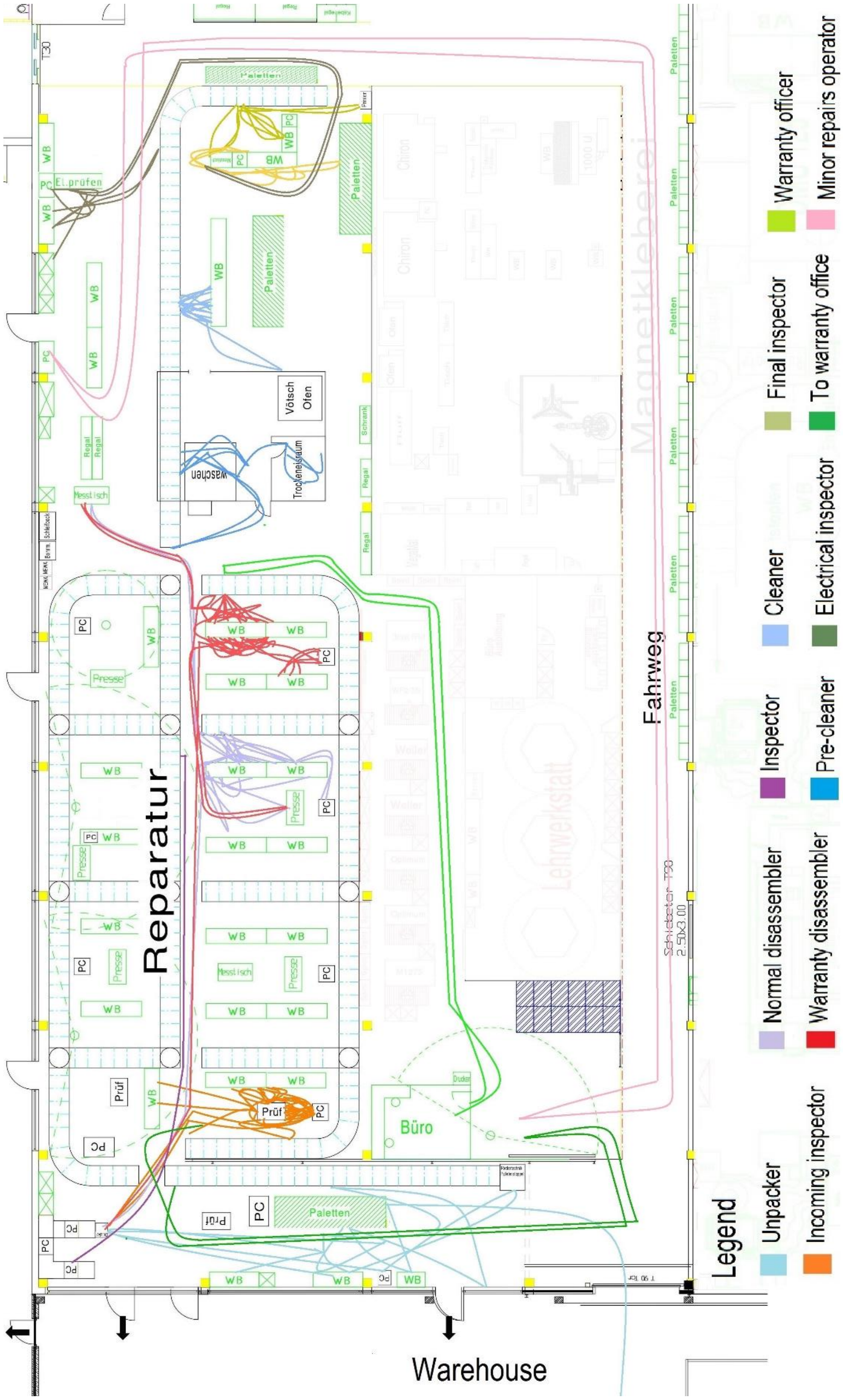


Figure 5.1: Spaghetti diagram for service area, Source: Own Illustration.

The spaghetti diagram of service area depicts high amounts of unnecessary movements of all workers in the service area. The longest paths taken by disassemblers are leftwards to access the printer to take printouts, and rightwards for concentricity measurement apparatus. Similarly, minor repairs operator and incoming inspector has to traverse long distances to reach the warranty office, which they frequent daily. Another noteworthy example is the motion of electrical inspector to take COF of a backlog stator, which is always placed at the final inspection workstation.

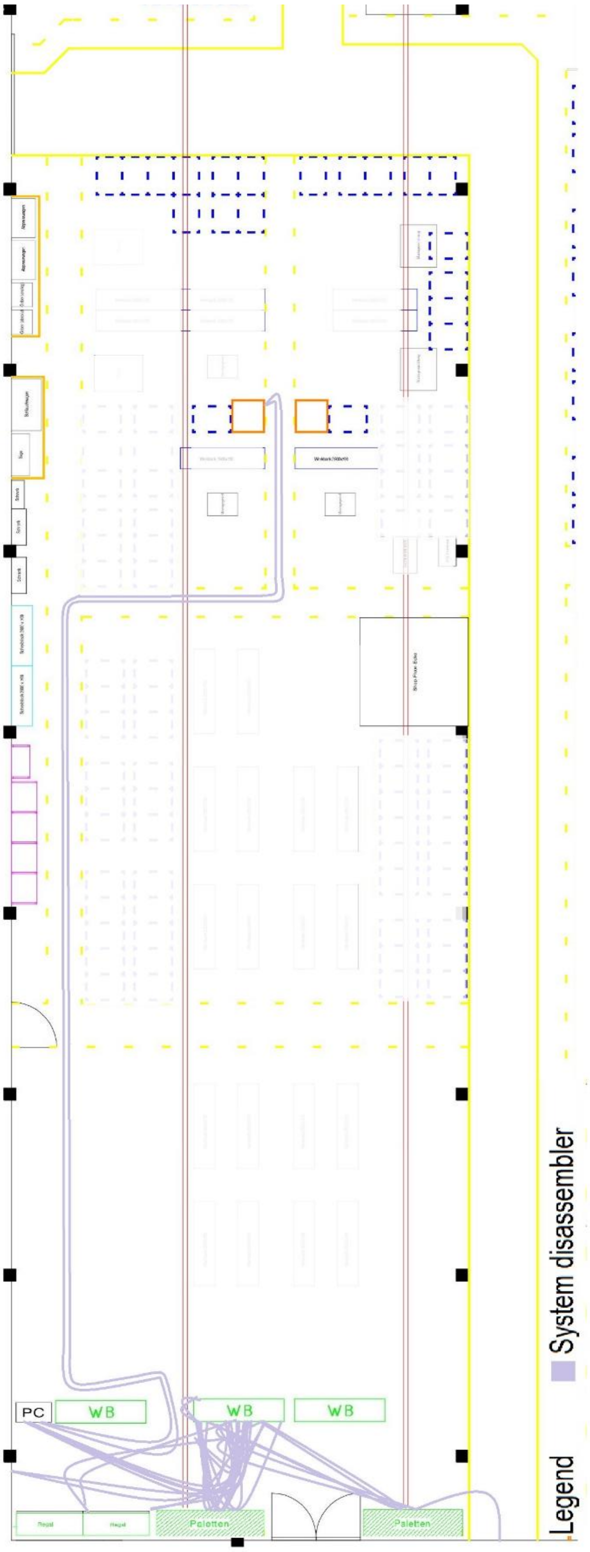


Figure 5.2: Spaghetti diagram for system disassembly area, Source: Own Illustration.

Similarly, the system disassembler also needs to traverse long distances. The longest path in this spaghetti diagram depicts his movement to reach the printer.

He also has to transport systems to system disassembly hall after incoming inspection from the service area located in another part of factory and after disassembly, transport back disassembled parts in three or four pallets one by one to the cleaning area. These movements are, however, unable to be depicted in this spaghetti diagram.

5.3. Current state VSMs

In this section current state of spindles with normal repair, spindles with warranty repair, and system repair are designed using the VSM tool. Process data extracted from SAP, information and material flow tracked along the shop floor serve as basis for VSM. Information flow is situated in the upper portion of VSM, material flow is situated in the lower portion and lead-times are shown beneath every process or inventory symbol. The various symbols used in VSM are shown in Table 5.5.

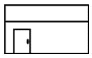
Symbol	Description	Symbol	Description
	Customer		First-in-first-out sequencing
	External shipment		Shipment
	Dedicated process		Inventory
	Electronic information		Supermarket
	Manual information		Operator
	Push flow		Warehouse
	Material pull		Go-see scheduling

Table 5.5: VSM symbols, Source: Based on Rother/Shook (1999), P. 109-111.

The current state VSM for spindles with normal repair is depicted in Figure 5.3 below. As mentioned in section 3.2.2.2, material flow starts with customer delivery, followed by unpacking, incoming inspection, disassembly, inspection, pre-cleaning, cleaning, electrical inspection and final inspection. At each station, after the operator inputs operating time and other details into SAP, which helps in tracking the progress and updating customer upon demand.

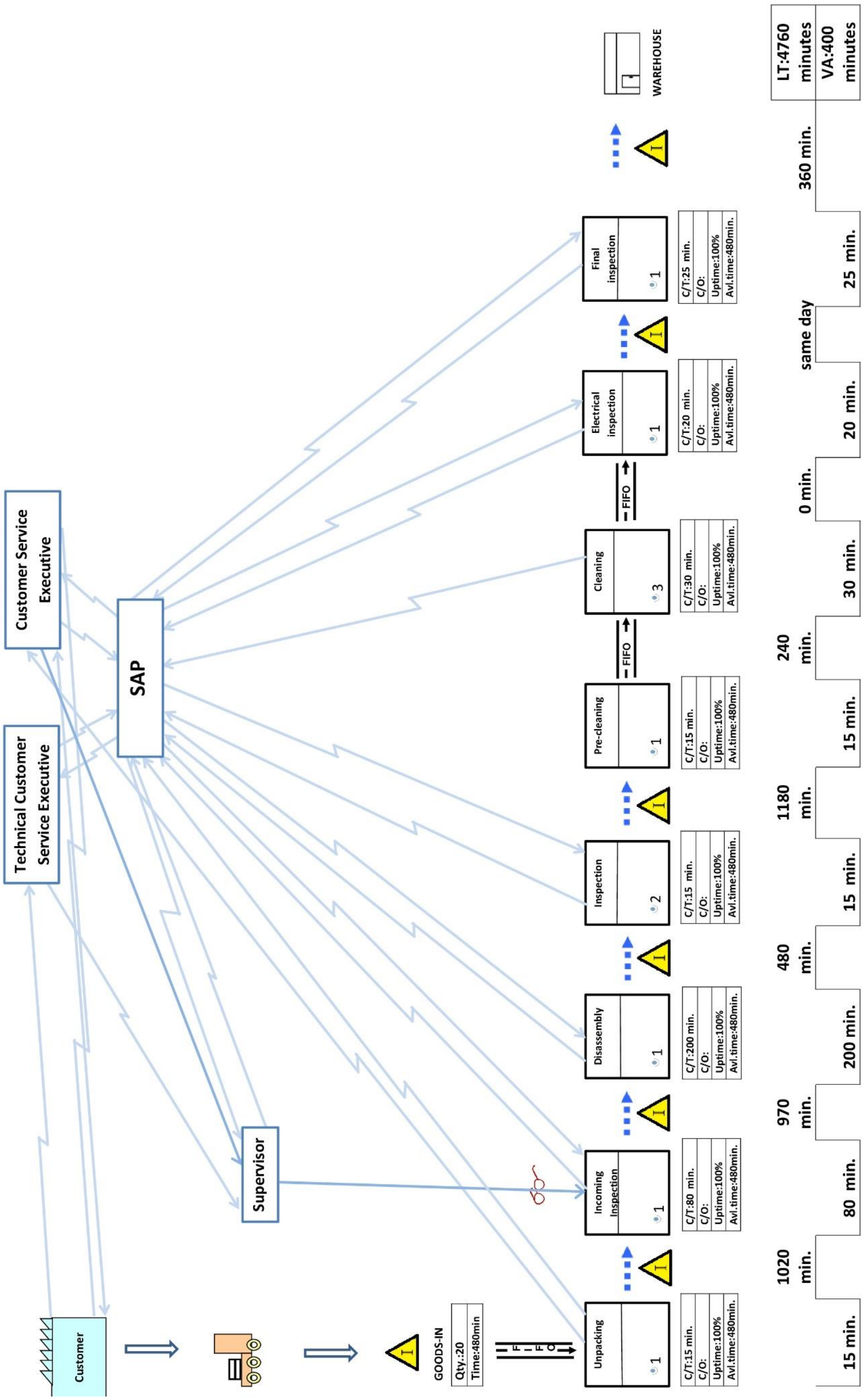


Figure 5.3: Current state VSM for spindles with normal repair, Source: Own Illustration.

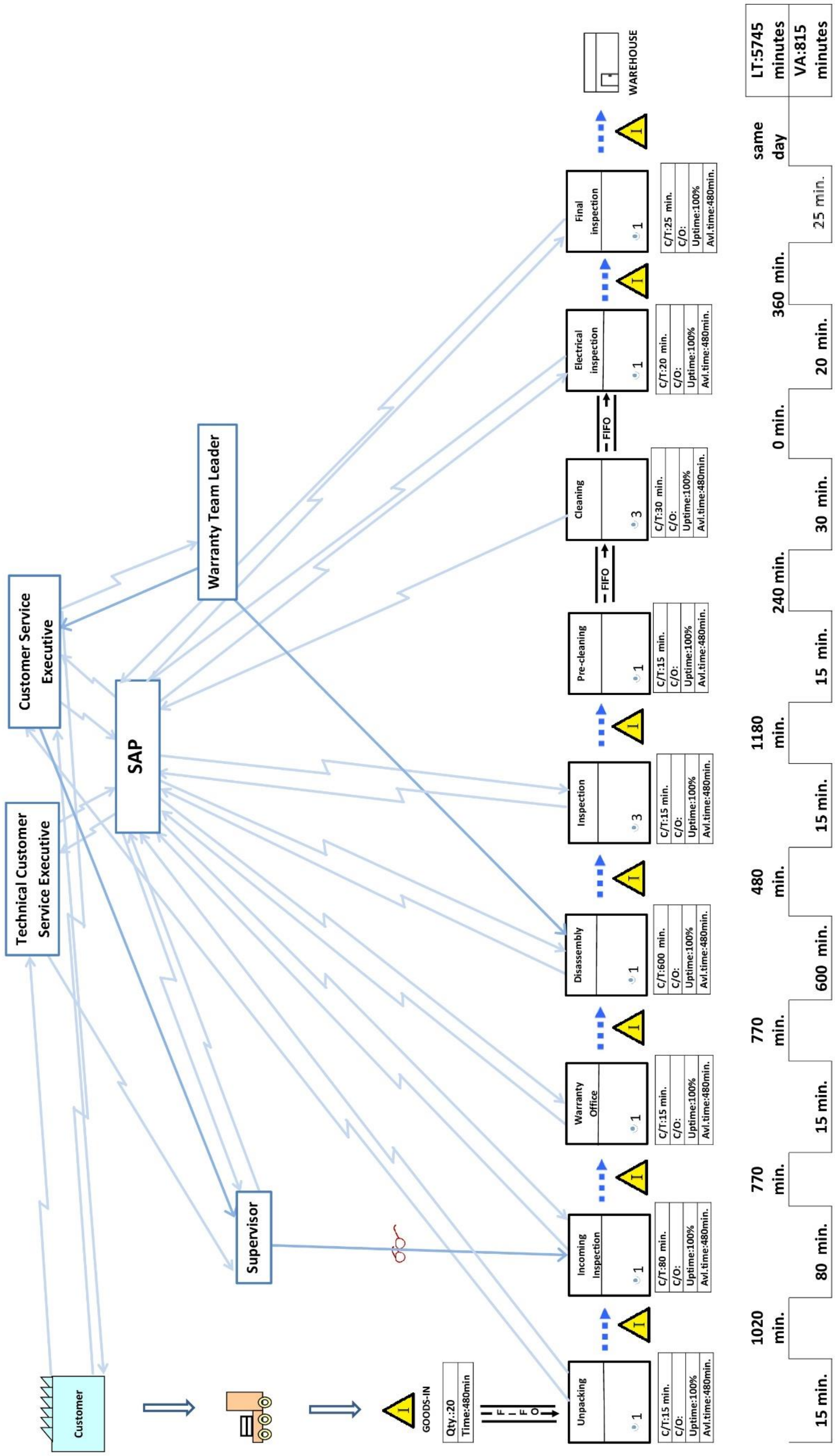


Figure 5.4: Current state VSM for spindles with warranty repair, Source: Own Illustration.

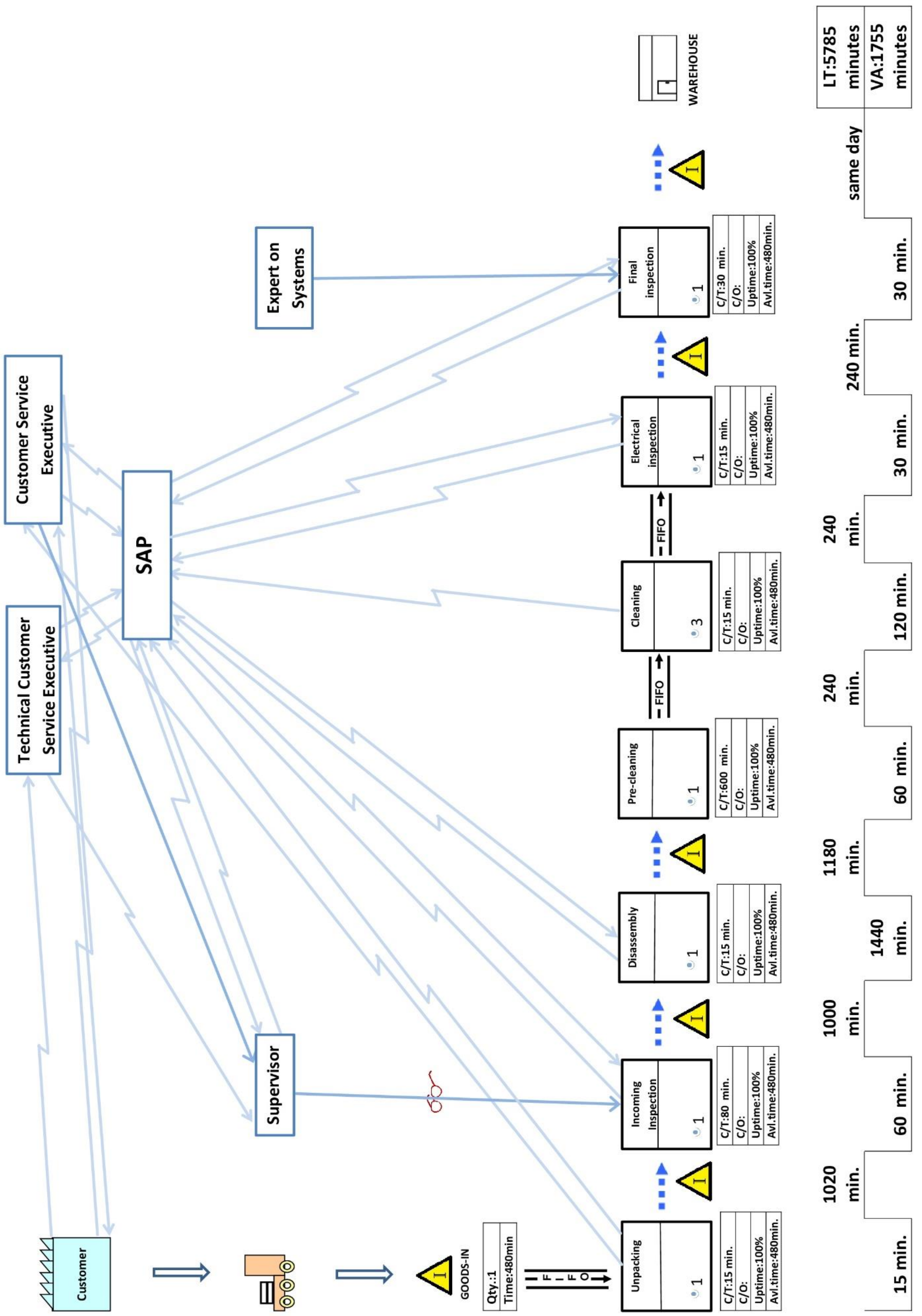


Figure 5.5: Current state VSM for systems, Source: Own Illustration.

5.4. Lead-time analysis

Lead-times calculated by each VSM could be divided into value added (VA) and non-value added (Abbr.: NVA) time. Value added processes are those that add value to the product, whereas non-value added processes are those that do not add value to the product. Below are analyses of lead-times obtained from each repair category.

5.4.1. Spindles with normal repair

Value added and non-value added times of each process on current VSM of spindles with normal repair are depicted in the graphs below.

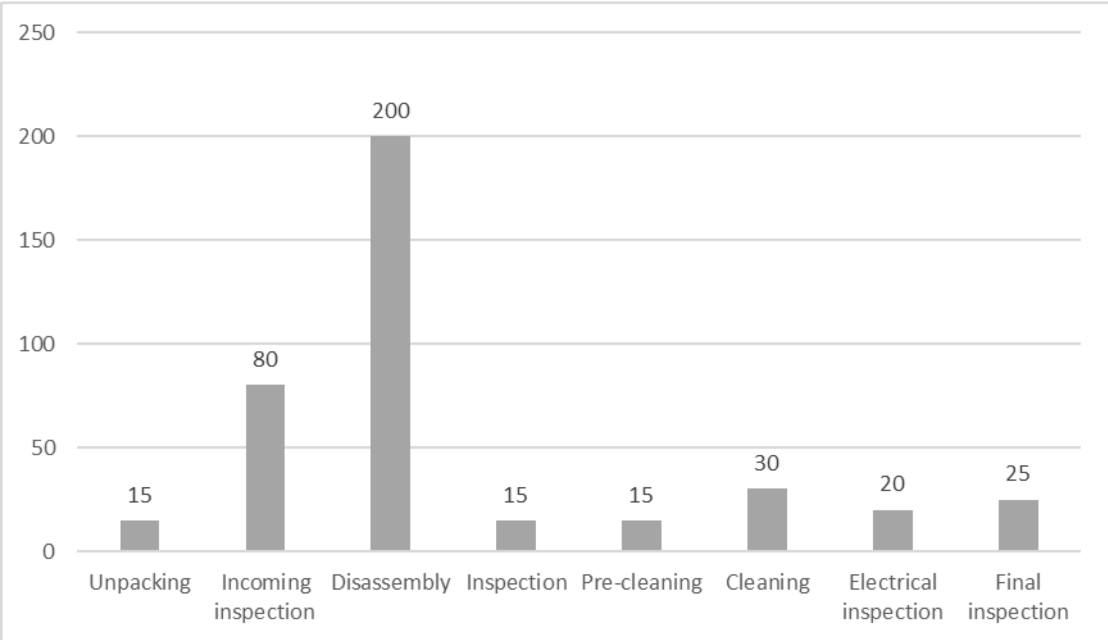


Figure 5.6: VA from current VSM of spindles with normal repair (in minutes), Source: Own Illustration.

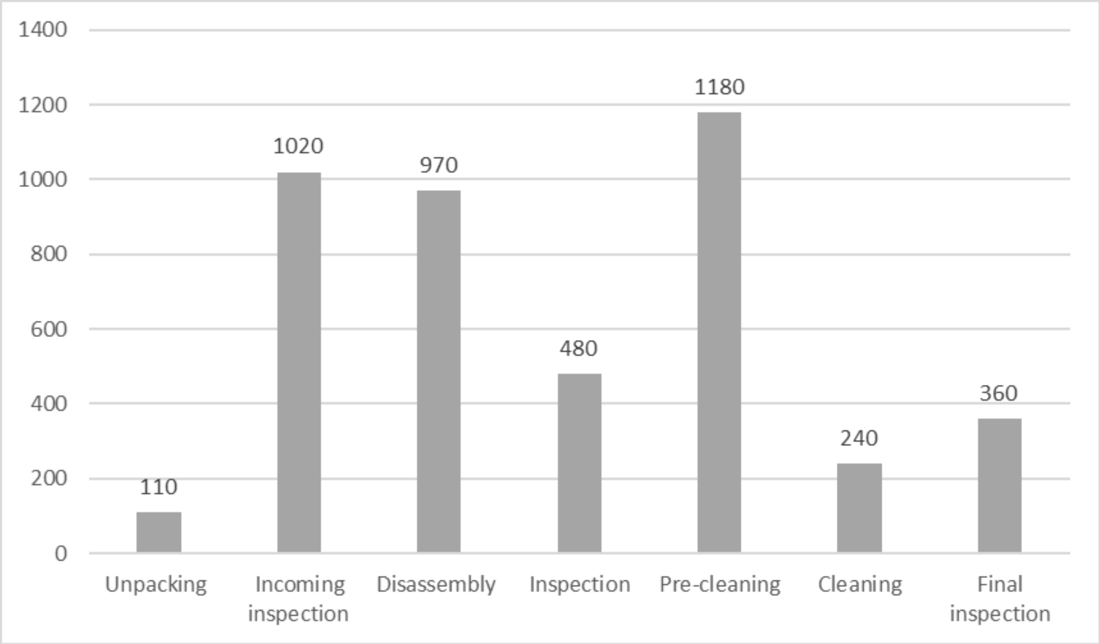


Figure 5.7: NVA from current VSM of spindles with normal repair (in minutes), Source: Own Illustration.

The results are summarized in Table 5.6 below.

	VA Time (min)	VA Time (days)	NVA Time (min)	NVA Time (days)
Total	400	0.83	4360	9.1

Table 5.6: Lead-times summary for spindles with normal repair, Source: Own Illustration.

5.4.2. Spindles with warranty repair

Value added and non-value added times of each process on current state VSM of spindles with warranty repair are depicted in the graphs below.

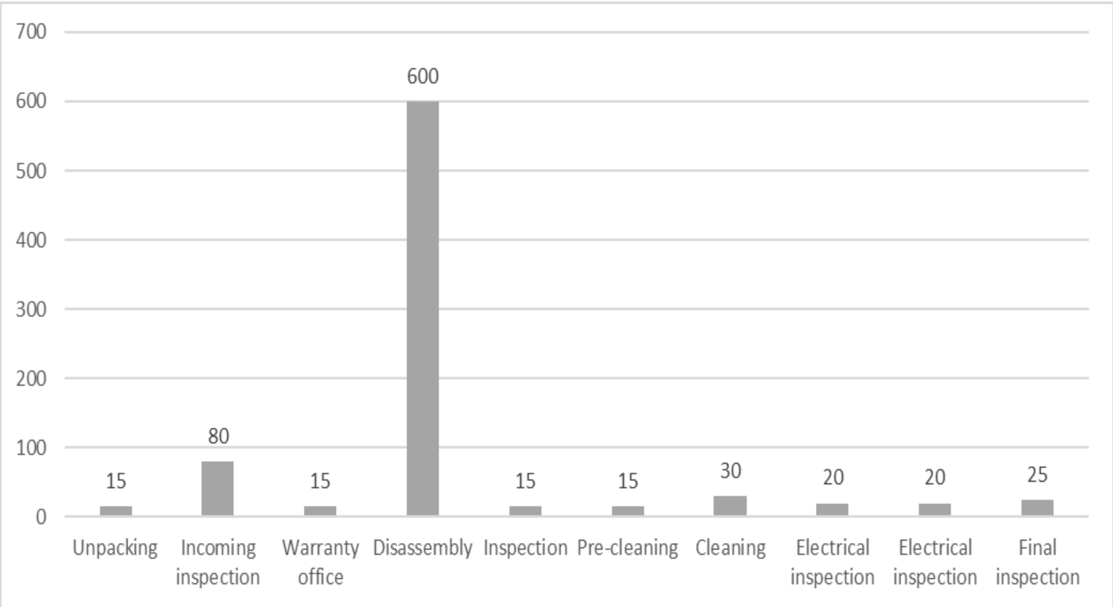


Figure 5.8: VA from current VSM of spindles with warranty repair (in minutes), Source: Own Illustration.

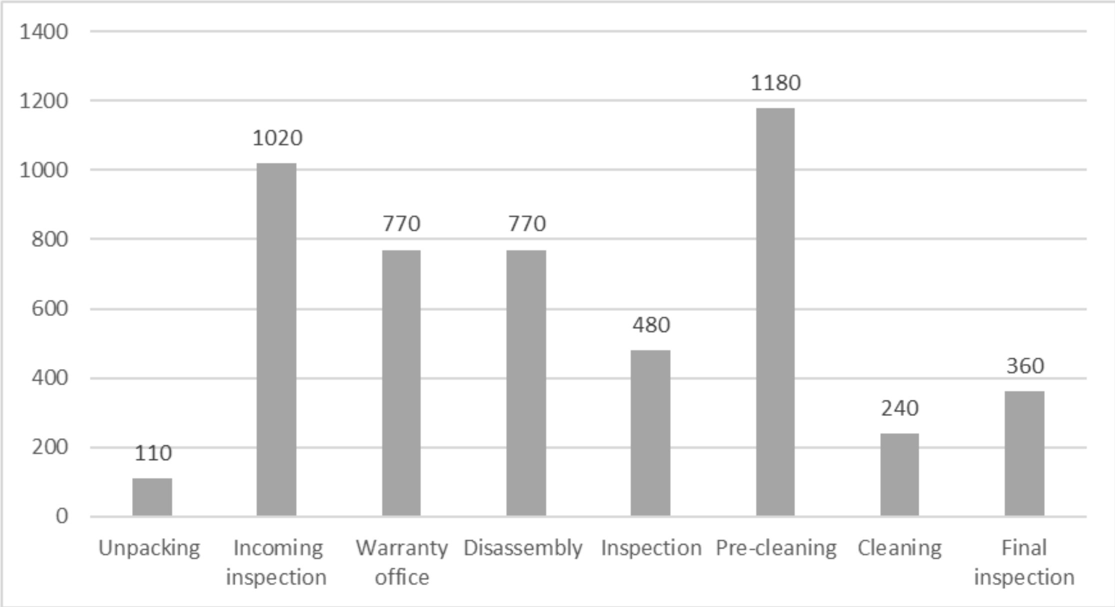


Figure 5.9: NVA from current VSM of spindles with warranty repair (in minutes), Source: Own Illustration.

The results are summarized in Table 5.7 below.

	VA Time (min)	VA Time (days)	NVA Time (min)	NVA Time (days)
Total	815	1.7	4930	10.3

Table 5.7: Lead-times summary for spindles with warranty repair, Source: Own Illustration.

5.4.3. Systems repair

Value added and non-value added times of each process on current state VSM of system repair are depicted in the graphs below.

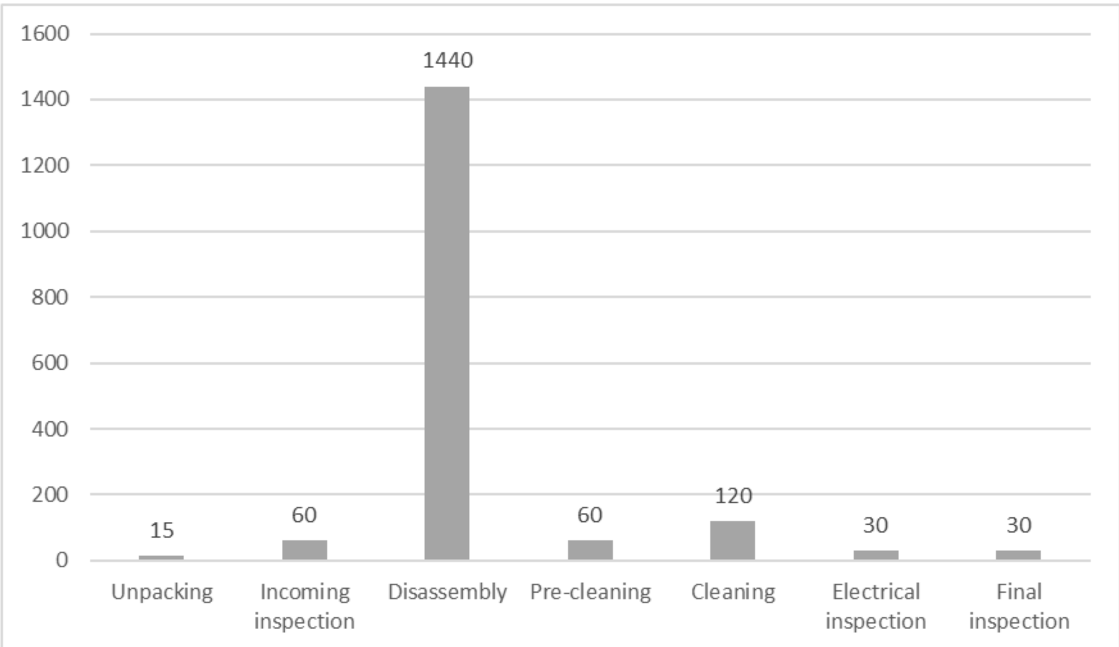


Figure 5.10: VA from current VSM of systems repair (in minutes), Source: Own Illustration.

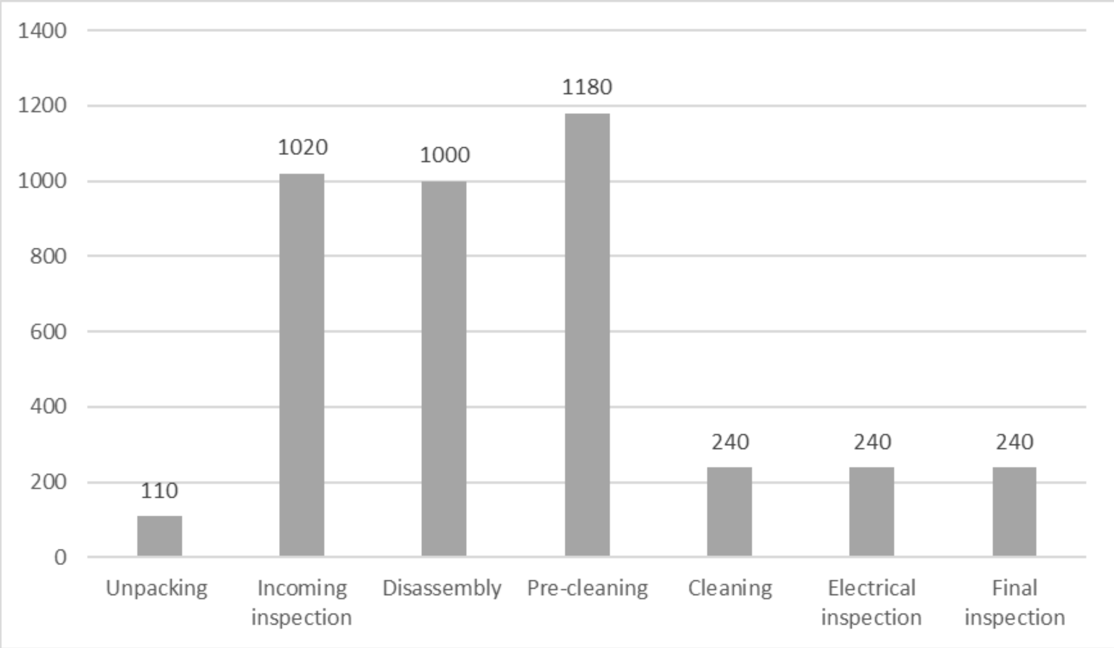


Figure 5.11: NVA from current VSM of systems repair (in minutes), Source: Own Illustration.

The results are summarized in Table 5.8 below.

	VA Time (min)	VA Time (days)	NVA Time (min)	NVA Time (days)
Total	1755	3.65	4030	8.4

Table 5.8: Lead-times summary for systems repair, Source: Own Illustration.

5.5. Summary

All extracted process data from SAP were thoroughly studied and analysed. The current VSMs were designed for the three value streams selected for this study using aforementioned process data and by tracking down material and information flow along the shop floor. Spaghetti diagrams were constructed to depict movement of operators across the shop floor.

Lead-time analysis shed light on stark disparities between value added and non-value added processes. Lead-time figures of non-value added processes are quite high in comparison to those of value added processes. This reveals the fact that there is a lot of waste that could be identified throughout the value stream and therefore a lot of room for improvement.

Opportunities for improvement are identified in the ensuing chapter and the future VSMs are designed.

6. Improvement proposals

Designing the future state begins by identifying and analysing improvement opportunities. Wastes are identified along value streams to define opportunities for improvement. Analysis of value added and non-value added processes are performed and wastes are detected throughout the three value streams. Each value stream is independently analysed. The opportunities for improvement are succeeded by the future state design done in the ensuing sections.

6.1. Opportunities for improvement

Wastes detected and opportunities for improvement are detailed below. They are itemized according to each value stream.

6.1.1. Spindles with normal repair

Along the current VSM, following wastes were detected:

- Waiting: for customer statement; for COF at disassembly area; for cranes, computers, tools, fixtures, measurement apparatus, press etc. at disassembly area; for re-cleaning if a part is found not cleaned properly by final inspector;
- Motion: for tools, fixtures, boxes, heating apparatus, press, information, print outs, ensuring material flow, measurement apparatus, computers at all stations; to bring COF and other paper based documents from office to shop floor; electrical inspector to take COF of backlog stators from final inspection area; final inspector has to go out of his workstation to place parts for rework; pre-cleaner comes out of cleaning area to push pallets into conveyor belt;
- Defects: at disassembly some parts need to be heated to high temperatures due to excessive adhesive on fasteners and windings; on the course of disassembly damage due to lack of proper instructions; on the course of disassembly damage due to variabilities in design;
- Inventory: large WIP after each workstation; highly contaminated stators separated from pallet to be dried overnight in oven after cleaning, resulting in batches of stators separated from their pallets now in warehouse after final inspection; spindle backlog due to excessive adhesives;
- Unused talent: Disassembly workers not trained to prepare inspection report;
- Transport: entire pallet transported from disassembly to rework if unable to detach parts due to excessive adhesives; stator backlog transported to warehouse after electrical inspection;
- Extra-processing: triple inspection of parts once each by disassembler, inspector and final inspector; parts classification at disassembly done on technical drawing, paper BOM and SAP BOM; cleaning of parts which might be scrapped at pre-assembly; disassembly observation written on paper first and then typed in SAP; unnecessary processes thought to be useful for the next station; manual operation in some steps instead of using machinery at disassembly; multiple steps due to obsolete software at all stations.

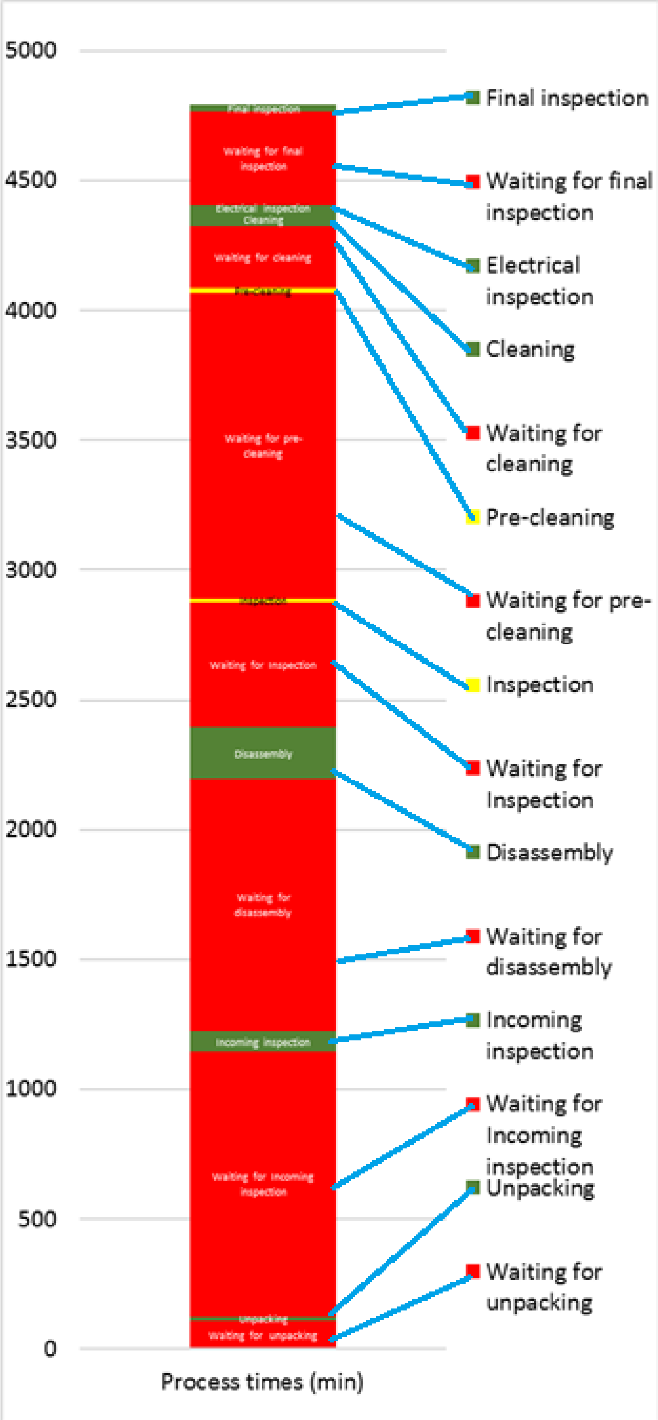


Figure 6.1: Current state Yamazumi chart for spindles with normal repair, Source: Own Illustration.

To eliminate the different lean wastes mentioned above, following actions are recommended:

- Pull system: The WIP levels between processes are quite high and cause high lead-times. In a pull system downstream process pulls material pulls from upstream processes. This means spindles are pulled only when they are needed, limiting the inventory levels. For this, one supermarket between unpacking and incoming inspection, one supermarket between incoming inspection and disassembly and a FIFO lane between disassembly and final inspection are introduced.
  Supermarkets contain the right-sized amounts of inventory that promote continuous flow to occur. In this case the WIP and hence inventory costs will decrease.

- FIFO lane: Although by principle material flow from pre-cleaning to final inspection is to follow FIFO principle, overnight drying of stators and isolated position of electrical inspection lead to formation of batches mentioned above. Reinstating the FIFO lane will guarantee the material flow as envisaged and this can be achieved by line balancing, layout redesign and improvised vacuum dryer.
- Layout redesign: Shared equipment like press, measurement apparatus, tools and fixtures need to be grouped adjacent to workstations, electrical inspection to be moved adjacent to final inspection, supermarkets to be introduced after unpacking and incoming inspection, cleaning area is to be segregated into three workstations, and a portion of conveyor belt is to be eliminated. There are several benefits by restructuring the layout. Workers would take fewer steps which means less movement and more time on value added activities. Moreover, elimination of a portion of conveyor belt would provide space for arranging shared equipment, supermarkets, process redesign, and new workstations.
- Line balancing: Electrical and final inspections could be combined as one process performed by a single employee, which would endure similar process time with other processes and ensure continuous flow. This is a major process redesign done as a part of line balancing. Layout redesign and improvised vacuum dryer would enable this transformation.
- Process redesign: A major process redesign is mentioned above. Another major process redesign is the elimination of inspection process, which aims at inspecting parts and creating a report. However, by creating predefined phrases that enable disassemblers to create inspection report themselves, eliminates the need for a separate inspection process and disassembly report mentioned in section 5.1.2. This could be achieved under digitalization initiative.
- Improvised machinery: overnight drying of stators tremendously contribute to inventory and motion wastes. By introducing an improvised vacuum dryer drying time would be reduced.
- Digitalization: Multiple digitalisation initiatives are suggested, which would greatly reduce cycle times and waiting times. One initiative suggested is creation of predefined phrases formed out of history that enable disassemblers to create inspection report themselves. Another initiative is the introduction of DCN database, whereby time for checking DCN as described in section 5.1.2 would be greatly reduced. Moreover, a lot of paperwork is transferred between service office, shop floor and within workstations; creation of a service portal would be a good solution for this.
- Service portal: A page on FK homepage could be dedicated to a customer service portal, where customers are able to register their spindles for service along with information on failure occurred, often referred to as customer statement. This eliminates the time spent waiting for COF before and after incoming inspection, eliminates paper transfer between office and shop floor and aids in better scheduling in service area.
- Reduce process variations: One of the major factors affecting cycle time in disassembly is the presence of excessive adhesive in fasteners and windings of components. While it is essential as spindles are subjected to high levels of vibration and torque, excessive adhesive makes unwinding and detaching parts quite difficult. In such an event disassemblers have to heat the parts to high temperatures resulting in time, energy losses and in worst cases, a rework. Assembly and service departments should reach a consensus on this issue. Other variations in processes can be solved by giving workers proper instructions.

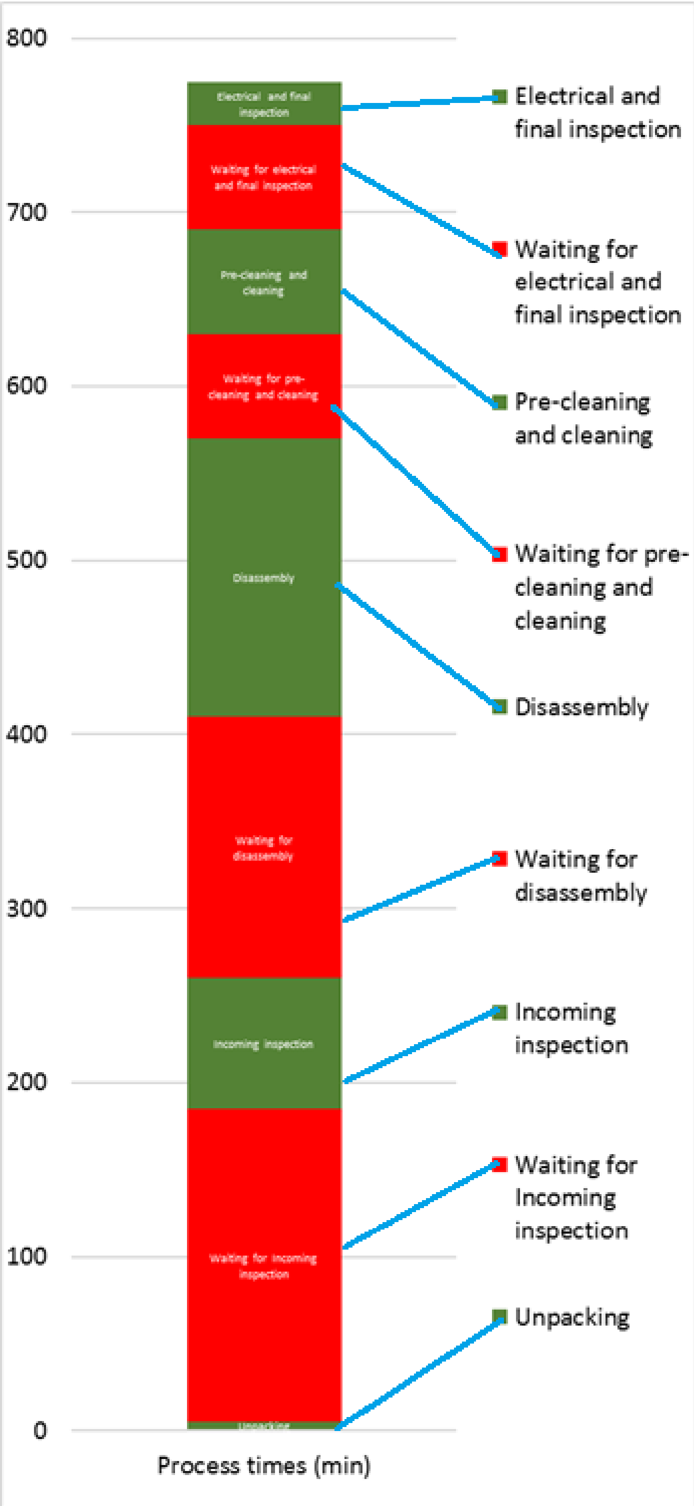


Figure 6.2: Yamazumi chart for spindles with normal repair after improvements, Source: Own Illustration.

6.1.2. Spindles with warranty repair

Along the current VSM of warranty repairs, following wastes were detected:

- Waiting: for warranty officer to inspect; for customer statement; for COF at disassembly area; for imaging equipment, cranes, computers, tools, fixtures, measurement apparatus, press etc. at disassembly area; for re-cleaning if a part is found not cleaned properly by final inspector;

- Motion: for tools, fixtures, boxes, heating apparatus, press, information, print outs, ensuring material flow, measurement apparatus, computers; to bring COF and other paper based documents from office to shop floor;
- Defects: at disassembly some parts need to be heated to high temperatures due to excessive adhesive on fasteners and windings; on the course of disassembly damage due to lack of proper instructions; on the course of disassembly damage due to variabilities in design;
- Inventory: spindles for test run are stored till test run machine is free on other side of building; large WIP after each workstation;
- Unused talent: Disassembly workers not trained to prepare inspection report;
- Transport: pallets are transported to and from warranty office;
- Extra-processing: quadruple inspection of parts once each by disassembler, warranty officer, inspector and final inspector; two inspection reports are prepared-one by warranty officer and another by usual inspector; parts classification at disassembly done on technical drawing, paper BOM and SAP BOM; disassembly observation written on paper first and then typed in SAP; manual operation in some steps instead of using machinery at disassembly; multiple steps due to obsolete software.

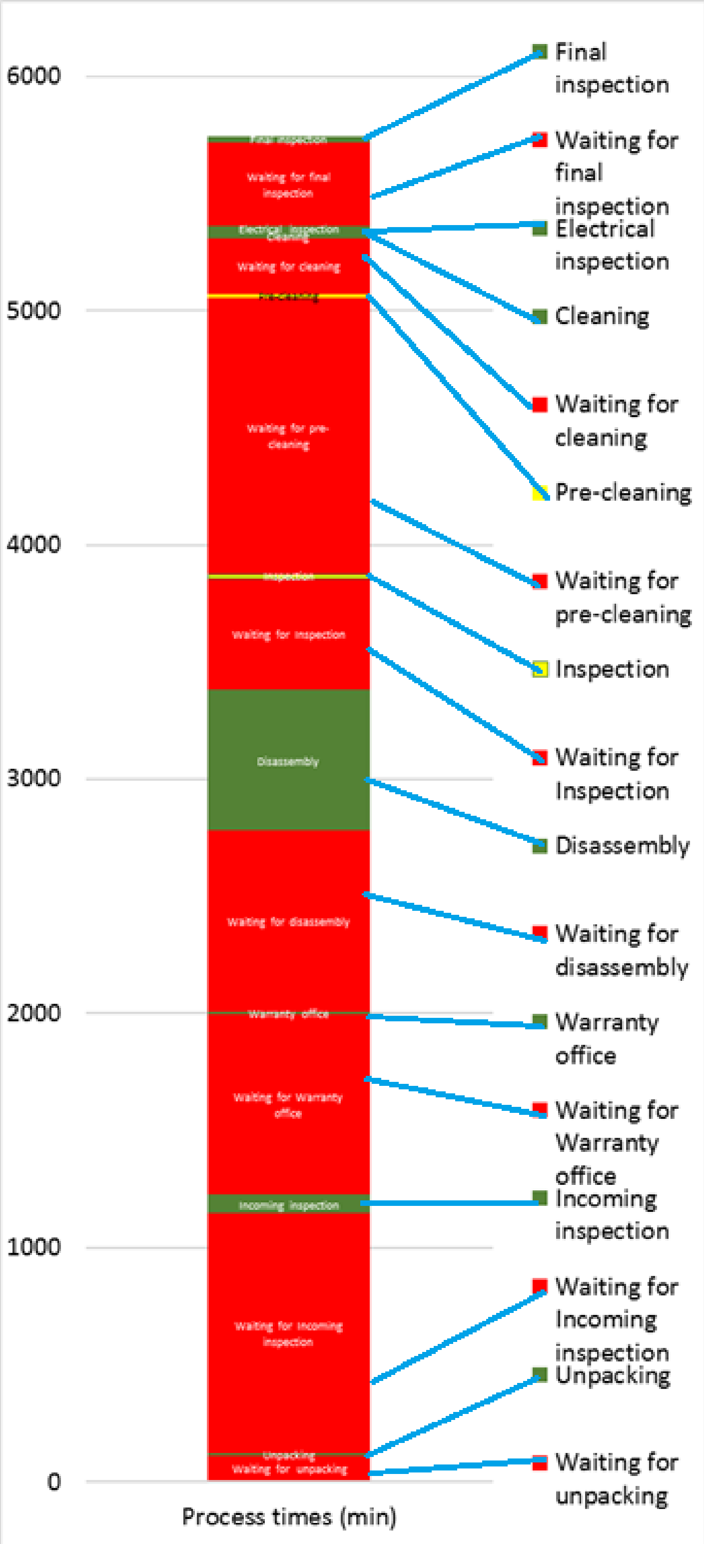


Figure 6.3: Current state Yamazumi chart for spindles with warranty repair, Source: Own Illustration.

Since warranty repairs follow same process steps as normal repairs except for warranty office inspection and disassembly, only improvement proposals not listed above in section 6.1.1 are mentioned here to avoid repetition. To eliminate the different lean wastes mentioned above, following actions are recommended:

- Layout redesign: Warranty disassembly workstations need to be arranged adjacent to each other and adjacent to warranty office to reduce transportation of spindles from and to warranty office and easier access in course of disassembly, where findings need to be periodically analysed with the warranty officers. Shared equipment like press, measurement apparatus, tools and fixtures need to be grouped adjacent to workstations.
- Supermarket: A supermarket is required after incoming inspection for spindles with warranty repair. Supermarkets contain the right-sized amounts of inventory that promote continuous flow to occur. In this case the WIP and hence inventory costs will decrease.
- Improvised equipment: An improved imaging set up is required. Due to the warranty claim posed by the customer, each component is to be observed closely, and close-up photographs of visible abrasions taken. With the present set up, a lot of time is spend to focus and come up with good photographs. Another addition could be the introduction of stack lights to notify warranty officer to perform warranty inspection before the spindle is placed in the supermarket and to analyse the findings of disassemblers during disassembly.
- Service portal: In the service portal mentioned above, the customers could make a warranty claim along with their statement while registering the spindle for repair. This eliminates the need for the TCSR to check the delivery dates, determine the validity of claim and classify as warranty repair after spindle is unpacked, since the service portal automatically classifies it even before the spindle reaches FK. This also aids in better scheduling for warranty spindles as their cycle times are quite high, and eradicates time spent waiting for COF before and after incoming inspection and paper transfer between office and shop floor.
- Review customer contacts: The contracts should be reviewed in order to lower cycle times for warranty disassembly. This suggestion will not be used in future VSM design, as estimation of figures are not possible due to limited access to customer contracts' information.

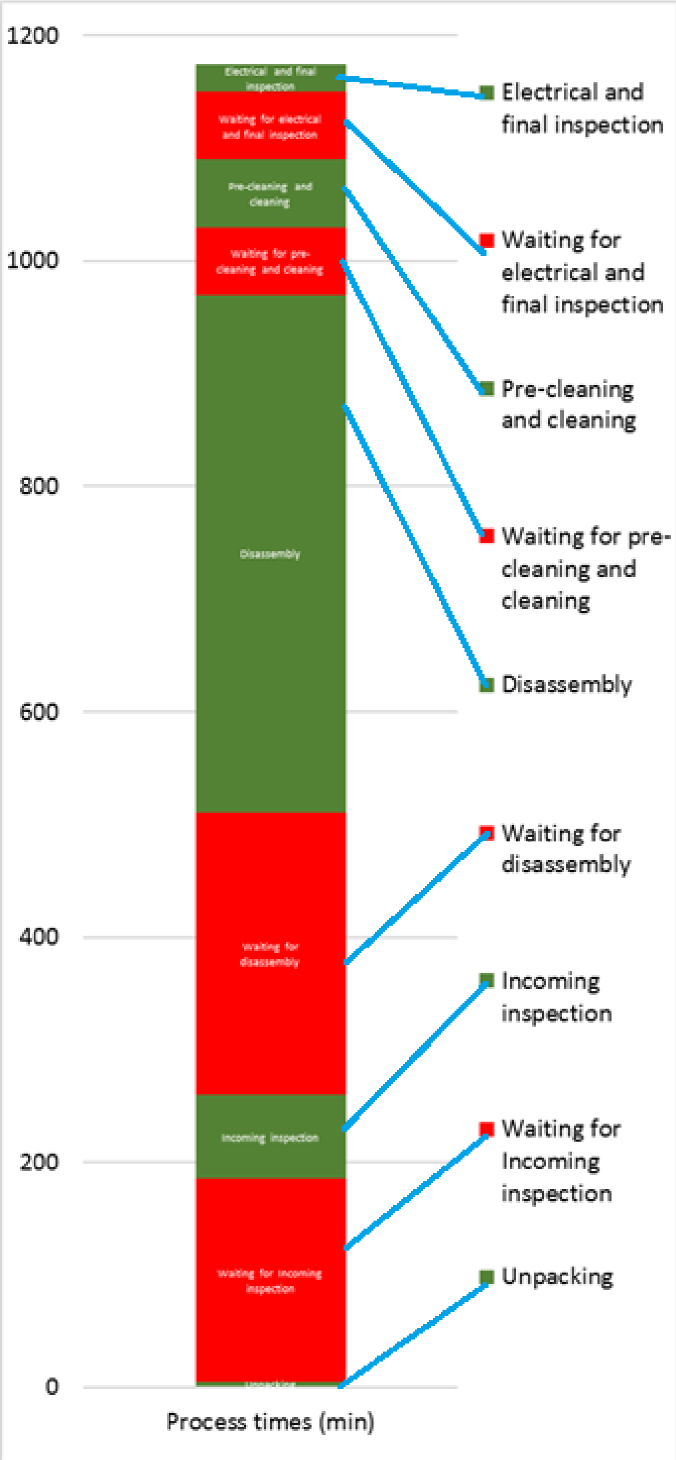


Figure 6.4: Yamazumi chart for spindles with warranty repair after improvements, Source: Own Illustration.

6.1.3. Systems repair

Along the current VSM, following wastes were detected:

- Waiting: for COF at system disassembly area;
- Motion: for tools, fixtures, print outs, material flow, to bring COF and other paper based documents from office to shop floor; pre-cleaner has to come out of cleaning area to load parts from pallet on floor to washing machine and return pallet to waiting area after after washing;

- Inventory: system backlog at incoming inspection and cleaning due to lack of proper scheduling inclusive of systems;
- Unused talent: spindle disassemblers not trained to perform system disassembly;
- Transport: systems transported to system disassembly hall located in another part of factory; after disassembly parts in three or four pallets have to be transported back one by one by the disassembler to the cleaning area;
- Extra-processing: enormous time spent on checking DCN due to multitude of subassemblies and subcomponents; cleaning of parts, which might be scrapped at pre-assembly; extra steps due to obsolete software.

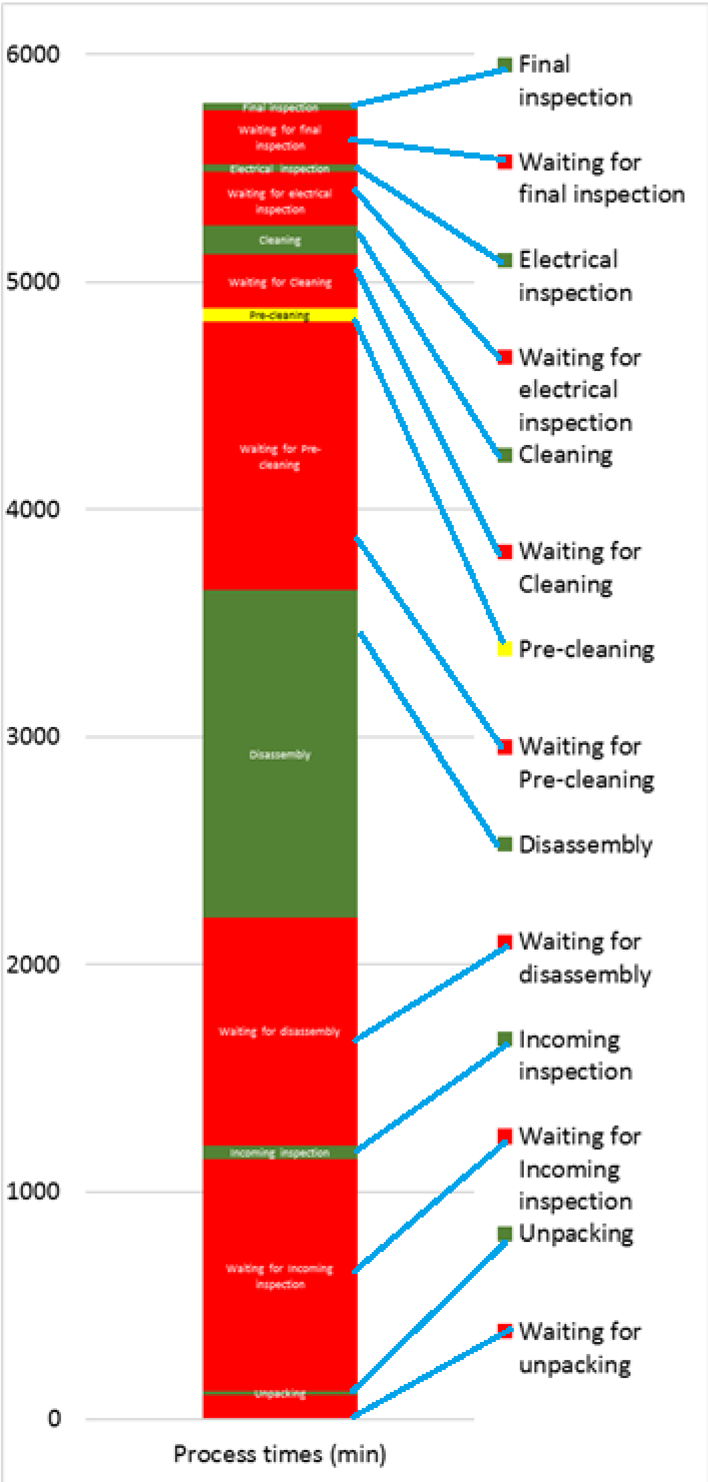


Figure 6.5: Current state Yamazumi chart for systems repair, Source: Own Illustration.

Since system repairs follow same process steps as normal repairs except for, disassembly and final inspection, only improvement proposals not listed above in section 6.1.1 are mentioned here to avoid repetition. To eliminate the different lean wastes mentioned above, following actions are recommended:

- Layout redesign: By eliminating a portion of conveyor belt, it makes enough room for all processes normally held in the service area and most importantly creates space for system disassembly. This solves many issues, namely, system backlog at incoming inspection and cleaning area, transport of pallets, unnecessary movements of system disassembler and cleaners, lack of training for spindle disassemblers to do system disassembly, and facilitates introduction of supermarkets after unpacking and incoming inspection.
- Digitalization: Multiple digitalisation initiatives are suggested, which would greatly reduce cycle times and waiting times. One initiative suggested is introduction of DCN database, whereby time for checking DCN as mentioned among wastes above would be greatly reduced. Another initiative is the creation of predefined phrases formed out of history that enable disassembler to create inspection report himself.
- Service portal: This aids in better scheduling for systems; owing to high cycle times for system repairs, additional labour assignment in periods of high demand can be done beforehand. It also eradicates time spent waiting for COF before and after incoming inspection and paper transfer between office and shop floor.

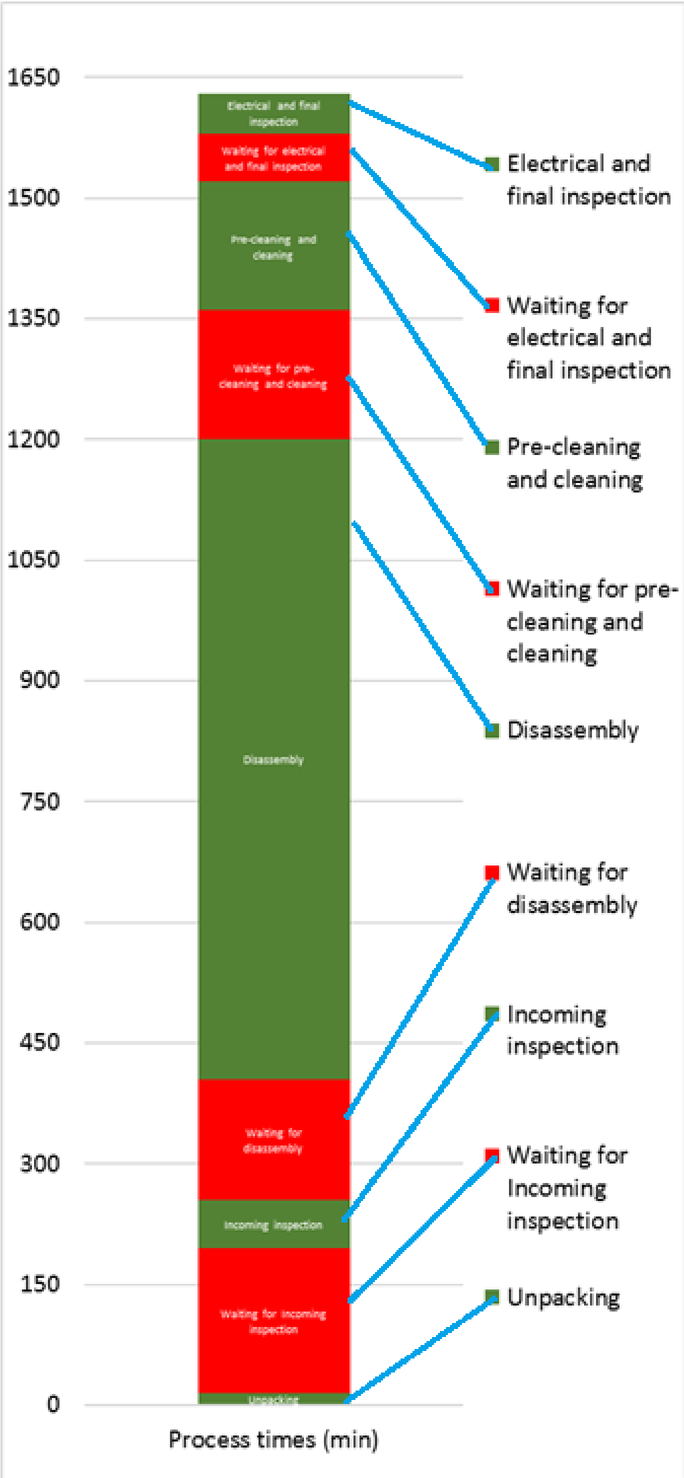


Figure 6.6: Yamazumi chart for systems repair after improvements, Source: Own Illustration.

6.2. Overview of processes after improvements

Future state layout and improvements in processes after implementation of proposed improvements are explained in subsequent sections.

6.2.1. Future state layout

As mentioned in the previous section, layout redesign is one of the most important improvement proposals.

This is set to reduce waiting times, labour hours, WIP, lead-times, space and movement, and to improve communication, shared use of equipment, line balancing etc. The proposed layout is illustrated below:

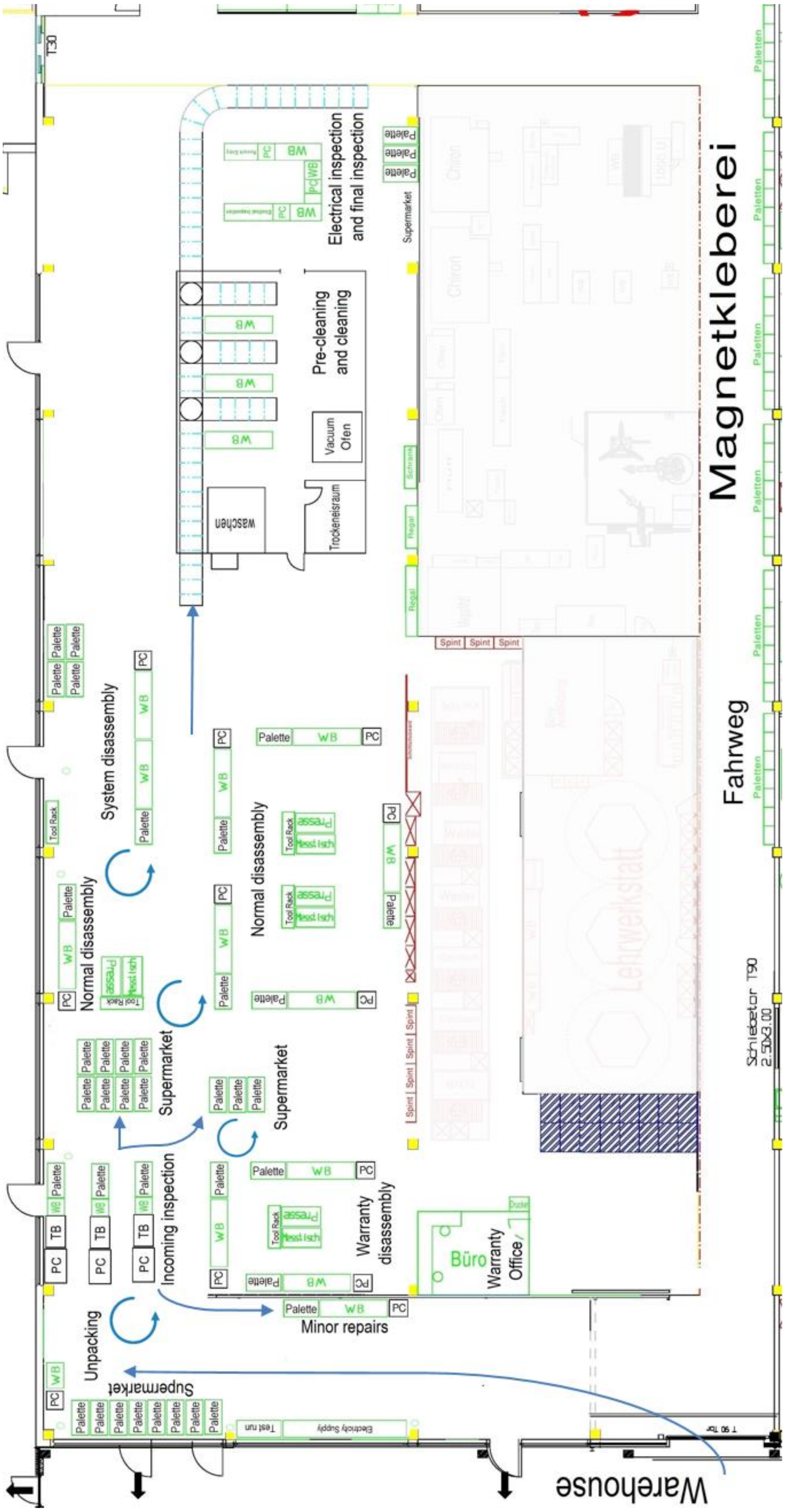


Figure 6.7: Proposed layout for service area, Source: Own Illustration.

- Unpacking area: It consists of a workbench, a computer and a supermarket for unpacked products to be pulled by incoming inspectors.
- Incoming inspection area: It comprises of three test benches each operated by an incoming inspector. Each test bench is equipped with necessary mechanical, hydraulic, pneumatic and electrical testing equipment along with a computer and a workbench. After the incoming inspection, spindles that are to be disassembled are split between two supermarkets. One supermarket is replenished with spindles for normal repair and systems, while the other supermarket is replenished with spindles for warranty repair. Products with minor repair are directly transferred to the minor repairs workstation.
- Minor repairs: After incoming inspection, products with minor repair are directly transferred to the minor repairs workstation. It is equipped with necessary tools, spare components and fittings to prepare the product for test run.
- Normal disassembly area: It is divided into six workbenches each operated by a disassembler. Each workbench consists of a computer, necessary tools and fixtures for the operation. Shared amenities like presses, tool racks and concentricity measurement apparatuses placed in the middle to facilitate equal access to all workstations. Spindles are pulled from the supermarket and after incoming inspection. After disassembly, pallet jack is used to transfer and load the pallet containing disassembled spindle onto the conveyor belt for pre-cleaning.
- Warranty disassembly area: It is divided into three workbenches each operated by a disassembler. Similar to the normal disassembly area, each workbench consists of a computer, necessary tools and fixtures for the operation. Shared amenities like presses, tool racks and concentricity measurement apparatuses placed in the middle to facilitate equal access to all workstations. Spindles are pulled from the supermarket after incoming and warranty inspections. After disassembly, a pallet jack is used to transfer and load the pallet containing disassembled spindle onto the conveyor belt for pre-cleaning.
- System disassembly: It consists of a workbench equipped with a computer, tools and fixtures for the operation.
  Systems are pulled from the supermarket and after incoming inspection. After disassembly, a pallet jack is used to transfer and load the pallet containing disassembled system components onto the conveyor belt for pre-cleaning.
- Pre-cleaning and cleaning area: Pallets containing disassembled spindles and systems are loaded onto the conveyor belt for pre-cleaning. It consists of a large washing machine, dry ice blast cleaning room and vacuum oven. After pre-cleaning the pallets head to the cleaning area, where each component is cleaned again manually.
- Electrical and final inspection area: After cleaning, pallets arrive to the electrical and final inspection area. From one pallet, its stator is picked by crane to place it on electrical inspection workbench, which is equipped with multiple electrical testing equipment and a computer. Meanwhile, the final inspector performs 100% quality check on other components in the pallet. Parts for rework are moved into the rework entry station. After both inspections, the pallet is transported to the warehouse by means of a forklift.

6.2.2. Description of improved processes

The unpacker brings the product by means of a forklift to the unpacking area. He then unpacks, transfers it to a pallet by a crane, attaches the SAP registration number attached to the pallet to be tracked and places it in the empty slot in supermarket.

The incoming inspector pulls a spindle from unpacked supermarket and lifts it to the test bench by an overhead crane. He then opens the last measurement protocol in the computer that would serve as a reference to his observations. Photographs are taken from all sides to document the received condition. This is followed by hydraulic test, insulation test, sensor test, geometry test, concentricity test and power check.

The results from each testing device is entered simultaneously in to an incoming inspection report in digital format. After incoming inspection, the spindle is placed on the empty slot of supermarket if it is a normal repair, if it is a warranty repair, he places it on the empty slot in the smaller supermarket after warranty spindles and if it is a case for minor repairs, transfers it directly to the minor repairs work bench behind. In case of systems, only insulation and sensor tests are conducted and the system is placed in the slot in the supermarket.

Process	Estimated cycle times (min)	
	Spindles	Systems
Unpacking	5	15
Incoming inspection	75	60

Table 6.1: Estimated process times for unpacking and incoming inspection, Source: Own Illustration.

In case of normal repairs, the disassembler pulls a spindle that has finished incoming inspection from the larger supermarket and lifts it over to his workbench using overhead crane. Photographs are taken to document the condition prior to disassembly. He then starts the disassembly operation by first removing peripheral components such as encoder, proximity sensor, rotary feed union and unclamping unit. O-rings and bolts are put into two different packets to be disposed. Now he uses an impact wrench to detach rear bearing shield, few rings, spacers and gripper. After the gripper is unscrewed, the drawbar can now be removed by tapping on the other side of the spindle. The impact wrench is used again to remove shaft nut and several bolts. Special fixtures are used to remove the rotor assembly from the stator, which is placed on the pallet with the help of overhead crane. The rotor assembly consists of several subcomponents. It is placed on the press to push down the long spindle shaft, which is then taken for concentricity measurement.

This then leaves with bearing housing and after pressing it down and operating on with different fixtures, cooling chamber, bearings and other subcomponents are detached. On the course of disassembly process, the disassembler checks originality components, photographs if required and places them into separate boxes in the pallet. The disassembler then moves to his computer, prepares an inspection report by selecting predefined phrases suitable for this case, attaches pictures, classifies parts on SAP BOM and finally loads the pallet using a pallet jack into the conveyor belt for pre-cleaning and cleaning.

Process	Warranty office	Dis-assembly	Pre-cleaning and cleaning	Electrical and final inspection
Estimated cycle times for spindles with normal repairs (min)	-	160	60	25
Estimated cycle times for spindles with warranty repairs (min)	5	460	60	25
Estimated cycle times for system repairs (min)	-	795	160	50

Table 6.2: Estimated process times for processes after incoming inspection, Source: Own Illustration.

In case of warranty repairs, as the incoming inspection is finished, the warranty officer is notified by means of a stack light. The warranty officer makes a preliminary assessment and figures out further course of action. If further action can be taken only after the spindle undergoes a test run, it is sent for test run, in which case the spindle is transferred behind to minor repairs operator, who is now responsible to manage test runs. Otherwise, the spindle is placed in the supermarket. The warranty disassembler pulls a spindle from the supermarket and follows the same steps detailed above. However, due to the warranty claim posed by the customer, each component is closely observed, measured when required, close-up photographs of visible abrasions taken and findings analysed with the warranty officers. The disassembler then moves to his computer, prepares an inspection report by selecting predefined phrases suitable for this case, attaches pictures, classifies parts on SAP BOM and finally loads the pallet using a pallet jack into the conveyor belt for pre-cleaning and cleaning.

In case of system repairs, due to the sheer size, numerous components and sub components, systems still take nearly two days to be disassembled. When full, pallet is transferred to pre-cleaning area, when a previous pallet on the FIFO lane has moved in to get pre-cleaned. Since a disassembled system can take up to four pallets for the parts to be laid on; up to two pallets could be transferred for pre-cleaning and cleaning in a day.

A cleaner pulls a pre-cleaned pallet from the conveyor belt and slides it over to his workstation. He then moves to the washing machine and transfers the pre-cleaned parts to its pallet on the conveyor belt. If a component shows a very high degree of contamination, it is then cleaned by dry ice blast cleaning method. In individual cases, where stators show high degree of contamination, they are too pre-cleaned in washing machine and are dried. After this he pulls a pallet, which had not been pre-cleaned ahead of the line, picks all components except stator manually from the pallet, places them in the washing machine and leave it to be pre-cleaned. He then continues to manually clean components of the pallet he had slide over to his workstation at the beginning. The distinction between current state is that there will be no separate pre-cleaner and the tasks of pre-cleaning process is to be done by each cleaner. As the next cleaner finishes cleaning his palette, he moves to the machine and repeats the same steps over again.

The final inspector pulls a pallet, which had undergone cleaning. He picks up the stator from the pallet and places it on the electrical inspection bench, on his left-hand side, which is equipped with multiple electrical testing equipment. He then attaches test leads to stator cables, a specialized software generates results in a few minutes. Meanwhile, he returns to the pallet and performs a 100% quality check on the rest of the components in the pallet. He individually inspects each part, verifies it with BOM, cross-checks BOM with DCN and places parts to be reworked on to rework entry desk on the right hand side. He checks the inspection reports, add results generated by the software and sprays a thin film of grease on the pallet to avoid corrosion while it waits in the warehouse. A forklift driver picks up pallets from the conveyor belt and moves it to the warehouse.

6.2.3. Line balancing

The objective of line balancing is to meet required operating rate and lower idle time to the possible minimum amount. Each process in the entire process chain should have an approximate same amount of process time. Since all the three value streams undergo almost same process steps, output of each process is taken as one single pallet regardless of the value stream to provide an approximate overview of three value streams.

For processes that have multiple workstations like incoming inspection, disassembly and cleaning, cycle times are divided over number of workstations of that process. This gives the time required for one output from each process. For instance, there are 3 incoming inspection stations and current cycle time for incoming inspection is 80 minutes. Now, the cycle time divided over number of workstations of incoming inspection gives time required for one output from the process, i.e., 26.7 minutes.

One of the problems identified along the current state VSMs was workload variations throughout different processes. Line unbalance was able to be reckoned by analysing the processes using process times and breaking down each activity into standardized tasks. Figure 6.8 shows the time each process takes. The times presented are in minutes.

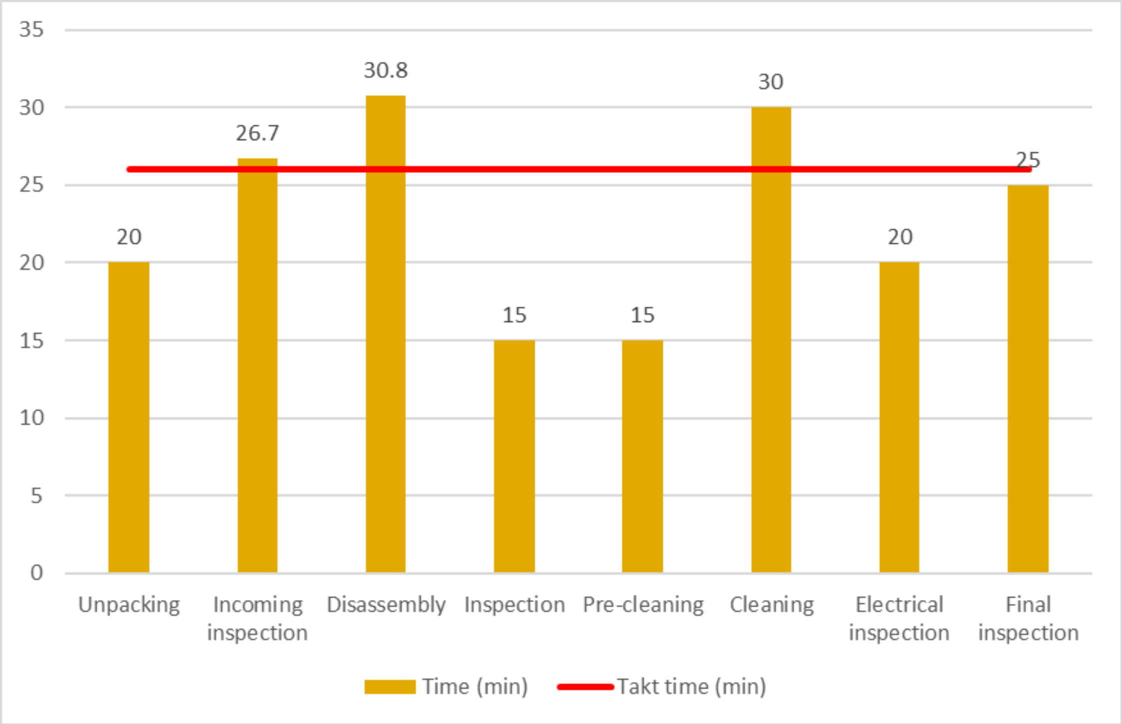


Figure 6.8: Current state line balancing (in minutes), Source: Own Illustration.

Form Figure 6.8, process time variations are quite evident. The takt time is 26 minutes. However, process times for incoming inspection, disassembly and cleaning clearly goes beyond the limit. The final inspection is closest to the takt time, which denotes that the operator performing this process is busy most of the time. However, inspection and pre-cleaning takes just over half the time to complete the task, which denotes that the operators have idle time.

The next task is to quantify the optimum number of operators working on the processes. This is calculated by dividing the sum of process times by the takt time. The result obtained is 16 operators, in contrast to the actual figure of 18 operators. This means that it is possible to eliminate two processes and their tasks could be shared between remaining processes.

A closer look at the inspection process revealed that this process could be eliminated in its entirety through the digitalization initiative. By improving the layout and transferring the tasks of electrical inspection to final inspection, owing to similar cycle times, it was possible to merge the two processes together to be performed simultaneously, effectively eliminating one process to achieve a more balanced assembly line. Similarly, the layout of the cleaning area was altered and the tasks rearranged to merge the two processes into one, effectively bringing the process time of cleaning below takt time. Process improvements in incoming inspection and disassembly would ensure that they would also not exceed takt time. Subsequent to transferring the tasks, with consideration of all other process improvements, the processes were analysed to obtain future state results. The future state line balancing can be seen in Figure 6.9. The times presented are in minutes.

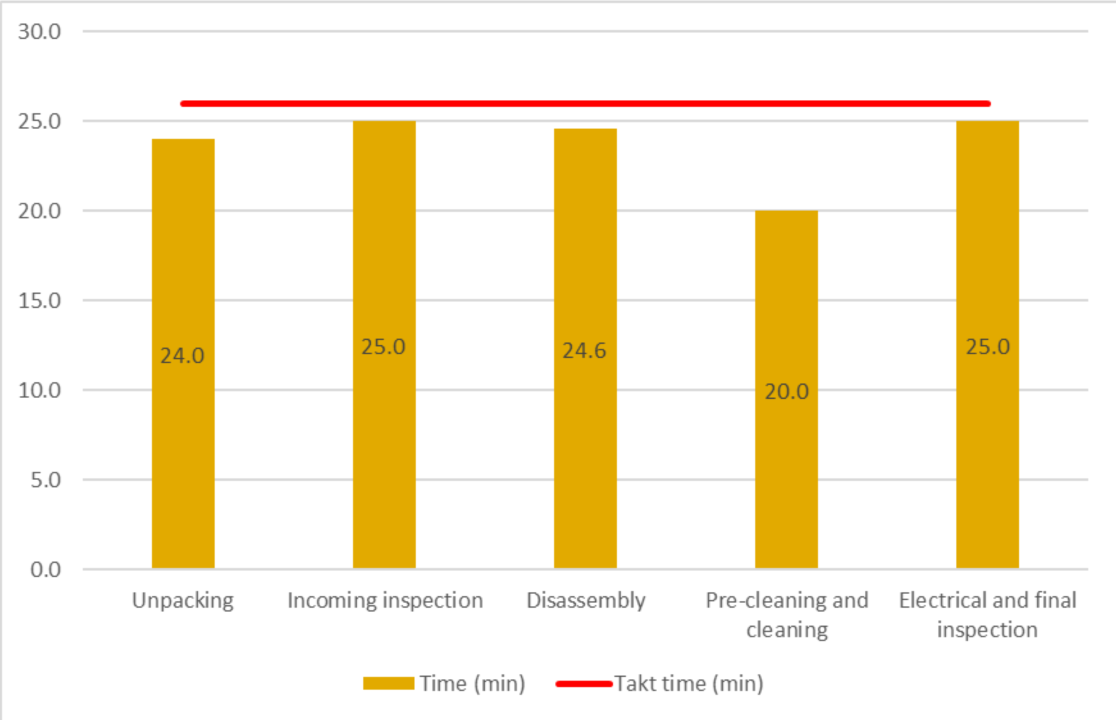


Figure 6.9: Future state line balancing (in minutes), Source: Own Illustration.

The results show one process eliminated and two processes merged. Maintaining process times below takt time is hence ensured.

6.3. Future state VSMs

Based on improvement proposals laid out earlier, future state VSMs of the three value streams are designed and analysed in this section.

6.3.1. Future state VSMs

Many improvements were made on the current state VSM of spindles with normal repair in consideration with the improvement proposals laid out earlier.

Considerable improvements can be seen in information flow on upper part of the VSM, and in material flow and lead-times in the lower part of VSM. The times shown have been estimated and visualised by using Yamazumi charts. The future state VSM of spindles with normal repair is analysed below:

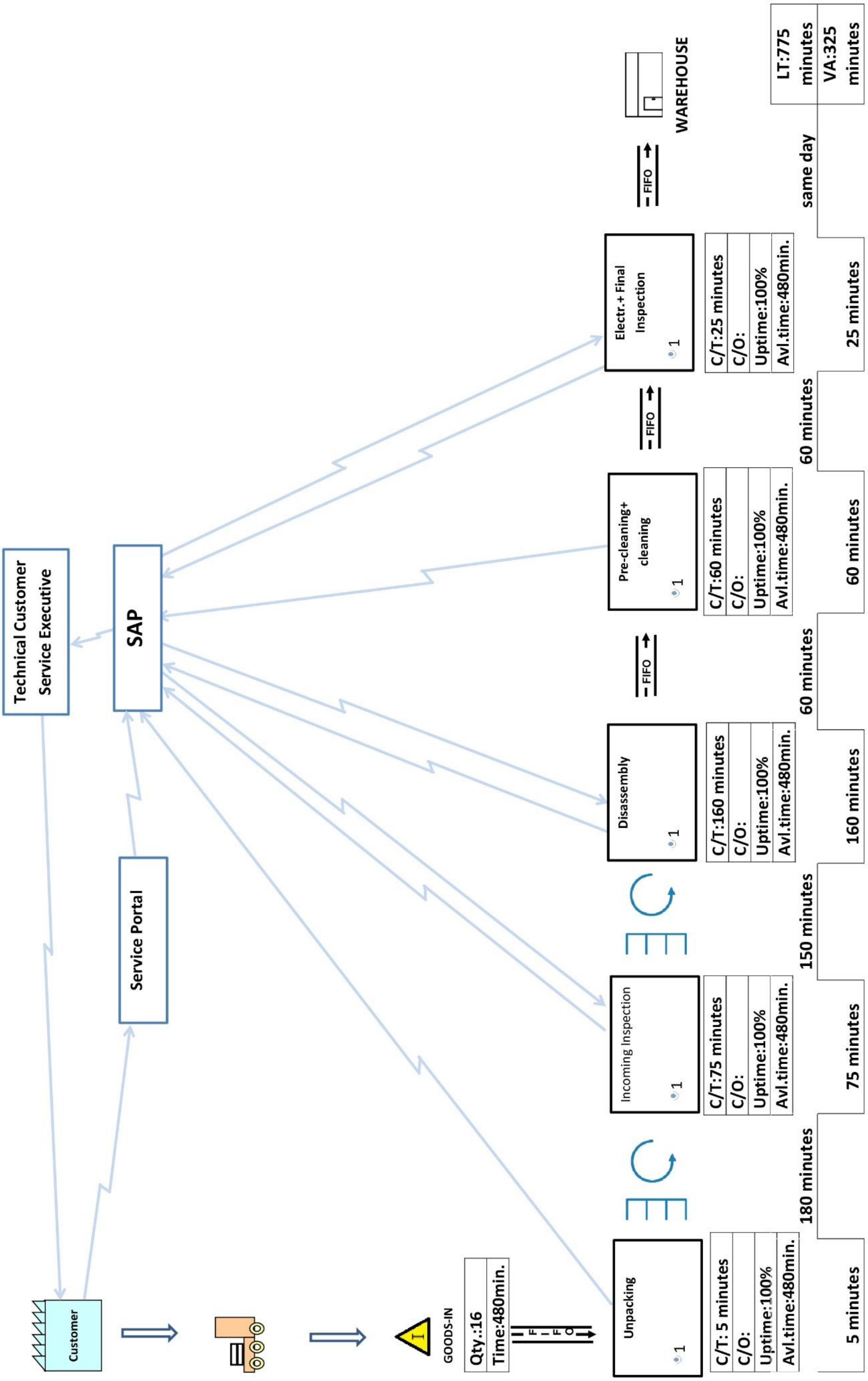


Figure 6.10: Future state VSM for spindles with normal repair, Source: Own Illustration.

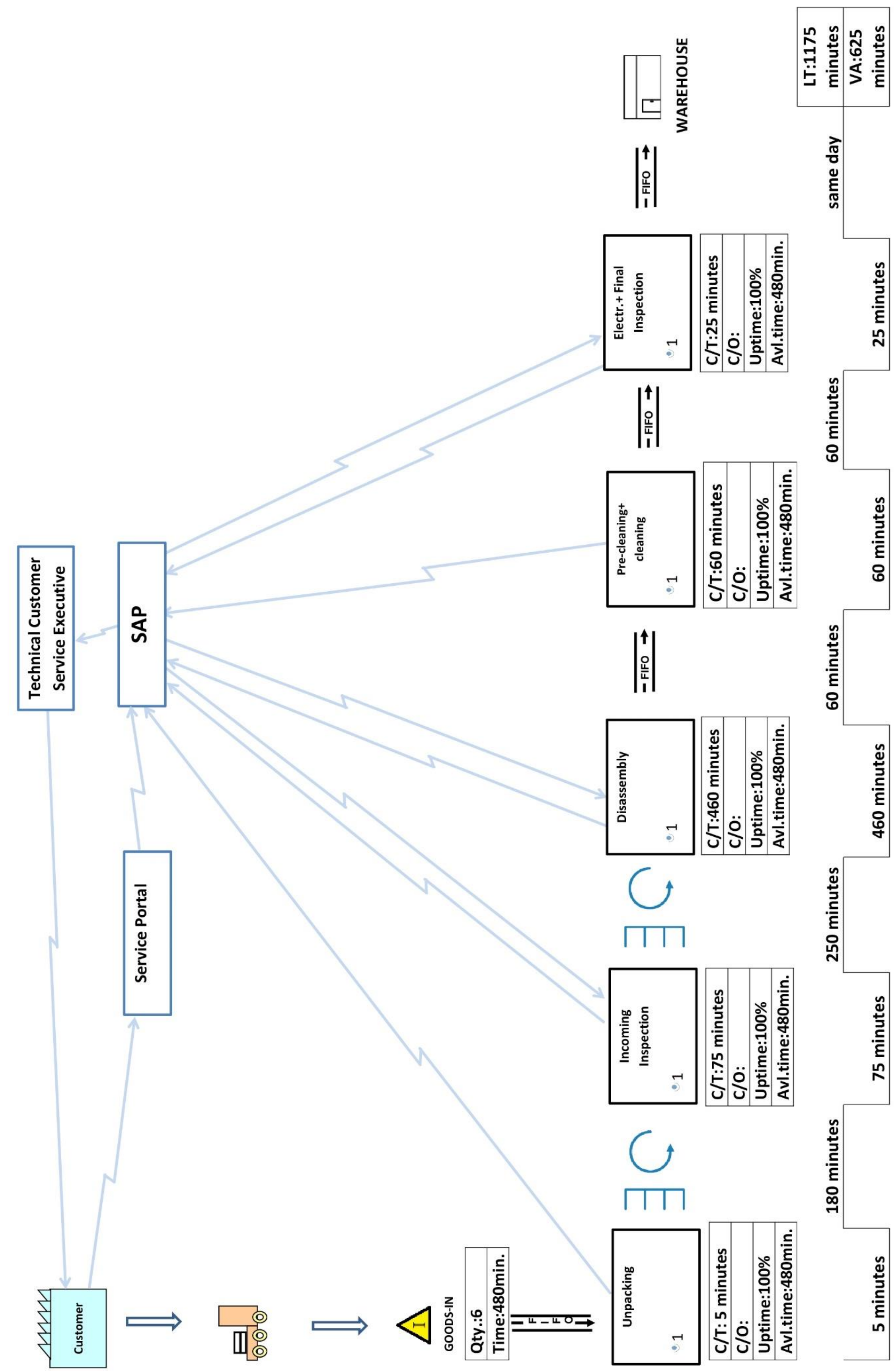


Figure 6.11: Future state VSM for spindles with warranty repair, Source: Own Illustration.

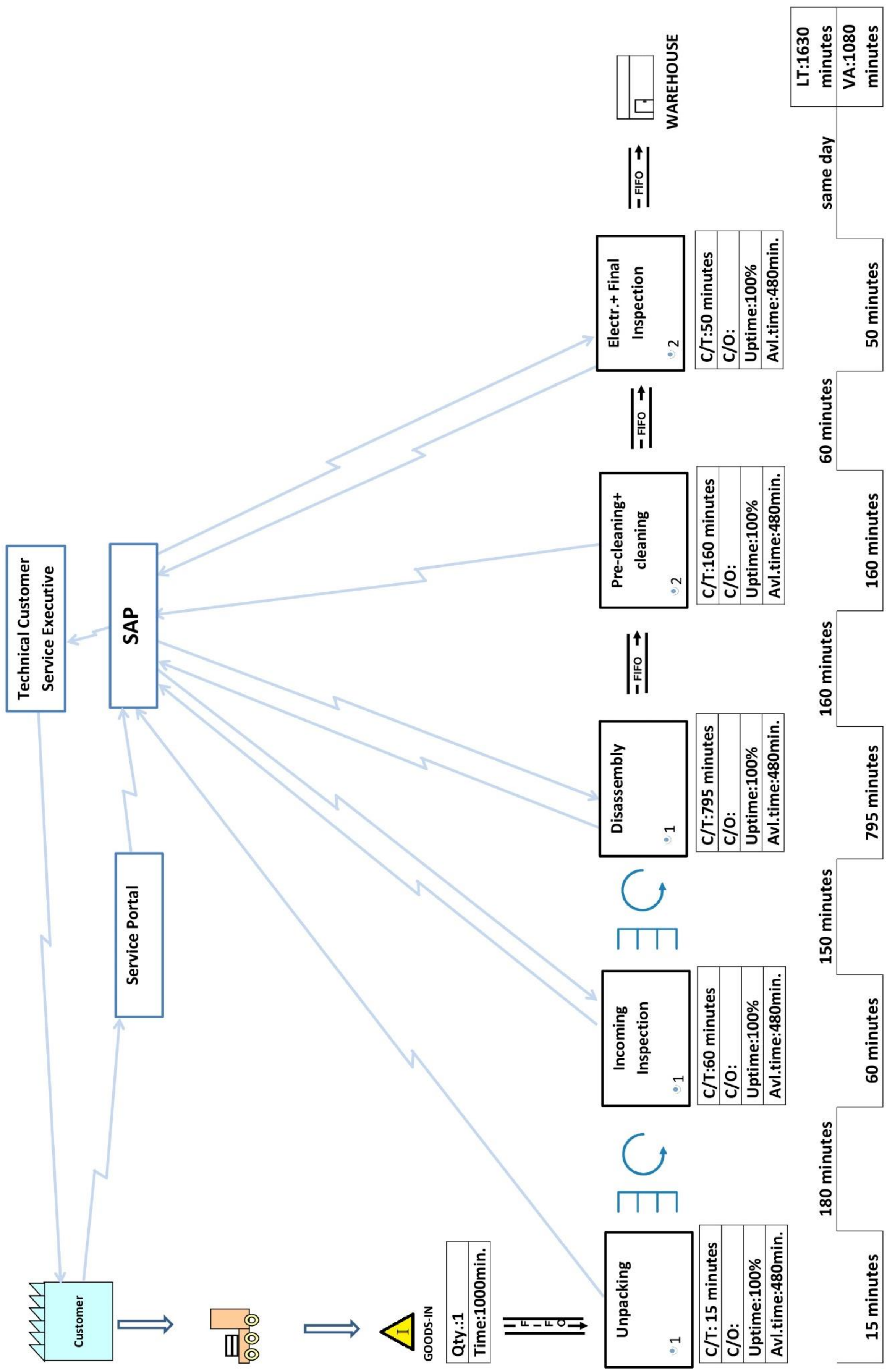


Figure 6.12: Future state VSM for system repair, Source: Own Illustration.

6.3.2. Information flow analysis

The information flow is illustrated on the upper half of VSM. It starts when the customer registers his spindle or system on the service portal of FK for repair with details on whether he would claim warranty cover and an overview of the defect that has occurred. The portal is in turn integrated with SAP. This would aid in scheduling by helping to form a forecast of demands in SD. The product then arrives at FK, the unpacker unpacks it, a COF is already generated since it was registered earlier and classifies it whether it falls under normal spindle repair, warranty spindle repair or system repair. An SAP registration number for the product is automatically generated at the end and is attached to the pallet to be tracked. After each process, the operator gives a feedback into the SAP system, so that the progress is tracked by TCSR, who would respond to customer's technical queries.

6.3.3. Material flow analysis

The forklift driver transfers a pallet from the conveyor belt to warehouse after electrical and final inspection. The final inspector then tends to the next pallet, which has undergone pre-cleaning and cleaning according to FIFO principle and performs electrical and final inspection. As the final inspector takes the pallet for electrical and final inspection, the pallet next in line is taken for pre-cleaning and cleaning according to FIFO principle. As the pallet is moved for pre-cleaning and cleaning, a disassembler loads his disassembled pallet onto the conveyor belt using a pallet jack, pulls a normal spindle, warranty spindle or system as designated to him from the supermarket and starts his next disassembly. Now an incoming inspector pulls a pallet from unpacked supermarket and starts incoming inspection. Empty slots act as signals, which calls for new pallet. Therefore, the unpacker transfers a product from warehouse, unpacks it and replenishes his supermarket.

6.3.4. Lead-time analysis

Value added and non-value added times of each process on future state VSM of spindles with normal repair are depicted in the graphs below.

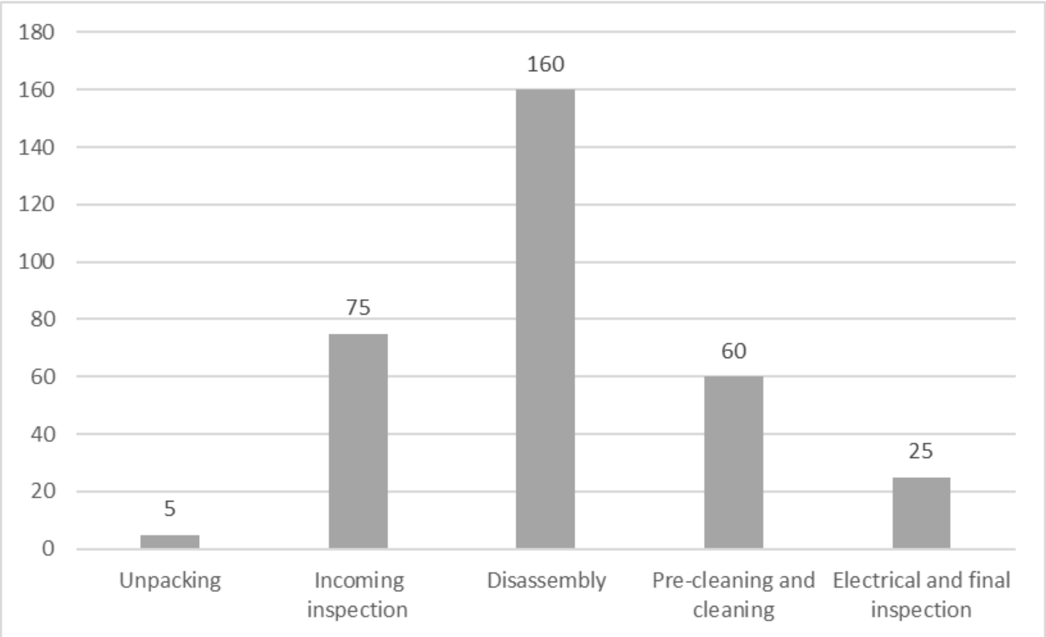


Figure 6.13: VA from future state VSM of spindles with normal repair (in minutes), Source: Own Illustration.

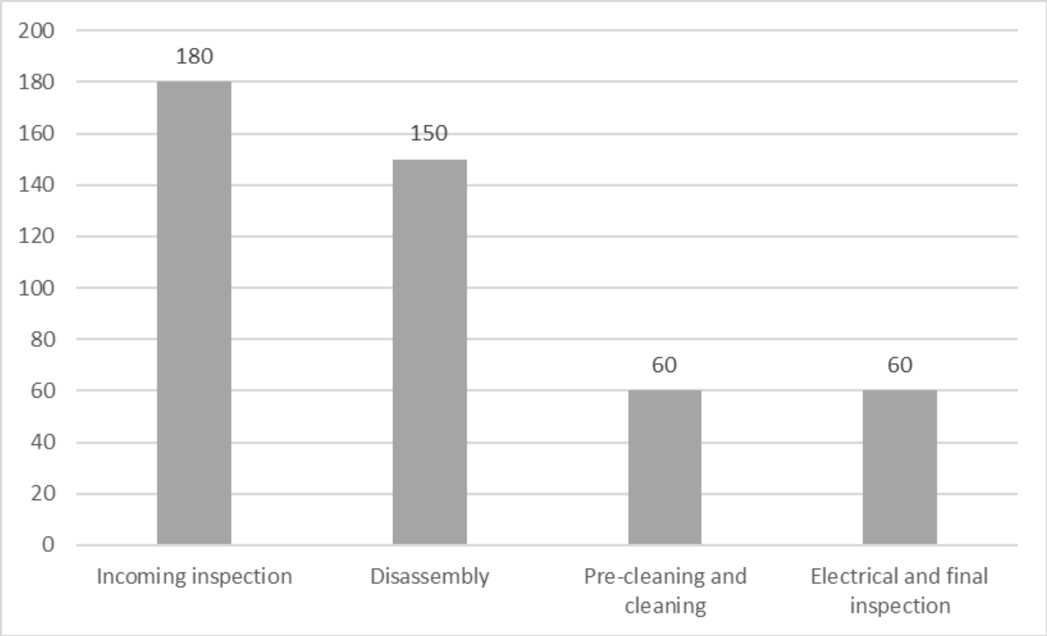


Figure 6.14: NVA from future state VSM of spindles with normal repair (in minutes), Source: Own Illustration.

The results are summarized in Table 6.3 below.

	VA Time (min)	VA Time (days)	NVA Time (min)	NVA Time (days)
Total	325	0.68	450	0.94

Table 6.3: Lead-times summary for spindles with normal repair, Source: Own Illustration.

Value added and non-value added times of each process on future state VSM of spindles with warranty repair are depicted in the graphs below.

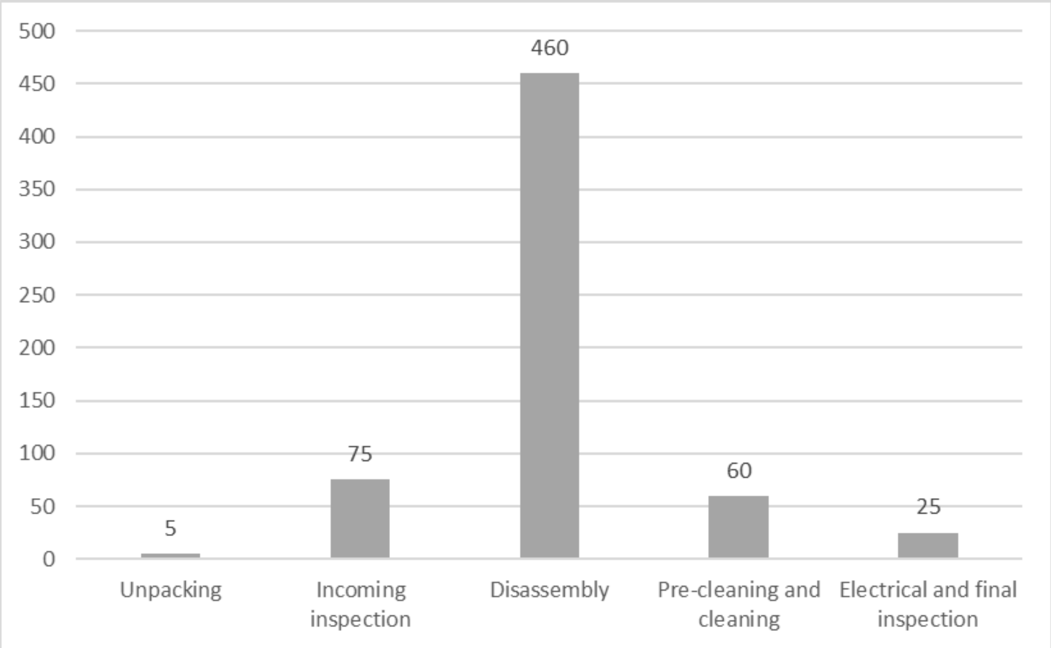


Figure 6.15: VA from future state VSM of spindles for warranty repair (in minutes), Source: Own Illustration.

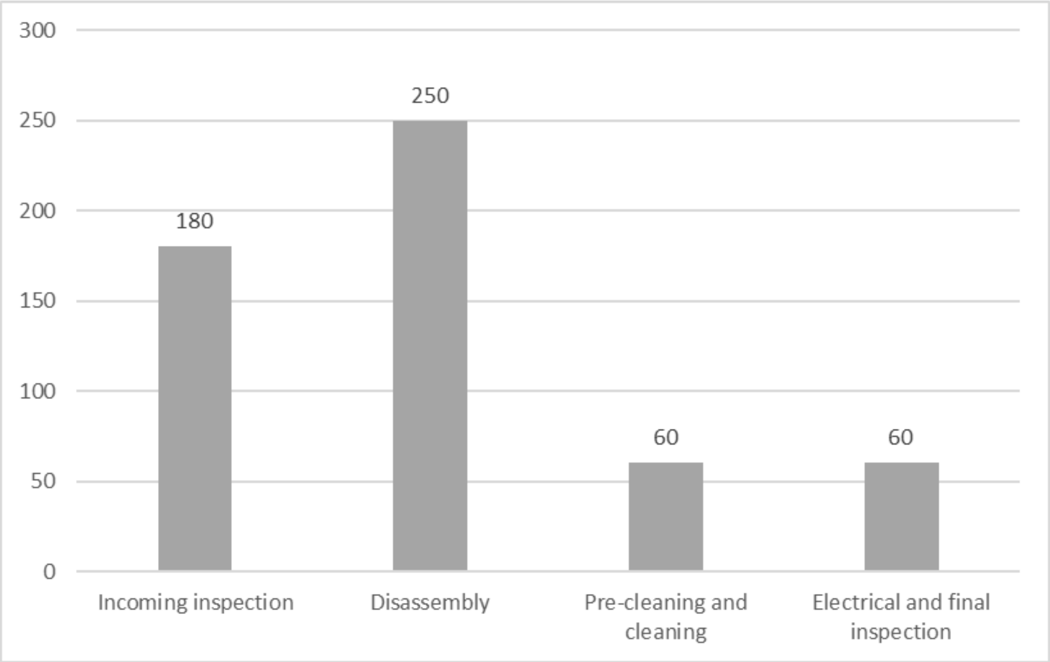


Figure 6.16: NVA from future state VSM of spindles for warranty repair (in minutes), Source: Own Illustration.

The results are summarized in Table 6.4 below.

	VA Time (min)	VA Time (days)	NVA Time (min)	NVA Time (days)
Total	625	1.3	550	1.1

Table 6.4: Lead-times summary for spindles with warranty repair, Source: Own Illustration.

Value added and non-value added times of each process on future state VSM of system repair are depicted in the graphs below.

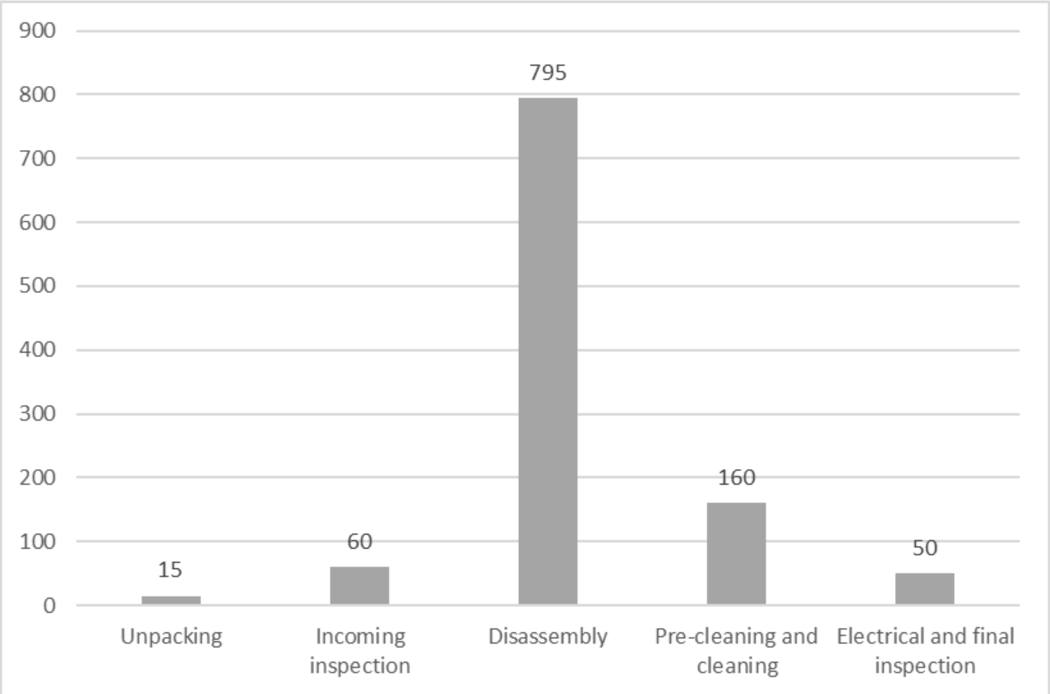


Figure 6.17: VA from future state VSM of system repair (in minutes), Source: Own Illustration.

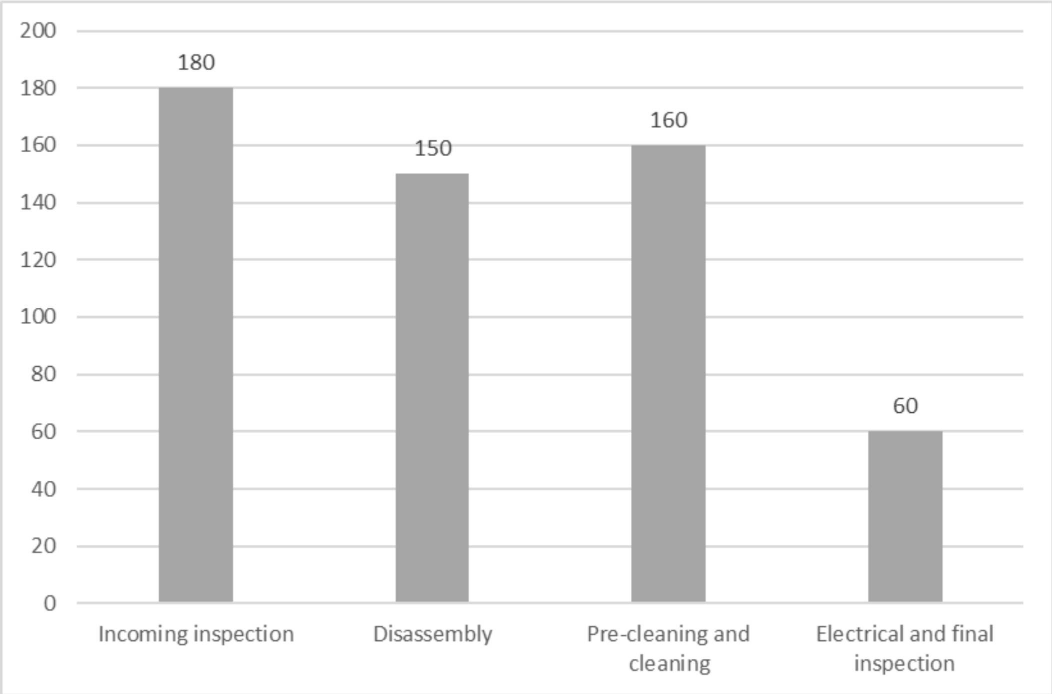


Figure 6.18: NVA from future state VSM of system repair (in minutes), Source: Own Illustration.

The results are summarized in Table 6.5 below.

	VA Time (min)	VA Time (days)	NVA Time (min)	NVA Time (days)
Total	1080	2.3	550	1.1

Table 6.5: Lead-times summary for system repair, Source: Own Illustration.

6.4. Results analysis

In this section, the results obtained from improvements proposed for the three value streams are analysed and advantages of the proposed future state over the current system are described.

6.4.1. Efficiency

Eliminating waste at workstations to minimize idle times and non-value-added work along the value streams is one of the most important objectives of this study. Considering higher output of the future state by a smaller number of operators in reduced process times, it is evident that the efficiency of the service area would increase as a result of this study. Besides, reducing NVA times between processes by introducing a pull system, layout redesign, improvised machinery, digitalization, reduced process variations and redesigning processes that caused takt overdue are other factors that would improve efficiency of value streams.

6.4.2. Fulfilment rates

The current requirement in the service department is for a product to go through all the processes from unpacking to delivering to the warehouse within five working days. However, from analysing SAP data, it became known that after undergoing the processes only 12% of products are delivered to the warehouse within five working days and 42% are delivered within ten working days. This will have clear improvements by reductions achieved in lead-times, such that a 100% fulfilment rate can be achieved.

6.4.3. Process times

Improvements on current processes focus on eliminating wastes within and removing non value adding processes. By introducing a pull system, layout redesign, improvised machinery, digitalization, reduced process variations and process redesign, an average process time reduction of 26.8% is achieved.

	Current state	Future state	Reduction
Process times for spindles with normal repairs (min)	400	325	18.75%
Process times for spindles with warranty repairs (min)	815	625	23.3%
Process times for systems repairs (min)	1755	1080	38.5%
Overall process times reduction			26.8%

Table 6.6: Comparison of process times for current and future states, Source: Own Illustration.

6.4.4. Lead-time reduction

The lead-times across the three value streams are compared and lead-time reductions are projected in the following tables. An average lead-time reduction of 78.6% is achieved.

	Current state	Future state	Reduction
Lead-times for spindles with normal repairs (min)	4760	775	84%
Lead-times for spindles with warranty repairs (min)	5745	1175	80%
Lead-times for system repairs (min)	5785	1630	72%
Overall lead-times reduction			78.6%

Table 6.7: Comparison of lead-times for current and future states, Source: Own Illustration.

6.4.5. Labour reduction

By implementing improvement proposals, a reduction in the number of operators in the shop floor and customer service representatives in the service office can be achieved, thereby increasing labour productivity. An overall improvement of up to 19 % in labour productivity is possible in the future state.

	Current state	Future state	Reduction
Operators	18	16	11%
Customer service representatives	11	8	27%
Overall labour reduction			19%

Table 6.8: Comparison of labour requirement of current and future states, Source: Own Illustration.

6.4.6. Shop floor area reduction

Many factors were taken into consideration when planning the new layout. To begin with, material flow has to be improved and unnecessary movements and waiting times for tools and other equipment have to be reduced. Next, supermarkets need to be introduced to limit WIP and shortest distance to supermarkets has to be assured in the proposed layout. As mentioned earlier, due to lack of space in the current layout, system disassembly is done in a different hall, which needs to be integrated into the main service area. Electrical inspection workstation is to be moved adjacent to final inspection to enable process transformation and a higher overall flexibility of workers across all processes is needed. The proposed layout is also planned in a way that will preserve the cleaning and final inspection areas of the current layout to reduce reorganization cost. Therefore, the key notion of new layout planning was to enable all the improvement proposals as possible with minimal reorganisation costs. An average shop floor area reduction of 29.8% is achieved.

	Current state	Future state
Shop floor area requirement (m^2)	1113.75	781.75
Shop floor area reduction		29.8%

Table 6.9: Comparison of shop floor area requirement for current and future states, Source: Own Illustration.

6.4.7. Cost analysis

Minimal implementation costs was an important factor in shaping improvement proposals. Key contributors to reorganization cost include elimination of a portion of conveyor belt and relocation of large equipment such as presses or hydraulic arm etc. New investments to be made are into development of the service portal, DCN database and buying a new vacuum dryer. Considering the scale of the change, it could be said that avoiding radical solutions and trying to preserve the current state as much as possible has helped to keep costs for improvement at relatively low levels.

Estimated figures of costs and savings are tabulated below:

Cost categories	Costs (€)
Investments (Service portal, DCN database, vacuum dryer)	26,500
Reorganisation costs	5000
Miscellaneous (maintenance of equipment etc.)	3000
Total costs	34,500
Savings categories	**Annual savings (€)**
Labour (operators)	64,000
Labour (customer service representatives)	142,000
Miscellaneous (office material etc.)	2,000
Total savings	208,000

Table 6.10: Cost analysis, Source: Own Illustration.

6.5. Implementation strategy

All stakeholders are required of to have a similar understanding of the objective and the anticipated state to successfully implement the improvement proposals laid out. Everyone is ought to realize the current situation of the company, its goals and how they will be achieved. It can be assured that everyone will do his or her part of the job, only if every individual understands the roadmap.

As such, planning the implementation is of utmost importance. A renowned approach for continuous improvement is the Plan-Do-Check-Act (Abbr.: PDCA) cycle. This is described in detail below:[83]

- Plan: Vision of the company is conceived in this step. Goals are set and quantified, which helps in analysing efficacy of improvements.
- Do: Put the plan to action. All the improvement proposals are executed and new data is collected in this step.
- Check: The new data that was obtained in the step before is analysed. Trends and abnormal events are identified. Further improvement opportunities that might pave way to a new PDCA cycle could be identified in this step.
- Act: Corrective measures, if needed, should be applied to the implementation. If something in the renewed processes is not going as planned, which could be fixed with ease, should be corrected in this step. A new PDCA cycle needs to be initiated, if the issue demands a planned resolution.

The first step is already done in this study. The current VSMs were analysed and opportunities for improvement were found and quantified. Ensuing steps have to be taken, to adhere to the strategy:[84]

- An action team should be formed.
- Timelines for implementation of improvements have to be devised.

[83] Cf. Moen/ Norman (2006), P. 6-7.

[84] Cf. Dombrowski/Mielke (2014), P. 567-569.

- Improvement opportunities has to be classified. This is done by sorting them as: urgent implementation, short-term implementation, or long-term implementation.
- Improvement opportunities needs to be ranked according to the level of difficulty to implement, resources needed and their availability;
- All employees should be apprised of the improvements that are going to be implemented.

Involvement in the improvement process by very individual working in the area must be ensured. Improvement process as a whole will be easier to achieve if people feel themselves that they are involved and that the changes could potentially improve their working condition.

After team assignment, timeline definition, and classification and ranking of opportunities, an action plan is to be made. Subsequently, after executing the action plan, the new data obtained is analysed and the results consolidated in form of savings is to be presented to the management. It is quite important to exhibit the results for all stakeholders to be aware of the achieved improvements.

6.6. Conclusions

The opportunities for improvement of current state VSMs were identified by studying the three value streams. Designing future VSMs were possible through analysis of improvement opportunities.

Results of data analysis of the future VSMs are:

- Reduction of total lead-time on all the three value streams;
- All processes conform to takt time;
- Reduction of two operators, two processes and three CSRs;
- Reduction of man and material movement and shop floor area requirement.

Finally, an implementation strategy is devised and the PDCA is suggested as guideline for its implementation.

7. Final conclusions and future work

This study is aimed at implementation of lean methodologies in order to improve productivity of the service department in Franz Kessler GmbH, a CNC spindle manufacturer in Germany. The methodology followed was founded on the design of VSMs for three value streams, the spindles for normal repair, the spindles for warranty repair, and the systems repair.

The study began by designing current state VSMs through analysis of data collected along the processes. The subsequent identification of wastes led to the shaping of improvement opportunities. These opportunities were instilled in the future VSMs as follows:

- Implement a pull system between consecutive processes;
- Introduce supermarkets and FIFO lanes to facilitate the pull;
- Conform processes to takt time by line balancing;
- Redesign the layout;
- Reduce process variations;
- Bring about digitalization.

After the designing future VSMs, lead-times and savings were analysed. Estimated results are:

- Lead-time improvement in spindles for normal repair of 84%;
- Lead-time improvement in spindles for warranty repair of 80%;
- Lead-time improvement in systems repair of 72%;
- Fulfilment rates increased to 100%;
- Savings in shop floor area requirement of, approximately, 29.8%;
- Annual savings in operating expenses of, approximately, €208,000.

In terms of lead-times and savings, results from future VSMs portray significant, quite encouraging improvements. To put them into action, based on the renowned PDCA cycle, an implementation strategy was developed.

To conclude, the application of lean methodologies in this case study was quite capable in achieving improvements. This is also in line with the impacts explained in the literature review. As such, the study of the lean methodologies in a German case study has positively contributed to this research spectrum.

In the future work, in order to model the proposed improvements and validate the results, a simulation methodology is to be employed. Testing different scenarios in a cost effective manner without blanching the randomness of involved processes is possible through simulation. Each individual activity in the processes should also be meticulously analysed. A more meticulous analysis can pave way for identification of more improvement opportunities and, as such, greater savings and lead-time reductions. In addition, further analyses of the shop floor layout redesign might bring about opportunities that can increase productivity further.

I hope that this work would turn out to be of good use for the service department and would be further developed for successful implementation of lean methodologies in Franz Kessler GmbH.

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Appendix A

Item	Qty.	Part description	Material
1	1	Spindle Shaft	Steel Ck45
2	1	Front Inner Spacer	Steel st52
3	1	Front Outer Spacer	Steel st52
4	1	Rear Bearing Seat	Steel 16MnCr5
5	1	Rear Bearing Housing	Steel st52
6	1	Front Preload Spacer	Steel st52
7	1	Rear Preload Spacer	Steel st52
8	1	Rear Bearing Flange	Steel st52
9	1	Encoder Plate	Steel st37
10	1	Encoder AMO WMK201.30.512	
11	1	Front Inner Labyrinth	Steel st52
12	1	Front Outer Labyrinth	Steel st52
13	1	Locknut M95x2	
14	1	Locknut M100x2	
15	2	M6 x 8 DIN 913	
16	1	Bearing NN3020-TB-KR-CC1	
17	1	Rear spacer	Steel st52
18	1	Cylinder Flange	Steel st52
19	1	Rear Preload Flange	Steel st52
20	1	Encoder Ring AMO WMR100.512	
21	1	Rotor 1FE1093-6WV11-1BC0	
22	1	Stator 1FE1093-6WV11-1BC0	
23	2	O-ring 01	Rubber NBR70
24	2	O-ring 02	Rubber NBR70
25	1	O-ring 03	Rubber NBR70

26	1	O-ring 04	Rubber NBR70
27	1	O-ring 05	Rubber NBR70
28	1	O-ring 06	Rubber NBR70
29	1	O-ring 07	Rubber NBR70
30	1	O-ring 08	Rubber NBR70
31	1	O-ring 09	Rubber NBR70
32	2	O-ring 10	Rubber NBR70
33	34	M5 x 16 DIN 912	
34	25	M6 x 16 DIN 912	
35	6	M8 x 8 DIN 913	
36	12	M10 x 25 DIN 912	
37	6	M6 x 55 DIN 912	
38	16	M5 x 30 DIN 912	
39	2	M4 x 8 DIN 912	
40	1	Protection Flange	Steel st37
41	2	Protection Plate	Steel st37
42	12	M4x10 DIN 7991	
43	1	O-ring 11	Rubber NBR70
44	2	Fitting Male Straight Thread 1/4"	
45	1	Conduit Fitting VG.M25-K	
46	1	Stator Housing	Steel st52
47	1	Front Bearing Housing	Steel st52
48	1	Front Protection Flange	Steel st37
49	8	M8 x 25 DIN 912	
50	4	Bearing 7020A5-TRS-DB-EL	Rubber NBR70

Table: A typical spindle BOM, Source: Kutlu (2016), P. 69-70.

Appendix B

QF 53 Error List

KESSLER

In event of a product malfunction, please complete the error list and attach it to the product or send it to service@kessler-group.biz . An incomplete error list may lead to delays in the repair process.

Customer data of end customer:

Company	
Street	
ZIP Code / City	
Country	
Phone	
E-Mail	
Technician	
Product removal date	
Machine name	
Machine serial number	

Product data:

KESSLER serial number (see type plate)	
Machine operating hours	
Product operating hours	
Number of clamping cycles	
Number of shifts	☐ 1/Shift ☐ 2/Shift ☐ 3/Shift ☐ 3+/Shift
Main operating rpm	
Operating mainly with internal cool. Lubricant?	☐ Yes ☐ No
Customer's range of parts	☐ Steel ☐ Cast Iron ☐ Plastics ☐ Aluminium ☐ Others: ____________
Tool balanced	☐ Yes ☐ No
Initial start-up of product	☐ At Facility (OEM) ☐ At Customer Date: ____________
Serial number change (replacement product)	Number: ____________ Date: ____________

Please check the applicable error descriptions:

Collision ☐ Yes ☐ No
Transport damage ☐ Yes ☐ No

Electrics und Connections
- ☐ motor breakdown
- ☐ power connection / cable carrier damaged

Tool clamping system
- ☐ problems with clamping / unclamping
- ☐ geometry of tool holder damaged
- ☐ hydraulic oil leakage
- ☐ cone cleaning air defective

Cooling lubricant supply
- ☐ internal cooling lubricant supply failure
- ☐ outer cooling lubricant supply failure
- ☐ minimum lubrication failure
- ☐ cooling lubrication leakage
- ☐ permanent leakage rotary union

Clamping
- ☐ clamping defective / function restricted
- ☐ clamping leakage

Cooling
- ☐ coolant leakage
- ☐ motor overheating

Bearing, gear and sealing
- ☐ sealing air / purging air defective
- ☐ bearing overheating °C:
- ☐ oil-air lubrication / grease re lubrication defective

Sensor and monitoring system
- ☐ speed and position encoder signal failure
- ☐ analogue data encoder defective
- ☐ proximity switch defective
- ☐ piston monitoring of release unit defective
- ☐ leakage monitoring failure
- ☐ temperature monitoring of motor defective
- ☐ bearing temperature monitoring defective
- ☐ vibration sensor failure
- ☐ adjusting nut monitoring failure
- ☐ linear expansion sensor failure
- ☐ eddy current sensor failure

Spindle body
- ☐ mechanical damage

Geometry
- ☐ radial runout failure
- ☐ surface quality issues
- ☐ dimensional deviation of work piece
- ☐ linear expansion during operation
- ☐ deviations in shape and position
- ☐ axial play
- ☐ offset
- ☐ positioning error

Operating performance
- ☐ vibrations
- ☐ running noise
- ☐ speed fluctuations
- ☐ shaft / axis blocked

Detailed failure description / provided components:

Figure: Error checklist, Source: Own Illustration.