Master Thesis

Determination of Profitability Influencing Factors within a Sealing Production Process

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Abstract

The initial problem for this work is based on the fact that a manufacturing company is facing a profitability problem within their existing production chain for sealing products. This problem was partly covered due to the fact that the manufacturing process for products of the second major product category (anti-vibration elements) can be operated in a profitable way. The existing production monitoring system is currently only able to assess direct losses caused by rejects. A quantitative or qualitative detection and evaluation of indirect losses does not take place. Therefore, a potential influence of these types of losses regarding the profitability problem can only be suspected.

Based on this lack of transparency, the necessity for a holistic production monitoring system is given, which is able to address both loss categories transparently and provide starting points for further improvements to reduce discovered deficiencies. After a preliminary analysis of the existing production process, a performance measurement toolkit - based on the "Overall Equipment Effectiveness" metric system - is developed and adapted to the existing conditions of the production process. An important condition for the new metric system implementation is to keep the effort of manual data entry during the introductory period for employees as low as possible, since a direct integration into the existing monitoring system is not possible within the scope of this thesis project.

The developed production data sheet contains all necessary data fields and forms the basis for further analysis. Using an automated evaluation system, the direct and indirect impact of the three production protagonists (machine, machine operators and products) among themselves can now be visualized for the first time, including under-performance, inadequate equipment availability and product rejects. With the usage of appropriated calculations, these losses can now be transformed in order to display their corresponding monetary loss. As might be expected, the costs caused by indirect types of losses are showing a significant proportion of the total sum.

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Introduction

1.1 Initial Situation

Fabrication processes are among the most important operations in a production company. In many cases, companies are reluctant to work on the improvement of the performance level and quality of current workflows as long as they still fulfill their purposes. But even if a company is making profit, this does not mean that their performance is at its best level and will be sufficient in the long run. After all, the factors influencing the company's profit can change quickly: Competitors can gain an advantage concerning product quality and price or employees may leave the company, which has a tremendous influence on process stability and efficiency. This means that companies have to react quickly in face of these changes if they wish to preserve their competitiveness.[1]

The competitiveness of companies depends on their ability to deliver value-added goods or services that satisfy the demands or requirements of the customer in a profitable way. Therefore, cost-increasing deficiencies within the production workflow should be avoided at any time. As business or manufacturing processes are harder to imitate by competitors than a certain product, the superior goal of a company should lie in well-functioning processes across the whole value-chain in order to hold their competitive position.[2]

Traditional approaches of companies to hold or regain their position in the global industry with the help of cost cutting projects like outsourcing, manpower reduction or cutbacks on investment projects often only lead to positive results in a short-run. These efforts mostly worsen the whole situation in the long-term by creating huge disturbances in the remaining processes and therefore the aim of creating value-added goods or services for the customers will be aggravated artificially.[3]

A company who wants to improve their cost situation should focus on the reduction of all non-value-added activities that occur within a process. These value-destroying and cost-driving activities (e.g. failure costs), which are likely to take 20 to 30% of the production resources (time, material, energy), are also categorized under the term *hidden factory*.[4] The significance of the hidden costs is shown by the fact that a failure rate of produced items about 2%, can account up to 25% of the failure costs on the basis of the company's turnover.[5]

The necessity for a steady identification and reduction of hidden costs is also due to the economic development of the country in which the company is situated. This thesis will examine a company in Turkey, a country which has seen a strong economic progress in the years 2002-2012 with an average growth of the Gross Domestic Product (GDP) of about 5% per year. The Organisation for Economic Co-operation and Development (OECD) is expecting the same growth rate in the following five years, making Turkey the strongest developing country

[1] cf. Niermann and Schmutte (2014), p. 213.
[2] cf. ibid., p. 214.
[3] cf. ibid., p. 215.
[4] cf. Schmelzer and Sesselmann (2010), p. 139.
[5] cf. ibid., p. 260.

of the OECD-countries.[6]

The inflation rate in Turkey has remained steadily high in the last nine years with about 8% per year, resulting in a constant rise of the average wages, which increased about 14% between 2010 and 2012 alone (4,3€ per hour in 2012).[7] The still significantly low wages were seen as the main competitive advantage against other low-cost European countries like Hungary or Poland. However, companies with a high degree of manual work in their production have to compensate the rising cost situation in order to hold their position against new emerging countries (Romania, Bulgaria).[8]

Despite the expectations of the OECD and other economic research groups, an initially local protest for the preservation of a municipal park has developed into a wide-ranging political crisis and revealed how fast the economic framework can change within a country. Doubtable reactions of the government to disband the demonstrations and other upcoming political disclosures have caused much concern among investors regarding the country's political and economic stability.[9]

A huge withdrawal of planned investments of foreign companies and investors has led to a massive fall of the Turkish currency (24,4% against the Euro between March and December 2013), making it even quite more difficult for domestic companies to grow.[10] One positive side effect of a weaker currency is that it can lead to increased orders because it also means a higher buying power for European companies, but it is feared that the negative effects of this new situation outweigh the few positive ones and lead the economic situation of Turkish companies into an uncertain future. It is also conceivable that new sourcing strategies of customers, especially those of the automotive Original Equipment Manufacturers (OEM), place the emphasis not only on price competitiveness, but also on surrounding economic and political factors, which can directly affect the delivery reliability of the company. Additional risks are for instance higher prices for raw materials, which can only be sourced in European countries and therefore reduce the profit margin.[11]

In these fast-changing times, companies have to concentrate on steady improvements of their existing processes and practices, not only to increase their revenues and profits, but also to prevent a decrease of their competitiveness.[12]

[6] cf. The Republic of Turkey, Prime Ministry (2014), http://www.invest.gov.tr/ (visited on 13.01.2014).
[7] cf. statista (2014), http://de.statista.com/ (visited on 13.01.2014); cf. Germany Trade and Invest (2013), p. 3.
[8] cf. Schröder (2012), p. 6.
[9] cf. Der Tagesspiegel (2013), http://www.tagesspiegel.de/ (visited on 29.12.2013).
[10] cf. Finanzen.at (2014), http://www.finanzen.at/ (visited on 13.01.2014).
[11] cf. PrasannaVenkatesan and Kumanan (2012), p. 325.
[12] cf. Gotro (2012), pp. 1-2.

1.2 Company Profiles

For an introduction to the background of the company, the following chapters give a brief presentation about Laspar Angst+Pfister, where this thesis was conducted. In addition, the problem case that lead to this thesis project is described along with its delimitations.

Angst+Pfister Group

Since its founding in 1920, the Angst+Pfister Group (APAG), headquartered in Zurich (Switzerland), has grown from a local dealer of industrial parts and materials to a worldwide supplier in a variety of different industries like automotive, railway and wind power. The completely private-owned company has subsidiaries in Switzerland, Germany, Austria, Italy, France, Belgium, the Netherlands, Czech Republic, China, and Turkey.[13]

Currently, 1400 employees worldwide are handling 45.000 customer relations in 50 countries. The average annual turnover of middle-size customers ranges from 10.000 to 100.000€, whereas key account customers are likely to generate revenues of about 10 M€ per year.[14]

In addition to a reliable provisioning of industrial standard parts to customers, the unique characteristic of the company is also defined by an engineering-led development of special product solutions based on the customers' demands in the field of the company's core product segments:[15]

- **APSOplast:** Semi-finished products and blanks out of thermoplastics and thermosets
- **APSOseal:** Sheet material and gaskets, O-rings with special certifications, profile seals, elements for hydraulic and pneumatic applications
- **APSOfluid:** High-performance hoses lines (rubber, plastic, metal), fittings
- **APSOdrive:** AC/DC linear drives, conveyor belts, chain drives
- **APSOvib:** Machine-bearing and insulating elements, sound absorbing materials, Rubber metal parts

At the end of 2012 the complete Laspar Group was acquired by Angst+Pfister and is now integrated into the main company group as a subsidiary. The strategy behind this acquisition is driven by the aim to build up a unique characteristic, distinguishing the company from other market competitors. Long-term goals are more independence from various suppliers, greater expertise in production technology and know-how, but also the ability to benefit from the cost advantage of in-house production.[16]

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[13] cf. Angst+Pfister Group (2013b), http://www.angst-pfister.com/ (visited on 16.12.2013).
[14] cf. Christof Domeisen, CEO Angst+Pfister Group (2013).
[15] cf. Angst+Pfister Group (2013a), http://www.angst-pfister.com/ (visited on 16.12.2013).
[16] cf. Christof Domeisen, CEO Angst+Pfister Group (2013).

Laspar Angst+Pfister Advanced Industrial Solutions A.S.

The origin of this subsidiary lies in the foundation of Laspar in 1982 in one of the industrial areas around Bursa/Turkey. Initially a manufacturer of rubber sealing parts for the domestic market, the company over the years raised their production volume with products like O-rings and gaskets. The product line of anti-vibration parts (rubber-metal compounds) started in 1994 and has become the main sales driver up to now. Customer focus for this segment lies mainly in the automotive industry (OEMs, Tier 1 suppliers), but a great number of produced items are also used in the agriculture, marine and heavy-duty industry. The company also has an own brand of standardized anti-vibration parts.[17]

Sealing products, however, will only be manufactured according to the design and specifications given by the customers, who are mainly Tier 1 suppliers of the worldwide automotive industry as well as domestic manufacturers of white good products and several other industrial products (heavy duty and military). The sealing segment generated 15% of the company's revenues (approx. 29 M€) in 2012; the forecast for 2013 shows no change at this ratio.[18]

The total workforce of 490 employees is divided into 350 people working in the anti-vibration segment and 140 people in the sealing segment. Both product lines are situated in the same shop floor. Together with an affiliated metal processing company, the sealing and anti-vibration segment formed the former Laspar Group. The metal shop affiliate is one of the main supplier of metal parts needed for the anti-vibration segment production and manufacturer of the molds used in both segments.[19]

1.3 Problem Statement

The current company's strategy was set to grow in terms of revenue and profit. This strategy is not limited to the sealing production line, but it is also the aim of the management to rise the segment's share on the total revenues in order to diversify risks of the anti-vibration segment like seasonal effects, decline in orders, price cuts by customers and rising raw material prices.[20]

In alignment with this strategy, investments on new machinery (three new injection molding machines) in the sealing segment were approved by the management of the APAG. It should be mentioned that such high investment are not likely to be granted again in the next few years, as the focus lies on an organic growth of manufacturing capabilities.[21]

It was also stated that economical Key Performance Indicators (KPI) of the sealing segment do not comply with the expectations, neither on part of the local management nor on part of the management of APAG. The increase of the company's 'KPI profitability' is the main target, as it

[17] cf. Laspar Angst+Pfister Advanced Industrial A.S. (2013), http://www.laspargroup.com/ (visited on 16.12.2013).
[18] cf. Eray Ulugül, CEO Laspar Angst+Pfister (2013a).
[19] cf. ibid.
[20] cf. Eray Ulugül, CEO Laspar Angst+Pfister (2013b).
[21] cf. Eray Ulugül, CEO Laspar Angst+Pfister (2013a).

constitutes the foundation for future growth. Actually, the sealing segment is not generating any profit in 2013.[22]

The company's order book guarantees a stable demand for 2014. The sales department even has to decline the majority of new and additional orders from customers, as there is no additional machine and labor capacity available to produce these items. Currently, the usable machine utilization time has reached its maximum of nearly 100%, also the labor force cannot be extended, as there already exists a 3-shift working system (24/7) and fresh engagements should be avoided.[23] The decline of new orders however represents a huge risk because the current acquisition rate of new contracts (from customer request to incoming order) is only 6% of the total requests.[24]

An additional plan to increase the delivery reliability for key account customers is to establish an inventory replenishment pull system for products with high annual demands. Automotive customers like Bosch, TürkTraktor or Magneti Marelli send their monthly demand data three months in advance, but at the moment this information is only entered into the ERP-System for the standard production planning. The company cannot benefit from this information advantage in order to produce high-demand items in advance, as there is no usable machine capacity free for buffered production.[25]

1.4 Goals and Objectives

Based on the issues mentioned in the previous chapter, the management of LPAP defined the "Determination of profitability influencing factors within the sealing production process" as the objective for this thesis project.[26]

Within the context of the defined goal, following preliminary analyses are commissioned:[27]

- Analysis of the current state of the sealing product family
- Analysis of production flow and process steps
- Analysis of current value stream

Possible methods to optimize the existing processes should be implemented in a way that the effects of the improvements are long lasting and not only visible during this project time. Not less important is the intense involvement of the employees for the application and execution of the new methods.[28]

[22] cf. Eray Ulugül, CEO Laspar Angst+Pfister (2013a).
[23] cf. ibid.
[24] cf. Sales Department, Laspar Angst+Pfister (2013).
[25] cf. Eray Ulugül, CEO Laspar Angst+Pfister (2013a).
[26] cf. Eray Ulugül, CEO Laspar Angst+Pfister (2013b).
[27] cf. ibid.
[28] cf. Eray Ulugül, CEO Laspar Angst+Pfister (2013a).

1.5 Delimitations

The definition of profitability used within this thesis is deviated from the EBIT-profitability (Earnings before Interest and Taxes profitability), which is characterized by the KPIs EBIT and Revenue (see equation 1.1)

$$\text{EBIT-profitability} = \frac{\text{EBIT}}{\text{Revenues}}$$

Equation 1.1: Calculation of the EBIT-profitability[29]

As mentioned in the previous chapter, the increase of sold items generated by a higher rate of production is not possible, as the machining and labor capacity have already reached their maximum. It is thus obvious that a gain of the EBIT-profitability rate with constant remaining revenues is only possible by increasing the EBIT value itself.

The EBIT of a manufacturing company can be calculated as described in table 1.1.

	Revenue
	Sales Revenue
−	**Operating Expenses**
	Costs of goods sold/manufactured
	Selling, general and administrative expenses
	Depreciation and amortization
	Other expenses
=	**Operating income**
+	Non-operating income
=	**Earnings before Interest and Taxes (EBIT)**

Table 1.1: Calculation of EBIT[30]

The optimization of all factors within the EBIT calculation would exceed the scope of this thesis, therefore the management narrowed the focus of this study to 'Cost of goods sold/manufactured', which is directly related to the current production process. The increase of revenues through price negotiations with customers or putting the focus on products with a better profit situation is part of the business strategy that is currently under development by the management of LPAP.

[29] cf. Berkstein (2011), p. 160
[30] cf. Bodie, Kane, and Marcus (2004), p. 452

2

Design of Production Processes

Different methodologies and theoretical concepts can be used to optimize an existing production process. Two of these concepts will be introduced as they are the fundament for the practical optimization phase of the existing sealing production process (see chapter 5). These concepts have proven their benefits within the manufacturing industry over many years and are still part of research studies at several academic institutions worldwide. The aim of this chapter is to present the background and basic ideas for each topic, as well as to briefly describe different methods and tools.

2.1 Lean Production

The basic concept of Lean Production (also known as Lean Manufacturing) was first introduced in 1988 by John Krafcik in his article "Triumph of the lean production system", which he wrote while working within the International Motor Vehicle Program (IMVP) study at the Massachusetts Institute of Technology (MIT). The IMVP aimed at a comprehensive assessment and evaluation of various automotive production systems worldwide.[31] The findings of this research were published 1991 in the book "The Machine That Changed the World" by WOMACK, JONES and ROOS, resulting in a huge impact to the global manufacturing industry.[32] In this book, the authors did not provide an explicit definition of lean production systems, but provided a general description of such a system based on its outcomes:

> *"Lean Production is lean because it uses less of everything compared with mass production - half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever-growing variety of products."*[33]

According to PLENERT (2007), Lean Production today is a collection of tools and methodologies to reach a company's goal and objective.[34] He also provided a possible definition for this thematic complex:

> *"Lean is a systematic approach that focuses the entire enterprise on continuously improving quality, cost, delivery, and safety by seeking to eliminate waste, create flow, and increase the velocity of the system's ability to meet customer demand."*[35]

[31] cf. Krafick (1998), p. 44.
[32] Taylor and Brunt (2001), p. 7.
[33] Shah and Ward (2007), p. 786.
[34] Plenert (2007), p. 146.
[35] Ibid.

2.1.1 Historical Background of Lean Production

The roots of the Lean Production concept lie in the economic and industrial situation of Japan directly after the Second World War. Most of the manufacturing plants were destroyed or could not start their normal production due to limited resources in terms of machining, labor and material capacities. To ensure the future of production for their country, Japanese production managers started to analyze in detail the American production system, which owed its costs advantage and efficiency to mass production with a low amount of different items (Economies of scale). The limitations of the Japanese market forced the managers to adapt the American system to a highly flexible production system with a lower resources demand that is still capable of high production rates.[36]

The leading role of this adaptation was taken by the Toyota Motor Company (TMC) and their production manager Taiichi Ohno. He was among those who developed the Toyota Production System (TPS) to conserve capital, eliminate waste, reduce inventory, reduce production times and operating expenses while increasing quality and production flexibility at the same time. This system is not limited to specific areas of production and affects every single part of the entire production process within the company.[37] What was different from other companies at this time was that the implementation of the organizational culture focused on the systematic identification and elimination of all waste from the production process.[38]

Many Japanese companies (mainly in the automotive sector; suppliers for the TMC) adapted the TPS for their own production but it was nearly unknown to Western automotive manufacturers until the early 1980s. They soon realized that the Japanese methods were superior to the ones used by European or American manufacturers by Toyota's example of producing a car with higher productivity, better quality while using less resources.[39] The research team led by Womack, Jones and Roos started the IMVP study project at the end of 1980 to identify the reasons for this gap between Japanese and Western methodologies.[40]

Lean Production thus does not denote a historically developed company-specific production system, but is based on best-practice approaches of Japanese companies to achieve a comprehensive production system, which were used for concept development in the IMVP benchmarking study. These systems (see figure 2.1) do not only include the methods of Lean Production but also elements of Taylorism, such as the division of labor and innovative forms of work such as group work and self-organization.[41]

[36] cf. Womack, Jones, and Roos (1991), p. 48.
[37] cf. Tinoco (2004), pp. 7-8.
[38] cf. United States Environmental Protection Agency (2003), p. 8.
[39] cf. Taylor and Brunt (2001), p. 3.
[40] cf. Womack, Jones, and Roos (1991), p. 13.
[41] cf. Gerberich (2010), p. 30.

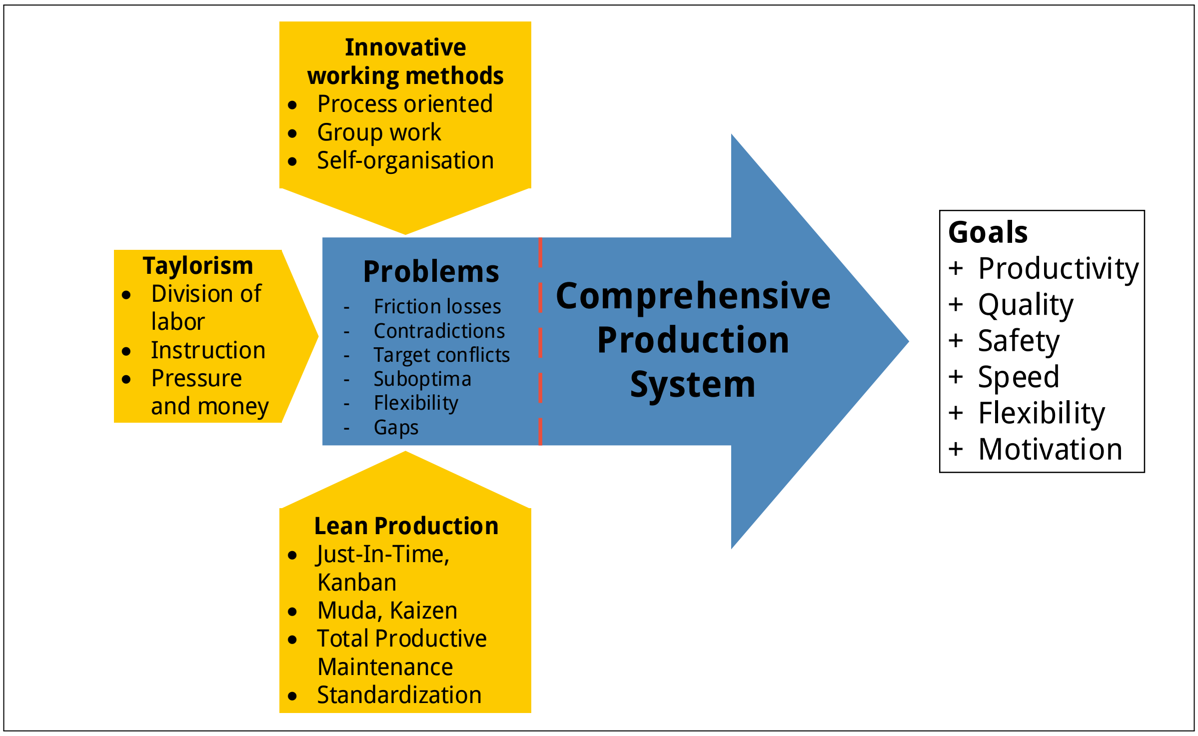

Figure 2.1: Influencing factors of a comprehensive production system [42]

[42] adapted from: Gerberich (2010), p. 31

In the IMVP study, the TPS served as the best-practice model for a comprehensive production system.[43] Figure 2.2 displays the composition of the TPS.

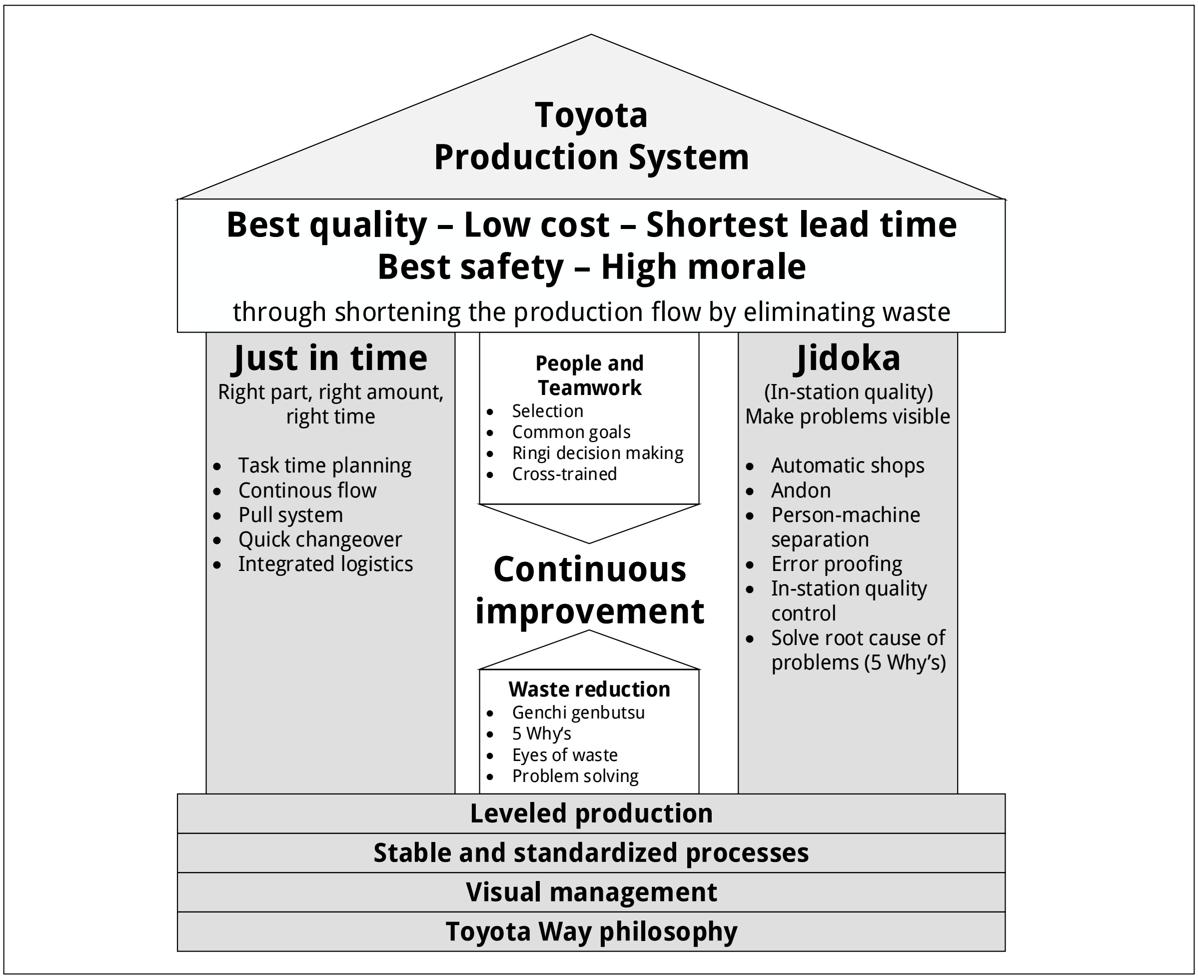

Figure 2.2: Toyota Production System[44]

The fundament of the production system should ensure the absolute reliability of production processes and workflows and is mainly alleviated by the standardization of all work processes. The left pillar includes logistical methods that should lead to the elimination of waste in the processes. This mainly includes the implementation of a uniform, balanced and timely production without overproduction (Just in time). The middle and right pillar (technological methods) covers methods that will lead to the avoidance of waste in production processes. This is essentially achieved by continuous improvement actions with employees directly at the production resources (Kaizen) and by an intelligent automation (Jidoka). More production process-related methods are the shop-floor design according to criteria of order and cleanliness, the consistent preventive maintenance, the multi-skilling of employees for flexible use and error prevention by foolproof design of devices and controls (Poka Yoke). Finally, the roof of the TPS forms the well-known triad of the main objectives of production: Top-quality, short

[43] cf. Zhang (2010), p. 83.
[44] adapted from: Liker (2007), p. 65

lead times and minimum costs. The visualization of the control processes in the production and the production results generated from metrics graphs provide transparency of target achievement.[45]

One example of the superiority of Japanese production philosophies in the 1980s was set by Mitsubishi with their takeover of a Chrysler manufacturing plant in Australia. By applying a Lean Production concept, they achieved a productivity increase of 115 percent and a reduction of the lead time per car from 59 to 24 hours within only five years.[46]

The Lean Production concept is no longer limited to the automotive industry: University institutes all over the world have conducted research on the theoretical foundations of Lean and its practical applicability to existing company processes.[47] Today, Lean principles are applied in the fields of logistics, distribution, services, retail, healthcare, construction, maintenance and even government.[48]

The basic requirement for all Lean methods is the implementation of Lean Management as the concept is not limited to the production area, but also includes all functions, structures and processes within a company.[49] For a steady and consequent application of the methods and principles the management has to effect a change in company culture, which includes employees at all levels.[50] Although many manufacturing companies have implemented different Lean elements, most of them did not accomplish a comprehensive cultural change, as there is still the widespread belief that an improved production planning system alone can solve the problems.[51] In fact, the consistent focus on recognizing and solving the roots of problems with the help of employees on-site is the core of Lean Production. Toyota, for example, sees problems as an opportunity to improve and profits from this approach every day. In contrast, companies with different business cultures often tend to hide from little problems until they grow to large, complex problems.[52]

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[45] cf. Erlach (2010), pp. 302-303.
[46] cf. Lederer (1984), p. 328; cf. Pfeiffer and Weiss (1994), p. 19
[47] cf. Taylor and Brunt (2001), p. 7.
[48] cf. Lean Enterprise Institue (2013a), http://www.lean.org/ (visited on 18.12.2013).
[49] cf. Pfeiffer and Weiss (1994), p. V.
[50] cf. Liker (2003), p. 10.
[51] cf. Rother (2007), p. 5.
[52] cf. Gerberich (2010), p. 99.

Critics of the Lean Production philosophy mentioned the disadvantage of the lack of objective performance limits for employees which, they argue, could lead to undetected overloads on their working power. This particularly stems from the fact that employees, in the course of the continuous improvement process, tend to over-rationalize themselves and their work activities:

> *"Because of Just in Time, zero-buffer and zero fault principle each production disorder causes for the individual worker not only extra work and extra burden, but often stress. Furthermore, there is the risk that less powerful employees are excluded by the permanent pressure to perform."*[53]

Another disadvantage of Lean Production is seen in the strong focus on continuous improvement processes to improve the value, which can prevent innovative leaps in production or workflow processes. Furthermore, while the self-steering control loops in the subunits (see chapter 2.1.2) are useful to organize the company flexible, the working principle of these loops has certain limits. By exceeding these limits, the whole loop circles can become unstable, which means that the Lean production philosophy is not protected against uncertainties of the company's surrounding market.[54]

2.1.2 Comparison of Lean to Mass Production

In the spring of 1950, Taiichi Ohmo and several other Toyota employees visited the then largest and most efficient mass production plant in the world: the Ford River Rouge complex in Dearborn, Michigan. In comparison to Toyota's lead time per car of about 1,8 days (2685 produced cars in the time between 1937-1950), the Ford manufacturing process allowed to produce 7.000 cars per day at this time.[55]

The Ford manufacturing process (as an ideogram for mass production) mainly consists of the following three elements:[56]

1. **Production line:** Sequential arrangement of production process activities within a factory.
2. **Division of labor:** Specialization of employees to perform specific working tasks and activities.
3. **Integrated supply chain for parts and materials:** Time efficient and resource saving provisioning of needed production materials.

This manufacturing process was ideal for a low-variant product palette and high production rates. Changing customer demands over the years towards more-complex cars resulted in

[53] Spath (2003), p. 42.
[54] cf. ibid., p. 41.
[55] cf. Womack, Jones, Roos, et al. (1992), p. 53.
[56] cf. Liker (2007), p. 48.

more complex organizational structures. A waste of resources and non-transparent production processes were the result, and had an adverse impact on the relationship between management and blue/white-collar workers, which came to be marked by mistrust, and on goal orientation. The pursuit of employees to improve the situation was obstructed by the complexity of the total system and a high degree of bureaucracy.[57]

After their analysis and evaluation, Ohno and the TMC criticized the Ford manufacturing process concerning the following points:[58]

- Separation of manual and mental labor
- Limitation of the employees' knowledge and capabilities by having them exclusively focus on particular activities
- Strictly defined workflows
- Single focus on performance achievements
- Demotion of the employees as an interchangeable factor ('Hire/Fire'-mentality)

Although Toyota adapted three main ideas from Ford, they made some important additions that were responsible for the future success of the TPS:

- **Organization:** The Ford production system can be described as a function-oriented planning and management of the company. The planning and management positions are responsible for the entire product range, but only for a particular process section.[59] The TPS has a process-oriented planning and management philosophy. The company is divided into result-oriented subunits, where employees of each subunit are responsible for the entire production process of a specific product range.[60]
- **Separation of work preparation and execution:** Ford's administration was managed by bureaucratic apparatuses of control and based on a steep hierarchy between administration and production. This bureaucratic complexity entailed long lines of communication.[61] At Toyota, however, work is administered by delegation of responsibility. The productive employees are asked to validate proposed plans to identify and eliminate non-value-added activities.[62]

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[57] cf. Oeltjenbruns (2000), p. 8.
[58] cf. Simon (1996), p. 8.
[59] cf. Frenz (1920), p. 20.
[60] cf. Gruß (2010), p. 32.
[61] cf. Frenz (1925), p. 20; cf. Frese (1987), p. 58
[62] cf. Krafick (1998), p. 43; cf. Shingo (1993), p. 45

- **Extensive division of labor and standardization:** In Fordism, the schematization and mechanization of labor enabled a concentration on individual, uniquely defined steps within a working process. A strong concentration of repeatable working steps allows for shorting the training periods for new employees. This, however, means that there is no optimization of the processes by productive know-how.[63] Toyota, in contrast, follows the principle of a clear description of standardized, optimizable processes while shortening the learning phase. The rotation of staff within and between workstations is understood as a continuous training to improve the flexibility of production.[64]
- **Systematic personnel selection:** By identifying the most appropriate work force, the theoretically calculated optimum of working steps in the Ford Motor Company could be ensured. As part of the TPS, the working steps were designed taking into account of ergonomic aspects, so that each worker could carry them out.[65]
- **Workplace design:** In the Ford production system a labor-scientific design of the workplace was created to ensure optimal working conditions in terms of temperature, light, color and layout. At Toyota, however, the workplace is designed to allow for a high degree of autonomy by the work teams.[66]

Table 2.1 summarizes the most decisive differences between Lean Production and Mass Production.

	Lean Production	**Mass Production**
Focus	Customer	Product
Operations	Synchronized flow and pull	Batch and queue
Overall Aim	Eliminate waste and add value	Reduce cost and increase efficiency
Quality	Prevention (built in by design and methods)	Inspection (a second stage, after production)
Business Strategy	Flexibility and adaptability	Economies of scale and automation
Improvement	Workforce-driven continuous improvement	Expert-driven periodic improvement

Table 2.1: Comparison between Lean Production and Mass Production[67]

[63] cf. Frenz (1925), p. 20.
[64] cf. Gruß (2010), p. 33.
[65] cf. ibid.
[66] cf. Oeltjenbruns (2000), p. 249.
[67] adapted from: Murman, Allen, and Bozdogan (2002), p. 97

2.1.3 Lean Principles

The following five key principles are considered the foundations of the Lean concept:[68]

1. **Identify the value from the customer's point of view:** The value of a product is defined by the customers and what they are willing to pay for. The manufacturing process has to be designed to produce an outcome that matches the customer's expectations.
2. **Identify the value stream:** The value stream includes all activities that are needed to produce a product.
3. **Flow:** An optimal production process is based on a continuous flow where no delays occur between the several process steps, especially between value and non-value added activities.
4. **Pull:** A process is only carried out if there is a demand for it. The trigger for starting the process can be internal and external customers.
5. **Perfection:** Desired state of production, which can only be achieved through the combined usage of the other four principles and subsequent continuous improvement activities.

Not widespread in literature is the existence of a sixth principle called *Respect for people*. The basic idea behind this principle is that a company should recognize that its workers are the most important resource. A working atmosphere needs to be established in which employees can brainstorm openly without fear, plan together in consensus, identify problems honestly and solve problems effectively and permanently.[69]

The application of these five (or six) principles can also be viewed as a general guideline for the implementation of the Lean methodology in a company.[70]

2.1.4 Value

The identifying of value is the most important step in implementing the five key principles of Lean Production. As mentioned, the value can only be defined by the final customer, mostly in terms of a specific product or service which meets with the customer's needs and expectations at a specific price, time and quality (see figure 2.3).[71]

[68] cf. Oppenheim, Murman, and Secor (2011), pp. 17-24.
[69] cf. ibid., p. 6.
[70] cf. Lean Enterprise Institue (2013b), http://www.lean.org/ (visited on 18.12.2013).
[71] cf. Womack and Jones (2003), pp. 40-48.

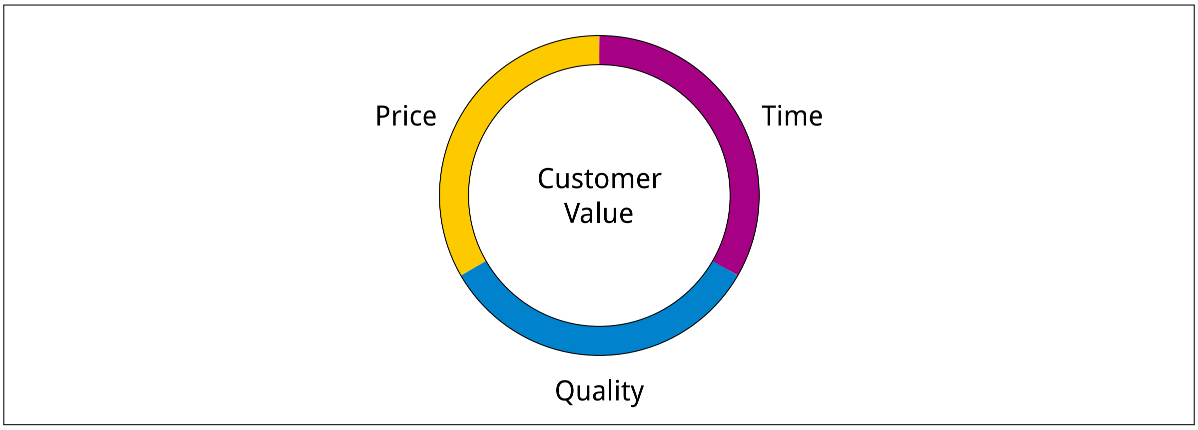


Figure 2.3: Structure of value for the customer[72]

Manufacturing processes and their sub processes can be divided into three categories to classify actions, whether they generate the demanded value or not:

- **Value-Added activities (VA):** Activities that increase the value from the customer's point of view for a product or service. They alone cause ultimately that customer requirements are achieved fully and economically.[73]
- **Non-Value-Added activities (NVA):** Any activity that causes costs but creates no value. This kind of activity is pure waste and needs to be eliminated as fast as possible with minimal or no capital investments and no influence on the end value in a short run. Categorized as Type Two muda[74].[75]
- **Necessary, but Non-Value-Added activities (NNVA):** These activities create no value, but they are still necessary at the moment because of the current limitations of technology, capital assets and operating procedures of the system under examination. The aim is to reduce the share of these activities in the total production process in the long run, but this reduction is likely to require capital investment and/or reengineering activity. Categorized as Type One muda.[76]

In reality, the ratio of value-added activities is likely to be responsible for a small fraction of the total production lead time. As it is harder (or even impossible, as the interpretational sovereignty belongs to the customer) to add value to a product or production process, the focus for companies should lay more on decreasing the ratio of Non-Value-Added activities, since they are easier to identify and fix.[77]

[72] adapted from: Slack (1998), p. 14
[73] cf. Lanau (2012), p. 191.
[74] Muda: Japanese word meaning "futility; uselessness; idleness; waste; wastage; wastefulness"
[75] cf. Womack and Jones (1996), p. 20.
[76] cf. ibid., p. 20.
[77] cf. Flinchbaugh, Carlino, and Pawley (2006), p. 15.

2.1.5 Seven Wastes

One of the most important targets of Lean manufacturing is the elimination of waste. During the development of the TPS at Toyota, Ohno identified seven loss categories in terms of money and resources (time and material) which occur in manufacturing processes and which are now known as "The seven wastes". Not only that these losses consume the most important resources, they also create no value for the product.[78]

The seven wastes can be differentiated as follows:[79]

- **Wait time:** This waste occurs whenever goods are not moving or being worked on and affects both goods and workers. The ideal state is a continuous and faster flow of goods. If waiting times for workers are unavoidable, time can be used for training or maintenance activities, they should not lead to overproduction.
- **Transport:** To put it bluntly, any movement of goods in the factory can be viewed as wastage as no additional value is created. This means that although a total removal is not feasible in reality, transportation activities should be minimized. In addition, long distances between two process operators or blue and white-collar employees are more likely to cause communication problems and double handings.
- **Unnecessary inventory:** Increases lead-time and prevents a fast identification of problems. Unnecessary inventories also cause higher costs for storage; hence, lower the competitiveness of the organization or value stream.
- **Defects:** Direct costs because of defective parts or machinery equipment. The TPS philosophy regards defects as an opportunity to improve the future quality of the process.
- **Overproduction:** Overproduction is regarded as the most serious waste as it inhibits a well-coordinated flow of goods or services and is likely to avert quality and productivity. In addition it causes excessive lead and storage times. Possible results are late detected defects, artificial pressure on workers and unnecessary work-in-progress stocks.
- **Inappropriate processing:** Occurs in situations where overly complex solutions are used for simple procedures, such as using a large inflexible machine instead of several small flexible ones. Over-complexity generally discourages ownership and tends to cause overproduction in order to recover the large investment in the complex machines. Such an approach encourages poor layout, leading to excessive transport and poor communication. The ideal, therefore, is to have the smallest possible machine, capable of producing the required quality, located next to preceding and subsequent operations. Inappropriate processing also occurs when machines are used without sufficient safeguards, such as poke-yoke or jidoka devices, which results in poor-quality goods.

[78] cf. Ohno (1988), p. 59.
[79] cf. Hines and Rich (1997), p. 47.

- **Unnecessary motion:** Tiring movements like stretch, bend and pick up can lead to poor productivity and often to quality problems. Motion-related issues which can cause chronic health problems have to be reduced or the workplace has to be changed in an ergonomic way.

Research and survey studies have shown different occurrence ratios of these waste reasons in production processes (see figure 2.4). Survey participants indicated waiting and overprocessing to be the main reasons for wastage inside a production process. It has to be mentioned that the high count of waiting is due to its catchall function for activities that do not fit in other categories. Likewise, any process that is identified as a non-value-added step could fit to this category. The survey also described overprocessing wastage as extra work that is required due to poor tool or product design.[80]

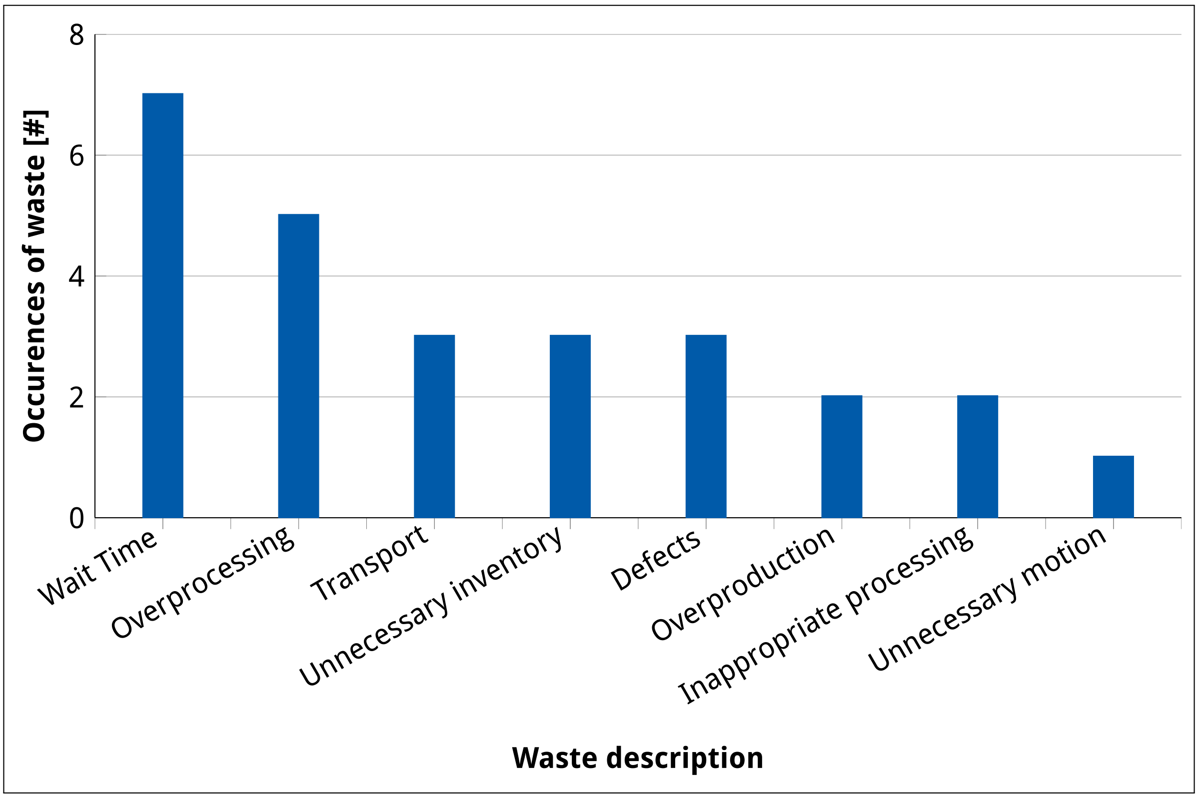


Figure 2.4: Most frequently observed waste in 26 research studies[81]

As mentioned before, the aim of a production process is to generate the desired value for the customer. The existence of waste within this process either prohibits the complete fulfillment of this superior goal or it generates higher costs than really needed. As can be seen in table 2.2, the waste categories have a different impact on the final value. All wastage categories are related to the value attribute *Cost* whereas the attribute *Quality* can only be decreased through actions concerning the defect rate of the produced items. Defect wastage is also the only

[80] cf. Slack (1998), p. 33.
[81] adapted from: Slack (1998), p. 34.

category, which affects all customer-related value attributes.[82]

	Quality	Cost	Time
Wait time		X	X
Overprocessing		X	X
Transport		X	X
Unnecessary inventory		X	
Defects	X	X	X
Overproduction		X	
Inappropriate processing		X	X
Unnecessary motion		X	X

Table 2.2: Linkage between waste and value attributes[83]

2.1.6 Continuous Improvement Process

Masaaki Imai introduced the principles of continuous improvement actions under the Japanese word *Kaizen*[84]. He added that at least one process should be improved in the company at each day.[85]

To implement this, Kaizen offers the necessary philosophy and various other instruments, which are summarized in the literature under the term "Kaizen umbrella".[86] By applying this concept, all employees from the manager to the shop floor worker should be integrated into this process for continuous improvement.[87] It is assumed that there are problems in any company and any department, which can be solved or enhanced by means of improvements in small steps and thus lead to higher customer satisfaction and an increase in product value.[88] The main attribute of Kaizen is the concentration on the process, which is as much important as the result itself, as the final result can only be improved when the corresponding processes are improved. According to this philosophy, employees should not be merely assessed on the basis of pure outcome criteria such as sales figures, but by the effort undertaken to achieve these goals.[89]

[82] cf. Slack (1998), p. 35.
[83] adapted from: Slack (1998), p. 35.
[84] Kaizen: Japanese for "improvement" or "change for the best"
[85] cf. Imai (1993), p. 24.
[86] cf. Bicheno and Holweg (2009), p. 192.
[87] cf. Imai (1993), p. 26.
[88] cf. ibid., p. 18.
[89] cf. ibid., p. 65.

The process of the Kaizen improvement is based on the "Plan, Do, Check, Act-Cycle", first introduced by William Edward Deming (see figure 2.5).[90]

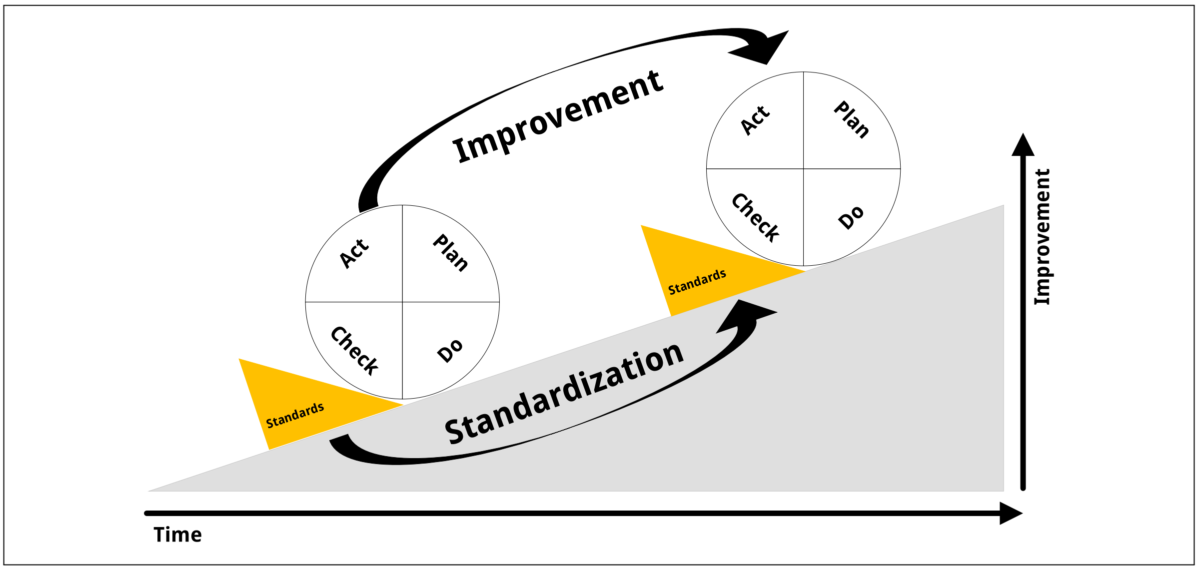


Figure 2.5: PDCA-cycle[91]

Prerequisite for continuous improvement processes (CIP) is the introduction of standards that have to be strictly followed by all employees.[92] To raise the level of an existing standard the CIP needs to be divided into four phases:

1. **Plan:** In this phase an action plan has to be developed in order to achieve the predefined goal.[93] The aim is to create an overview of targets, needed measures, responsible employees, required resources and a corresponding timeline.[94]
2. **Do:** Implementation of the plan.[95]
3. **Check:** Acquisition of new process data and comparison with data, which is collected prior to the modification. Evaluation of whether the modifications have improved the previous process or not.[96]
4. **Act:** As a final step, corrective and improvement measures are defined and carried out to reinforce the improvement already achieved.[97]

In addition, the newly defined process needs to be integrated into the existing production guidelines and is thus regarded as the new standard. Before a process can be further improved, the SDCA (Standardization-Do-Check-Action) cycle for stabilizing the new standards should be carried out in order to ensure that the improvement is permanent. These new standards form

[90] cf. Thomsen (2006), p. 95.
[91] adapted from: Dickmann (2007), p. 64
[92] cf. Imai (1993), p. 102.
[93] cf. ibid.
[94] cf. Liker (2007), p. 466.
[95] cf. Brüggemann and Bremer (2012), p. 16.
[96] cf. Liker (2007), p. 469.
[97] cf. Thomsen (2006), p. 96.

the basis for further improvements, meaning that the PDCA-cycle is repeated continuously.[98]

Continuous improvement processes increase the standard level in smaller steps, whereas improvements usually mean a big difference between the existing and new process. Such a leap in improvement is mainly due to new technological achievements and theories, which are usually associated with high costs. In addition, the time advantage against competitors can be relatively small.[99]

The left side of figure 2.6 shows how the useable effect of an innovation decreases over the time as "each system is left to decay from the time of its establishment".[100] Through the combination of continuous improvement processes and innovations the standard can not only be maintained over time but also increased by establishing Kaizen-related actions between two innovation phases.[101]

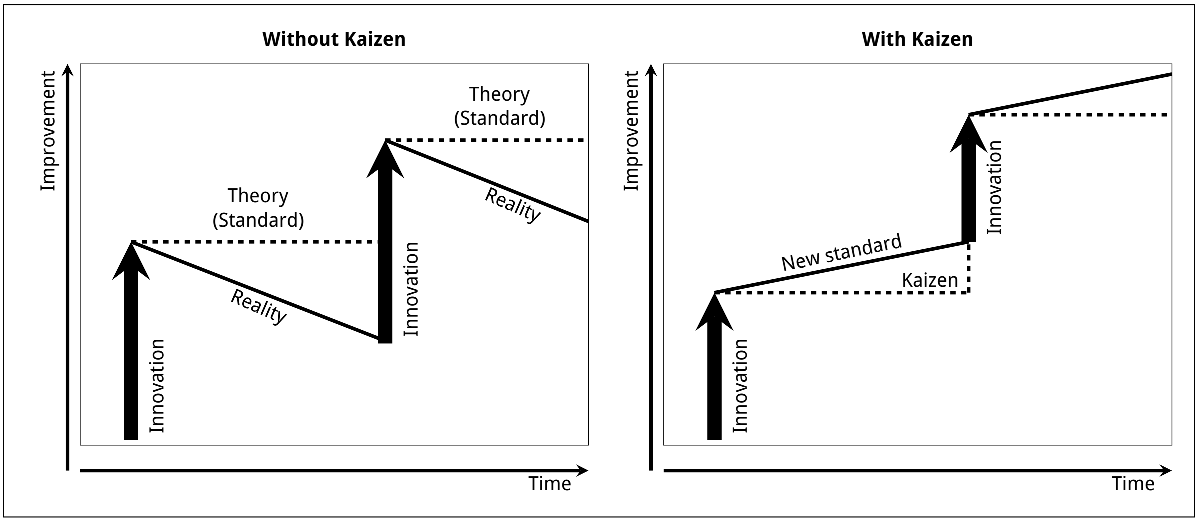


Figure 2.6: Innovation without and with Kaizen[102]

[98] cf. Imai (1993), p. 76.
[99] cf. ibid., p. 78.
[100] cf. ibid., p. 50.
[101] cf. Bicheno and Holweg (2009), p. 174.
[102] adapted from: Dickmann (2007), p. 50

Table 2.3 presents the main differences between different attributes regarding the implementation and effects of improvement actions through CIP and innovations:

	CIP	Innovation
Effect	Long-term and persistent, but undramatic	Short-term, but dramatic
Speed	Small steps	Big steps
Timeframe	Continuously and rising	Interrupted and limited
Chance of success	Consistently high	Abrupt and unstable
Protagonists	Every employee	Only a few “chosen ones”
Proceedings	Group work	Individual ideas and efforts
Concept	Maintain and improve	Demolition and rebuild
Recipe for success	Conventional know-how and state of the respective technology	Technological achievements, new inventions, new theories
Preconditions	Small investment, big efforts to preserve	Big investment, low efforts to preserve
Success orientation	People	Technology
Evaluation criteria	Performance and procedures for better results	Profit
Advantage	Ideally suited for a slowly rising economy	Suitable for a rapidly growing economy

Table 2.3: Comparison of CIP and Innovation[103]

[103] adapted from: Imai (1993), p. 48

2.2 Total Productive Maintenance

Value-based management is one of today's most important management philosophies. In contrast to the widespread practice of revenue and profit maximization, value-based leadership is committed to the sustainable growth of corporate values. This includes the interests of all stakeholders of a company and aims at creating value for all of these groups. The list of stakeholders includes not only investors, but also customers, employees, partners, suppliers, the environment and society.[104]

In Western companies the measurement of performance was long dominated by the criterion of shareholder value, and thus essentially investor-oriented. The development of the stock share price or profit increase thus constituted the sole factors influencing the performance review, which manifested itself in the desire of short-term profit maximization. The orientation of corporate goals towards the interest of this stakeholder group alone cannot achieve lasting success. Long-term business survivability is only possible if the objectives and operational activities of a company do not only pursue the increase of monetary values but also the increase of nonmonetary values like employee and customer satisfaction. The value-based leadership calls for an active influence on performance, cost, profit, and value drivers instead of the traditional cost and profit causation thinking. The sphere of influence should not be limited to the primary activities of companies, but also include supporting activities like human resources management, procurement or maintenance (see figure 2.7).[105]

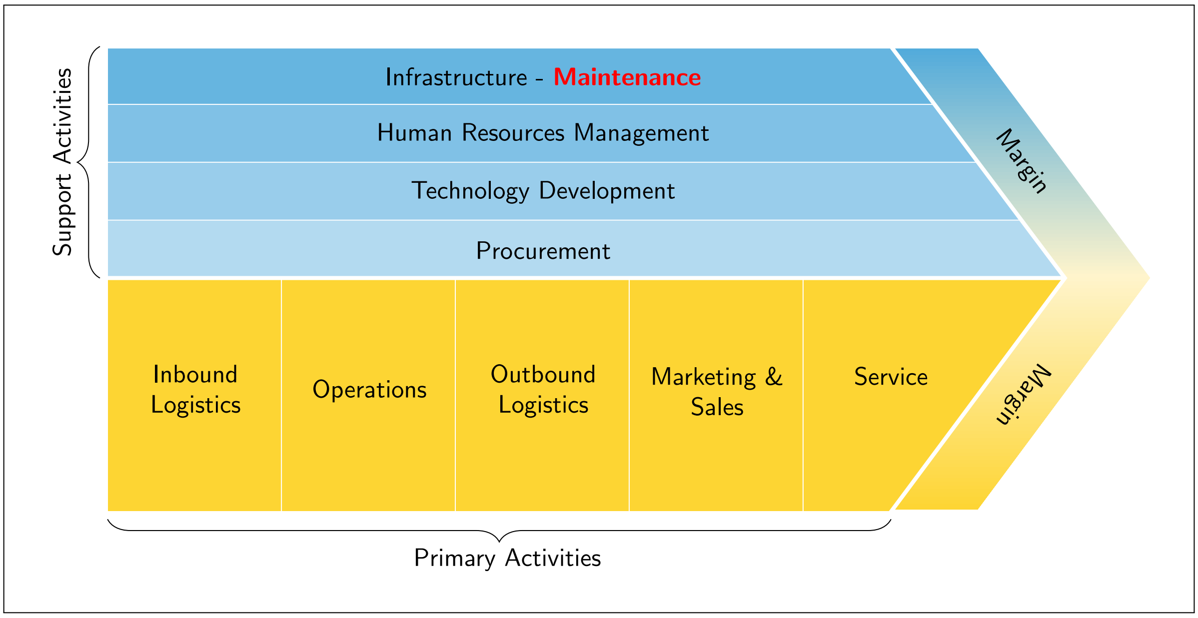


Figure 2.7: Value chain according to Porter[106]

[104] cf. Reichel, Mandelartz, and Müller (2009), p. 75.
[105] cf. ibid.
[106] adapted from: Reichel, Mandelartz, and Müller (2009), p. 76.

2.2.1 Value-added through Maintenance

Maintenance is one of the essential support activities in manufacturing companies, as it is responsible for the provision of production capacities. It makes a decisive contribution to value preservation and value enhancement of existing systems and their availability for production and also ensures high process stability and the associated product quality. Maintenance also influences the competitiveness of a company directly and thus represents an important competitive factor in the global manufacturing industry. Although companies are aware of the importance and potential of maintenance-related actions, a gap between knowledge and operation reality still exists. The predominant strategy of profit maximization often leads to strictly reduced maintenance budgets, as they directly influence the EBIT value. This strategy is characterized by singular measures for improvement and has no value-oriented objective. Long-term effects of this strategy, like reduced plant availability or effectiveness, are not taken into account and make it even harder to meet customer requirements such as short lead times and high production quality. An emphasis on the internal value stream allows the maintenance works to actively contribute to value creation within a company.[107]

Several concepts and approaches have been developed over the time in order to implement a value-added maintenance management system. Today, the following systems are best-known and have been analyzed widely in scientific studies for their effects on value appreciation:

- **Reliability Centered Maintenance (RCM):** "A systematic consideration of system functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable and effective preventative maintenance tasks. The main focus of RCM is therefore on the system functions, and not on the system hardware."[108]
- **Risk Based Maintenance (RBM):** Analysis and evaluation of the failure potential of technical equipment and their possible risks for humans, property and environment. Maintenance methods and cycles are based on the evaluation results.[109]
- **Total Productive Maintenance (TPM):** This approach combines maintenance activities with principles of the Lean methodology.[110]

The first two approaches are mainly criticized for not delivering a comprehensive concept for the design of maintenance management as their methods and tools are focused on the improvement of individual maintenance activities in object-, process- or function-oriented situations. The Total Productive Maintenance system is the only system to fulfill the requirements of value-added maintenance, as it is a holistic and self-contained concept analogous to comprehensive production systems like TPS — following the principle of avoiding any losses or wastage.[111]

---

[107] cf. Reichel, Mandelartz, and Müller (2009), p. 76.
[108] Rausand (1998), p. 76.
[109] cf. Khan and Haddara (2003), p. 562.
[110] cf. Baluch, Abdullah, and Mohtar (2012), p. 850.
[111] cf. Reichel, Mandelartz, and Müller (2009), p. 78.

2.2.2 Historical Development of TPM

In the early 20th century, the practice of maintenance in manufacturing facilities can be compared to a fire-fighting job. Only in cases of malfunctioning machines or processes, designated workers were called to fix the problems. Depending on the severity of the issue, the whole production flow could come to a standstill. This *Breakdown Maintenance (BM) or Run-to-Failure Management* is often associated with high spare parts inventory costs, high overtime labor costs, high machine downtimes and low production availability.[112]

The first scientific approach to maintenance was introduced by General Electric in the 1950s, called *Preventive Maintenance (PM)*, and resulted in a significant reduction of system failures. This time-based approach was based on statistical functions like *Mean-Time-Between-Failure (MTBF)* values and bathtub curve description of failure probability of new and old machines.[113] The success of this new approach gained the attention of several Japanese manufacturing managers (see also chapter 2.1.1), who analyzed the concept of PM and the possibility of adapting this technique for their domestic manufacturing industry. In 1953, twenty different companies created a supporting research group to work on this topic, which eventually led to the founding of the Japan Institute of Plant Maintenance (JIPM). The Japanese maintenance system coined the term *Corrective Maintenance (CM)*, a concept that mainly focused on the performance and reliability of the production facilities. In 1960, the idea of *Maintenance Prevention (MP)* was formulated. This concept aimed at the development and acquisition of plant equipment easy to operate and maintain and, thus, less cost-intensive.[114]

The first approach to combine the three single-focused approaches PM, CM and MP was put forward in 1961 by *Nippodenso*, then a subsidiary of the Toyota Motor Company. Their *Productive Maintenance* approach cannot be considered to be a holistic system because all the maintenance work was carried out by designated working teams.[115] The progressive automation of the production plants beginning in the mid-1960s made it more difficult to maintain a steady level of machine reliability. This forced Nippodenso to get rid of the barrier between machine operators and maintenance crew (reversal of division of labor). The knowledge of operators about their machines was now applied to maintenance working procedures and occurring waiting time between production cycles could now be used for autonomous maintenance activities, which reduced the general workload of the still existing professional maintenance crew. Based on the positive experiences of the new approach, the company gradually introduced this advanced methodology under the term *Total Productive Maintenance (TPM)* in most of their plants between 1969 and 1971.[116]

[112] cf. Mobley (2002), p. 2.
[113] cf. ibid., p. 3.
[114] cf. Rasch (2000), p. 187.
[115] cf. ibid.
[116] cf. ibid.

The further development of TPM was managed by the JIPM under the guidance of Seiichi Najakima, who also provided a definition of TPM:

> *"TPM is the optimization of plant and machine efficiency and requires the complete elimination of errors, defects and other negative phenomena - in other words, the waste and losses through the use of equipment and machinery"*[117]

2.2.3 Objectives and Goals of TPM

The Japan Institute of Plant Maintenance defined the following points as inevitable for companies who want benefit from TPM:[118]

1. **Cultural change:** TPM aims at the formation of a recognizable, collaborative corporate culture, which has a comprehensive impact on the efficiency of the production system.
2. **Zero losses:** TPM is a system to prevent wastage of any kind to achieve the objectives "no stoppage", "no defects" and "no failure" in the fields of "Gemba" (place, where the value-added processes in a company are done) and "Genbutsu" (all factors influencing the Gemba, man, machine, material) over the complete life cycle of a production system.
3. **Interdisciplinary involvement:** All departments of the company (development, production, marketing, management etc.) are included.
4. **Employee involvement:** All employees, from the CEO to the shop floor worker, are involved.
5. **Innovative forms of work:** Motivating management of small-group activities should ensure the achievement of "zero-losses".

The word *Total* refers to the three main characteristics of the TPM concept, which make it a comprehensive approach in comparison to other maintenance systems:[119]

1. Pursuit of total effectiveness of the production facilities by inclusion of all possibilities to prevent losses and damage-related disorders.
2. Implementation of a total maintenance system, taking into account especially preventive and perfective maintenance measures. Focus on the total plant life cycle management for the realization of easier and user-friendly maintenance of the machines.
3. Total involvement of all employees.

TPM is regarded as a holistic approach to maximizing the effectiveness of the equipment in so far as it explicitly encourages the interaction between the otherwise often isolated individual

[117] Nakajima (1988), p. 12.
[118] cf. Nakajima (1995), p. 31.
[119] cf. Rasch (2000), p. 190.

systems like humans, plant and environment.[120]

2.2.4 Basic Ideas

Based on the objectives of TPM, three essential basic ideas are identified, which are crucial for the successful application of the concept. In addition, it is easy to see that TPM shares two main ideas with the Lean Production methodology:[121]

1. **Zero-Failures:** All problems need to be identified and corrected, which prevent an undisturbed production process. Goal should be a plant efficiency of 100%, which can only be reached when the production system is characterized by no unscheduled machine stoppages, no quality losses issued by the production machines and no performance losses.
2. **Continuous Improvement Process:** Instead of implementing large and expensive measures to increase the plant efficiency, the company should focus on smaller and iterative steps to solve a problem (see chapter 2.1.6). This procedure is much less time and cost intensive.
3. **Orientation on the plant life cycle:** Already in the planning phase of the plant infrastructure and machine design, TPM aims at maximizing the plant efficiency through the usage of maintenance-friendly processes and machines. Teething problems during commissioning of new machines as well as ongoing maintenance costs should be attributed by continuous improvement actions.

2.2.5 Six Big Losses

Following the idea of Lean Production, the TPM system addresses the problem of losses or wastage within a production process. The assessment of these losses can reveal existing bottlenecks and problem areas of the production. From the vantage point of the TPM methodology, the evaluation of the losses serves as a source for the further improvement process, which aims at highest possible efficiency rate of the whole plant system.[122] The losses can be classified in different categories:

- **Machine breakdown:** This is the largest source of loss, and can be sub-classified as machine-dependent and machine-independent. Machine-dependent problems are caused by mechanical, pneumatic, electric or hydraulic defects of machines, whereas missing materials, tools/aids and lack of personnel (e.g. in cases of illness) are seen as independent from the machine. Not to be forgotten is that even small failures that occur frequently represent large losses.[123]

[120] cf. Al-Radhi and Heuer (1995), p. 13.
[121] cf. Rasch (2000), p. 191.
[122] cf. Al-Radhi and Heuer (1995), p. 17.
[123] cf. Al-Radhi (1997), p. 12.

- **Setup and adjustments:** These losses occur during setup action of machines for the production of a new part. The time starts when the production of a product is completed and ends when the produced outcomes of the new parts meet the required quality standards. What is important is the introduction of standards for setup procedures that define the optimal process.[124]

- **Small stops:** Idle and minor stoppages are short interruptions or disturbances of the system, which occur when parts remain hanging in a machine mechanism or tilt up. Since the cumbersome parts must be removed, the normal operation of the machine is disturbed. Such stoppages can be resolved quickly, but if they occur continually, they decrease the plant efficiency dramatically, especially at plants with a high degree of automation.[125]

- **Reduced speed:** Causes for speed losses are for instance malfunctioning pumps and motors. These problems are hard to notice and often only recognized after a long time by the operator. Aggravating is the fact that tact times are not monitored continuously and that the maximum values are often not known.[126]

- **Startup rejects:** Production processes are often accompanied by heating or cooling procedures that are necessary during start-up or run-out of the production. Thus, the achievement of a normal production rate is retarded, and performance losses of the system can occur. Defects on produced items are also caused when certain process parameters (e.g. Curing temperature, pressure) have not yet been reached.[127]

- **Production rejects:** Scrap and rework of defective parts (e.g. dimension or surface) are quality losses that occur frequently in the case of functional impairments to the equipment or if the interaction between the machine operator and the machine is insufficient.[128]

These six losses are also called indirect costs or lost opportunity costs of ineffective and inadequate maintenance. As companies often attempt to reduce direct costs (labor costs, spare parts; easily to assess) in order to increase their profitability, indirect costs are frequently not considered, as they are not tangible or visible. This situation can be easily described with the iceberg example (see figure 2.8), which illustrates that 7/8 of the total volume lie below the water surface. Costs created by losses below the surface are called *hidden factory or costs on non-conformity*. The outcomes of the iceberg's top are considered as maintenance efficiency, whereas the larger part below is referred to as maintenance effectiveness. Both areas are connected directly to each other, which means that the improvement of losses can decrease the direct costs. On the other hand, a decrease of direct costs is likely to have adverse effects

[124] cf. Al-Radhi and Heuer (1995), p. 22.
[125] cf. Al-Radhi (1997), p. 13.
[126] cf. Hartmann (1995), p. 92.
[127] cf. Rasch (2000), p. 197.
[128] cf. Al-Radhi and Heuer (1995), p. 27.

on indirect costs.[129]

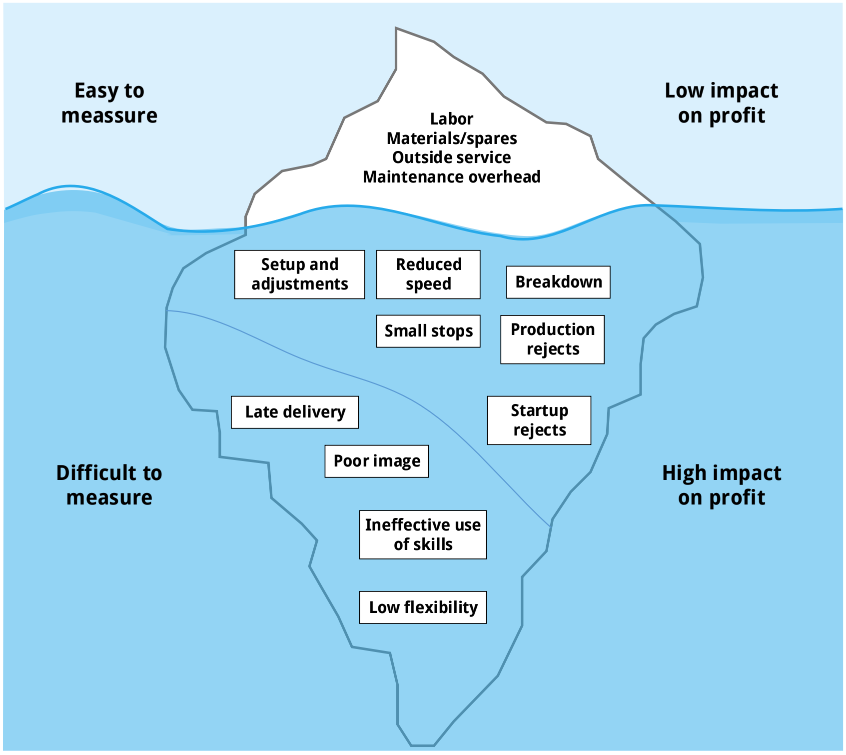


Figure 2.8: Direct and indirect costs of maintenance[130]

2.2.6 Overall Equipment Effectiveness

The Lean Production methodology does not feature a designated Key Performance Indicator (KPI) to clearly assess the initial situation on the one hand, and to display an increase or decrease after the improvement activities have taken place on the other hand. The JIPM and Nakajima introduced the KPI *Overall Equipment Effectiveness (OEE)* as the main metric for the effectiveness of the TPM methodology. The OEE is directly linked to the existence of the six big losses (see chapter 2.2.5).[131]

The OEE of a machine or a plant can be calculated as follows:

$$\text{OEE} = \text{Availability} \cdot \text{Performance} \cdot \text{Quality}\ [\%]$$

Equation 2.1: Calculation of the OEE[132]

[129] cf. Willmott and McCarthy (2001), p. 40.
[130] adapted from: Willmott and McCarthy (2001), p. 31.
[131] adapted from: May and Koch (2008), p. 245.
[132] adapted from: May and Koch (2008), p. 247

The three single factors (Availability, Performance and Quality) directly depend on measured values of the examined machine, its operator and the quality of the produced pieces.

Equation 2.2 displays the calculation of the Availability factor.

$$\text{Availability} = \frac{\text{Planned Operating Time}}{\text{Planned Operating Time + Downtime}}\ [\%]$$

Equation 2.2: Calculation of the availability factor[133]

The Performance factor is calculated according to equation 2.3.

$$\text{Performance} = \frac{\text{Actual Output}}{\text{Nominal Output}}\ [\%]$$

Equation 2.3: Calculation of the performance factor[134]

Equation 2.4 displays the calculation of the Quality factor.

$$\text{Quality} = \frac{\text{Produced Quantity} - \text{Defect Quantity}}{\text{Produced Quantity}}\ [\%]$$

Equation 2.4: Calculation of the quality factor[135]

Figure 2.9 shows how the useable calendar time is reduced by the three loss factors towards the so-called “Value operated time”. This value describes the total time of production (limited to the corresponding machining process) in which value for the product is created. All losses that occurred are thus considered as non-value-added activities.[136]

[133] adapted from: May and Koch (2008), p. 247
[134] adapted from: ibid.
[135] adapted from: ibid.
[136] adapted from: May and Koch (2008), pp. 245-247.

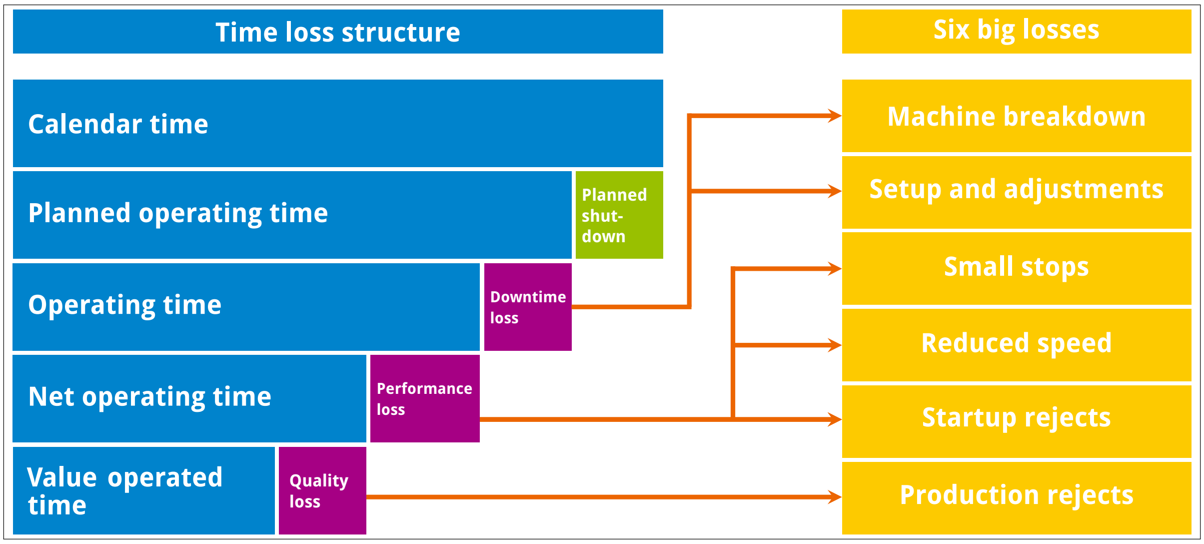


Figure 2.9: Time loss structure and six major losses hindering the OEE in the processing type equipment[137]

The OEE calculation starts at the maximal useable time within a whole year. Because of shift planning, holidays, breaks, strikes or planned maintenance activities, the usable time of 8760 hours (365 days · 24 hours/day) is reduced towards the *Planned Operating Time*. Downtime consists of time losses due to *Breakdowns* and *Setup adjustments*. The *Performance*-factor addresses the deviation between the theoretical (planned or defined) and the actual cycle time, caused by several speed losses. The last factor covers the losses through insufficient quality of the produced products, either caused by malfunctioning machines or non-conformity with the specifications.

The OEE makes a significant contribution to a transparent view on the production system as it considers availability, performance and quality aspects. Prerequisite for the calculations is the presence of the corresponding data. Therefore, a consistent data recording by the operating personnel is necessary for evaluation and the subsequent improvement phase.[138] Companies who were rewarded by JIPM for their excellent implementation of TPM achieved a word class performance value of the OEE of about 85% (Availability: ~90%; Performance: ~95%; Quality: ~99%). The ultimate target of the TPM system according to the no-failure and no-losses strategy is an OEE value of 100%, although it is nearly impossible to reach.[139]

[137] adapted from: Ohwoon and Hongchul (2004), p. 268
[138] cf. Rasch (2000), p. 201.
[139] cf. Nakajima (1995), p. 41.

Table 2.4 presents typical OEE values for different industries that were collected by different research studies. It can be said that a high degree of automation in companies, like paper manufacturing or chemical process engineering, is beneficial for high OEE values, as the disturbing influences of people or manual material handling is reduced to a minimum level.[140]

Industry	Top performer OEE	Average OEE
Manufacturing	85%	60%
Process	>90%	>68%
Metallurgy	75%	55%
Paper	95%	>70%
Cement	>80%	60%

Table 2.4: OEE values for different industries[141]

One essential problem of the OEE metric system is the correct and intensive collection of needed information and values. Although many companies have a tracking system for maintenance activities and a system for the recording of minor stoppages, neither of these data collections gives an appropriate and comprehensive view for the causes and effects of losses. It can often be observed that there is a certain resistance of operators and foremen against an ongoing data collection. Therefore it is important to design a less-time consuming data acquisition method that is also precise and delivers the needed quantity and quality of data. The acquisition of data can also be performed with the help of IT-systems in an automatic way in order to decrease the efforts for operators and still provide a higher level of assessment. Necessary for both systems is the standardization of the loss classes that occur during the production, depending on characteristics of the production process.[142]

2.2.7 Criticism of OEE metric

Despite the fact that the OEE metric wants to provide a holistic view for the effectiveness, several limitations exist that should be included in the evaluation of the acquired data. Mostly the OEE system is not intended for usage at the plant level, as it is a rough measure of selected equipment only. Furthermore it is not suitable to benchmark different assets, equipment or processes, but it can be only used to compare similar assets that are producing similar parts. Another point of criticism is the conversion of the three single calculation factors with different units (chronological time for Availability, units per time for Performance, counts of produced items for Quality), into percentages for comparison. For example, the total OEE percentage can increase while the actual quality value decreases tremendously. This missing statistical linkage needs to be worked out manually during the evaluation.[143]

[140] cf. ABB (2007), p. 17, http://www05.abb.com/ (visited on 09.01.2014).
[141] adapted from: ABB (2007), p. 17, http://www05.abb.com/ (visited on 09.01.2014).
[142] cf. Ljungberg (1998), p. 497.
[143] cf. Williamson (2006), p. 2.

2.2.8 Differences between Efficiency, Effectiveness and Productivity

At the beginnings of the TPM methodology, the OEE metric was defined as the *Overall Equipment Efficiency*, whereas now the definition *Overall Equipment Effectiveness* is used. The difference between both is that effectiveness is the actual output over the reference output, while efficiency refers to the actual input over the reference input. Therefore, an equipment efficiency value would display the ability of a company to produce well at the lowest overall cost. Consequently the equipment effectiveness would represent the ability to continually manufacture products that create value for the company. In a Lean-driven company culture, it is more useful to measure the performance of manufacturing systems by their effectiveness.[144]

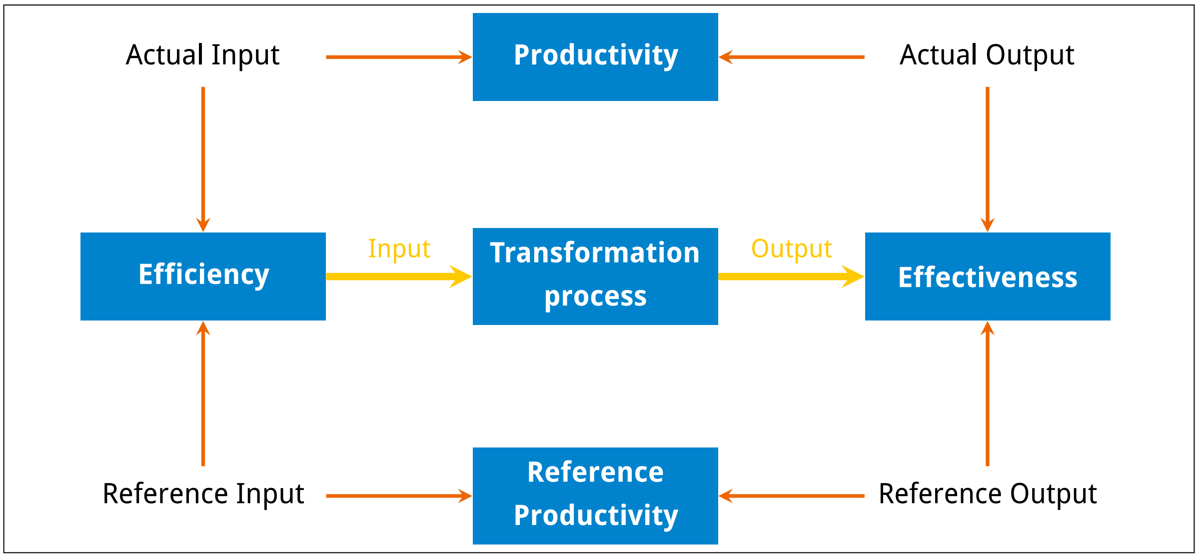


Figure 2.10: Efficiency versus Effectiveness versus Productivity[145]

2.2.9 Instruments to Achieve the Objectives

As mentioned before, TPM aims at the maximization of the Overall Equipment Effectiveness. Based on the ideas (see chapter 2.2.4) and objectives (see chapter 2.2.3), TPM is separated into five instruments, which are equipped with different tools and methods in order to raise the OEE value. The usage of the word *maximization* implies, that these instruments are executed repeatedly in accordance with the PDCA-cycle:

144 cf. Iannone and Nenni (2013), p. 32.
145 adapted from: Iannone and Nenni (2013), p. 33.

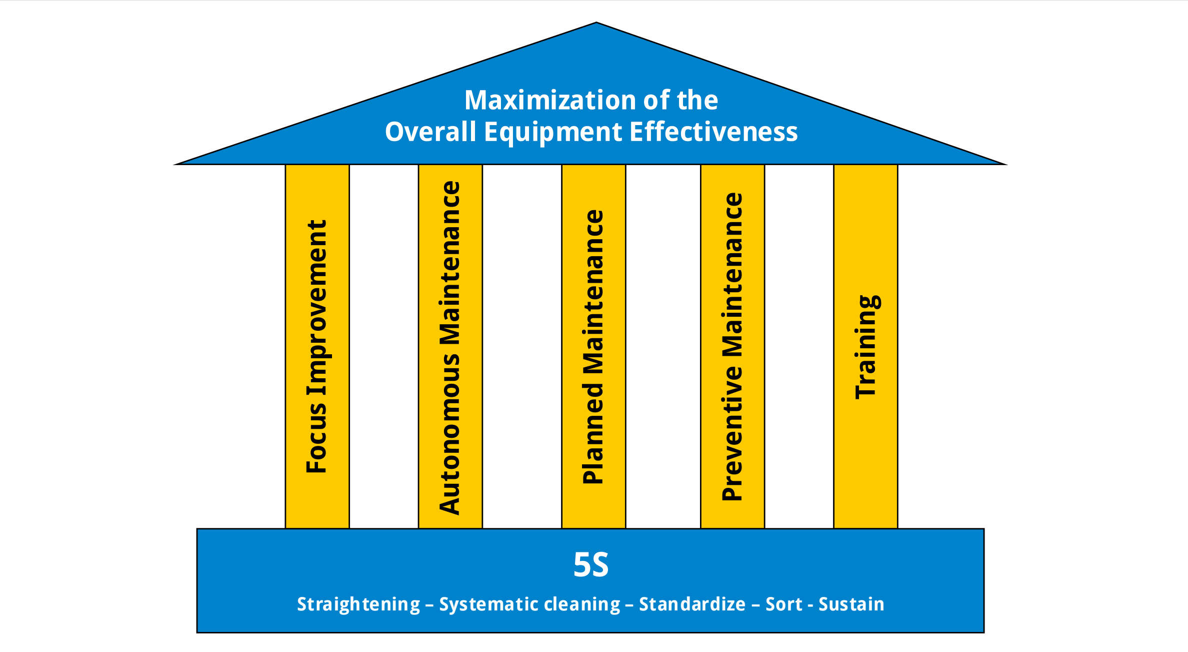


Figure 2.11: Five pillars of the TPM methodology[146]

Fundament of all instruments is the execution of the 5S toolset (see chapter 2.3.1) prior to any other related TPM activity. The identification of wastages and losses with this activity is seen as a quick win, as it eliminates possible distractions for the subsequent procedures of TPM.

2.2.9.1 Focused Improvement

The concept of continuous improvement actions regarding existing processes or workflows is based on the ideal of a highest possible degree of perfection within the whole production. Therefore all maintenance operations have to be designed in a sophisticated way, and optimized in an ongoing process, whereas previous conditions are considered as a standard and starting point.[147]

Cross-functional improvement teams should apply systematic tools and methods to identify high-potential problem fields. Aim is to identify vital machines or processes of the production, where failures could lead to a tremendous risk for the whole company. These objectives need to be prioritized for the subsequent actions. Furthermore, the biggest sources of losses or wastages caused by single machines must be examined, as they have a high impact on the OEE. The identification is often based on data on the six losses and wastages.[148]

Improvement teams should be interdisciplinary, with employees from the production, maintenance and quality departments. Optionally this can be extended by an additional planning team which coordinates the improvement actions. The main advantage of an interdisciplinary composition is that different experiences of team members come together and the boundaries of isolated thinking can be offset.[149] It is particularly important that the improvement teams

[146] adapted from: Al-Radhi and Heuer (1995), p. 37
[147] cf. Rasch (2000), p. 203.
[148] cf. ibid., p. 203.
[149] cf. Al-Radhi and Heuer (1995), p. 39.

develop a working mode which is not dominated by reactive investigations of symptoms and their disposal, but through which the causes of effectiveness losses are proactively detected and eliminated.[150]
The list of useable tools and methods to identify the major losses includes among others the 5-Why method and the Cause-Effect-diagram.[151]

2.2.9.2 Autonomous Maintenance

The basic aim of autonomous maintenance is handing over the responsibility for simple maintenance actions to employees in the production area. This is intended to raise the employees' awareness of emerging disorders and early problem recognition and, thus, to prevent unplanned stoppages. Other maintenance tasks, such as complicated repairs that require special skills, continue to remain in the responsibility of the maintenance department.[152]
Characteristic for the autonomous maintenance in Japanese companies is that the entire periodical maintenance activities of the production, including all inspections and minor repair work, are independently carried out by a group of well-trained production staff.[153]
The autonomous maintenance cannot be implemented over night to the whole production. Therefore the JIPM suggested a 7-step program for the implementation (see figure 2.12).

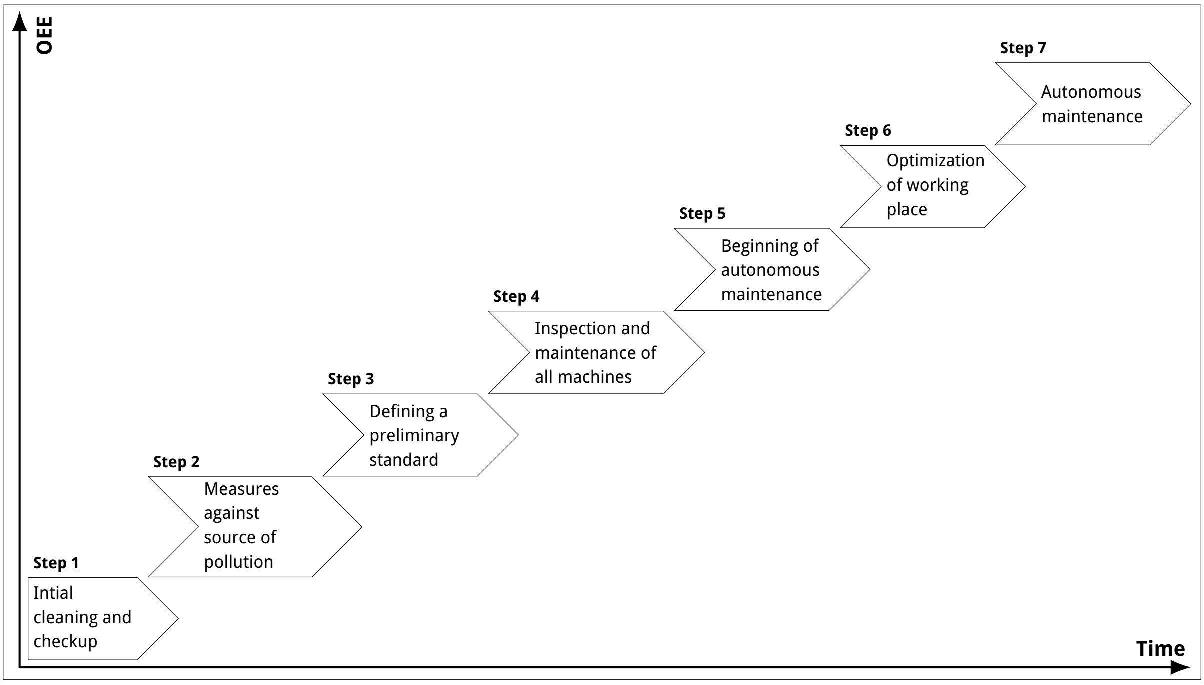


Figure 2.12: Seven steps towards autonomous maintenance[154]

In the first three steps, the production staff creates a basic condition level of the machines

[150] cf. Rasch (2000), p. 204.
[151] cf. Al-Radhi and Heuer (1995), p. 41.
[152] cf. ibid., p. 57.
[153] cf. Hartmann (1995), p. 113.
[154] adapted from: Al-Radhi and Heuer (1995), p. 61

(cleaning operations and preventions from dirt). The achieved level serves as the initial basis for the autonomous maintenance. Steps four and five highlight the importance of more thorough inspections, including the resulting measures. It is particularly crucial to set standards that increase the sensibility of employees to deviations from the target state of the system and to promote the knowledge about necessary maintenances. In these two steps the decrease of machine failures is likely to become clearly visible. The focus in steps six and seven lies on improvement actions based on the experience and better knowledge gained in the previous steps. The activities are then extended to the whole working environment.[155]
The success of the different steps needs to be verified with the help of audits, which either reveal deviations according to the defined standards or reward the correct implementation.[156]

2.2.9.3 Planned Maintenance

The planned maintenance pillar essentially describes the tasks of the remaining activities of the maintenance department. These are usually tasks which require special qualifications and should not be kept decentralized for economic reasons. These activities are mainly characterized as specialized maintenance and inspection measures, but also as complex repair work. In addition, measures with significant security risks for people and objects are carried out within this sphere of influence. The planned maintenance program is also responsible for implementing activities, which increase the productivity and quality of production processes and reduce the effort required for normal maintenance activities.[157]

2.2.9.4 Preventive Maintenance

Preventive maintenance addresses the basic idea of a plant's life cycle orientation. The aim is the continuous development of production machines and processes in relation to process safety, as well as operating and maintainability and starts already at the stage of product development. Thus, the reliability and productivity of the systems can be increased. Additional effects are reduced manufacturing and maintenance costs. Preventive maintenance also leads to a shortened time between system design and the start of series production. Preventive maintenance can also be seen as a seven-step program (see figure 2.13).[158]

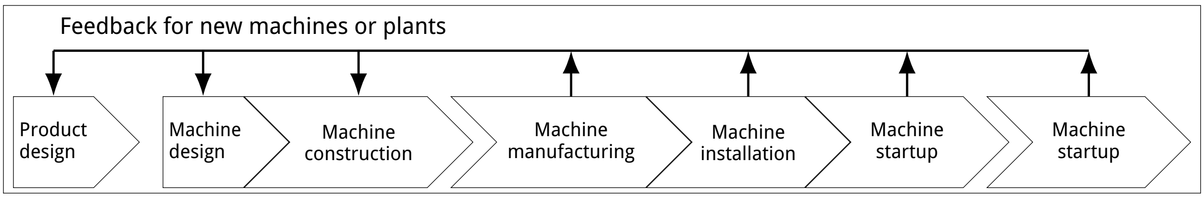


Figure 2.13: Seven steps towards preventive maintenance[159]

[155] cf. Al-Radhi (1997), p. 39.
[156] cf. ibid., p. 74.
[157] cf. Rasch (2000), p. 213.
[158] cf. Al-Radhi and Heuer (1995), p. 123.

Important for steps one to three, is that practical experiences of production and maintenance are introduced into the plant/machine design. During steps four to six, the design is checked and analyzed by production and maintenance employees for its maintenance- and user-friendliness. In the subsequent and final phase, the machine goes online, which will show if all criteria have been properly considered. However, as there is always the possibility of encountering problems which have not been sufficiently taken into account during system development, it is important to get feedback from production and maintenance employees. This is intended to ensure that the lessons learned will be incorporated in future projects and that mistakes are avoided as much as possible.[160]

2.2.9.5 Training

One essential factor for the successful implementation of TPM are training activities destined to increase the workers' awareness for this methodology and to present the different principles. With the help of external or internal guidance, the people are getting familiar with the different tools and methods, whereas "Training on the Job" should be preferred. The aim of the training is not the pure transfer of theoretical knowledge, furthermore it has to show possible practical approaches for problem solving on specific issues that occur within the production process. Companies, which successfully implemented TPM, consider trainings as the key element for the whole TPM methodology.[161]
Following topics may be dealt within training courses for employees without presenting a high extra burden for employees:[162]

- TPM awareness
- Basic principles
- Tools and methods
- Communication and teamwork skills
- Preventive Maintenance
- Planned Maintenance
- Technical knowledge for machine operations

[159] adapted from: Rasch (2000), p. 219
[160] cf. Al-Radhi and Heuer (1995), p. 74.
[161] cf. ibid., p. 99.
[162] cf. Klein-Schneider (2003), p. 16.

2.3 Tools

Several tools have been developed or adapted to support and maintain the implementation of methodologies like Lean Manufacturing and Total Productive Maintenance. The fundamental idea for all of these tools is to bring value-decreasing activities to the fore in order to eradicate them in the near future. As mentioned before, both methodologies share the common idea of a value-based and value-added manufacturing operation. In table 2.6 several tools will be introduced shortly and it will be described how they facilitate the optimization of processes. The sub-chapters to follow will discuss three tools in detail.

Tool	Description	Effects
Andon	Visual feedback system for the plant floor that indicates the production status, alerts when assistance is needed, and enables operators to stop the production process.	Acts as a real-time communication tool for the plant floor that brings immediate attention to problems as they occur, so they can be instantly addressed.
Bottleneck Analysis	Identify which part of the manufacturing process limits the overall throughput and improve the performance of that part of the process.	Improves throughput by strengthening the weakest link in the manufacturing process.
Continuous Flow	Manufacturing where work-in-process pieces smoothly flows through production with minimal (or no) buffers between steps of the manufacturing process.	Eliminates many forms of waste (e.g. inventory, waiting time, and transport).
Gemba (The Real Place)	A philosophy that reminds to get out of the offices and spend time on the plant floor, the place where real action occurs.	Promotes a deep and thorough understanding of real-world manufacturing issues by first-hand observation and talks with plant floor employees.
Heijunka (Level Scheduling)	A form of production scheduling that purposely manufactures in much smaller batches by sequencing (mixing) product variants within the same process.	Reduces lead times (since each product or variant is manufactured more frequently) and inventory (since batches are smaller).

continued on next page

Tool	Description	Effects
Hoshin Kanri (Policy Deployment)	Align the goals of the company (Strategy), with the plans of the middle management (Tactics) and the work performed on the plant floor (Action).	Ensures that progress towards strategic goals is consistent and thorough, eliminating the waste that comes from poor communication and inconsistent direction.
Jidoka (Autonomation)	Design equipment to partially automate the manufacturing process (partial automation is typically much less expensive than full automation) and to automatically stop when defects are detected.	After Jidoka, workers can frequently monitor multiple stations (reducing labor costs) and many quality issues can be detected immediately (improving quality).
Just-In-Time (JIT)	Pulling parts through production based on customer demand instead of pushing parts through production based on projected demand. Relies on many lean tools, such as Continuous Flow, Heijunka, Kanban, Standardized Work and Takt Time.	Highly effective in reducing inventory levels. Improves cash flow and reduces space requirements.
Kanban (Pull System)	A method of regulating the flow of goods both within the factory and with outside suppliers and customers. Based on automatic replenishment through signal cards that indicate when more goods are needed.	Eliminates waste from inventory and overproduction. Can eliminate the need for physical inventories (instead relying on signal cards to indicate when more goods need to be ordered).
Poka-Yoke (Error Proofing)	Design error detection and prevention into production processes with the goal of achieving zero defects.	It is difficult (and expensive) to find all defects through inspection, and correcting defects typically gets significantly more expensive at each stage of production.
Takt time	The pace of production (e.g. manufacturing one piece every 34 seconds) that aligns production with customer demand. Calculated as Planned Production Time / Customer Demand	Provides a simple, consistent and intuitive method of pacing production. Can easily be extended to provide an efficiency goal for the plant floor (Actual Pieces / Target Pieces).

continued on next page

Tool	Description	Effects
Value Stream Mapping	A tool used to visually map the flow of production. Shows the current and future state of processes in a way that highlights opportunities for improvement.	Exposes waste in the current processes and provides a roadmap for future improvement.
Visual factory	Visual indicators, displays and controls used within manufacturing plants to improve communication of information.	Makes the state and condition of manufacturing processes easily accessible and clear to everyone.

Table 2.6: Lean and TPM supporting tools[163]

2.3.1 5S

5S is a Japanese methodology and tool for the reorganization of work areas such as warehouses, offices and production facilities with the goal of executing processes optimally involved in a workplace, thus enhancing performance, safety and cleanliness.[164] It was mainly popularized by Ohno within the framework of TPS and by Shingo, who introduced the concept of Poka-Yoke. 5S is also seen as a starting point for improvement processes, including Kaizen and TPM (see chapter 2.2.9), as clean and well laid-out workplaces make it easier to identify wastage during a process.[165]
The methodology's name refers to the titles of the five pillars of 5S (see figure 2.14:

1. **Sorting (Seiri):** At this step, items not used and needed at the workplace are discarded, keeping only items that are essential for the working process. The identification of tools or objects with a doubtable usage frequency can be simplified by the usage of red tags, which workers put on things they did not use in their working shift. A tag can be removed once this object is used again. After a pre-defined timespan all remaining red-tagged items are removed from the working place.[166]

2. **Straightening (Seiton):** All remaining items need to be stored in easily accessible places.[167] An ergonomic design on the arrangements of tools should be considered to prevent unnecessary fatigue of workers.[168]

[163] adapted from: Lean Production (2014), http://www.leanproduction.com/ (visited on 06.01.2014).
[164] cf. Peterson and Smith (1998), p. 2.
[165] cf. Sarkar (2006), p. 2.
[166] cf. Bicheno and Holweg (2009), p. 78.
[167] cf. Thomsen (2006), p. 150.
[168] cf. Bartholomay (2007), p. 20.

3. **Systematic cleaning (Seiso):** Steady cleaning and straightening of the workplace to ensure an easy finding of needed tools and objects. Workers need to be trained to perform these activities automatically after a working process is finished.[169]

4. **Standardize (Seiketsu):** After successfully performing of the first three pillars of 5S, the newly introduced activities and regulations can be defined as the new working standard for a certain process.[170] A well-defined standard also makes it easier to maintain the new status quo.[171]

5. **Sustain (Shitsuke):** Workers are encouraged to show self-initiative and self-discipline to abide by the rules and standards.[172] The repeated execution of the 5S principles should ensure a well designed working place, even when the boundaries will be changed (see Continuous Improvement Process, chapter 2.1.6).[173]

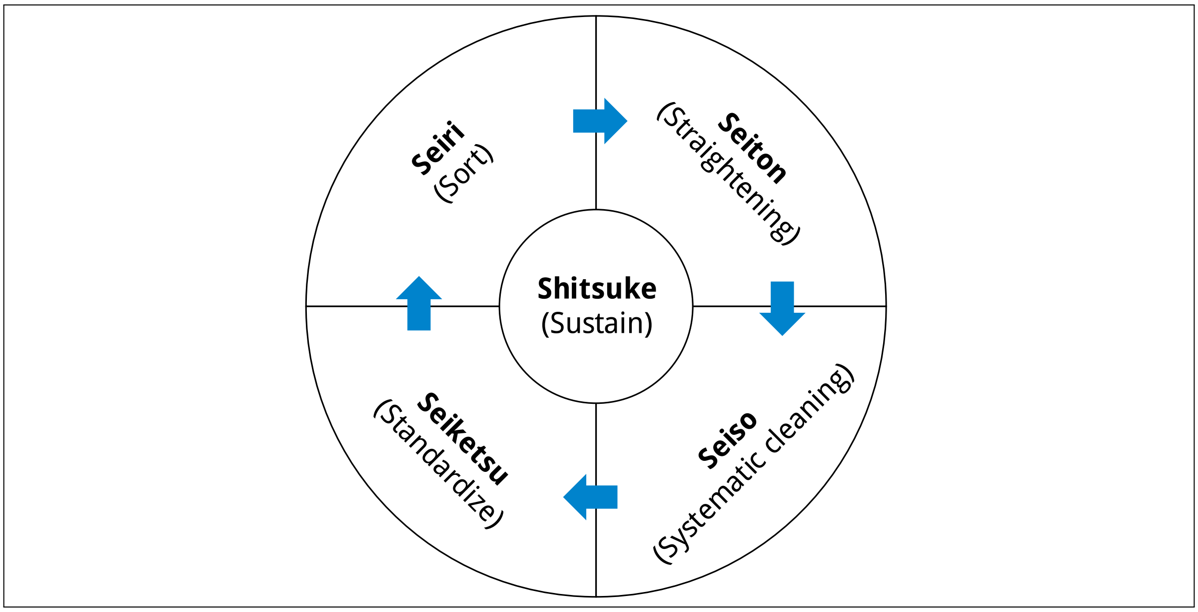


Figure 2.14: The five pillars of 5S[174]

The benefits of the 5S method are reduced non-value-added activities like searching or movement, as only the necessary equipment is present and easy to find. Also the safety level of working places is likely to increase too through a higher level of cleanliness and order. Main benefit of the 5S method is easier identification of wastage.[175]

[169] cf. Bicheno and Holweg (2009), p. 469.
[170] cf. ibid., p. 79.
[171] cf. Liker (2003), p. 150.
[172] cf. Bicheno and Holweg (2009), p. 80.
[173] cf. Liker (2003), p. 150.
[174] adapted from: Hirano (1996), p. 13
[175] cf. Hirano and Talbot (1995), p. 20.

2.3.2 5-Why

In the practice of daily operations in companies, operators or managers tend to solve problems immediately on the basis of visible circumstances. The disadvantage of these approaches is that the problem will occur again and again and people get distracted from their actual work or the production flow gets disturbed up to a critical level. From the Lean perspective, this behavior is considered as waste and therefore as unacceptable, meaning that the roots of the occurring problem have to be eliminated as soon as possible.[176]

After all, the visible problem is in most cases not the main reason for the failure of a machine or process. The initial solving based on the symptoms of the problem will not be long-lasting, as it does not deal with the root cause. The 5-Why method provides an easy but also systematic and iterative approach to identify the root causes, as it encourages the enquirer to ask *Why?* until the real cause of the problem is found.[177]

Although it has been applied successfully in many companies, the 5-Why method also has some limitations: The method does not identify a root cause if the cause is unknown due to a possible lack of technical knowledge. A problem also exists when a symptom has its roots in a combination of different and independent causes. Teruyuki Minoura, former managing director of Toyota's global purchasing department, criticized the method for the fact that success heavily depends on the skills of the interrogator. He added that people often tend to deduct instead of observing the problem itself.[178]

Following a short example for the use of the 5-Why method:[179]

1. **Why did the machine stopped?**
   The fuse is blown because of electrical overload.

2. **Why was the machine overloaded?**
   The lubrication of the machine bearings was not sufficient.

3. **Why were the bearings not lubricated?**
   The oil pump did not function sufficient enough.

4. **Why did the oil pump has this problem?**
   The axis bearing was decrepit.

5. **Why was the bearing decrepit?**
   Dirt got inside the bearing.

With the help of consistent inquiry, the (possible) root cause could be found. To prevent further

[176] cf. Gorecki and Pautsch (2013), p. 94.
[177] cf. ibid.
[178] cf. Quality digest (2009), http://www.qualitydigest.com (visited 10.01.2014).
[179] cf. Imai (1993), p. 75.

machine stoppages, a filter was installed to prevent similar situations from reoccurring.[180]

2.3.3 Cause and Effect Diagram

The cause and effect diagram is also known as Ishikawa (named after Kaoru Ishikawa) or fishbone diagram and gained popularity in the 1960s, when it was used for quality management processes at Kawasaki shipyards[181]. The basic principle of this technique has been known since the 1920s. It is also part of the seven basic tools of quality control.[182]

Purpose of the cause and effect diagram is to connect a defined problem with its main causes. In subsequent actions, a root cause finding process (5-Why method or creativity techniques) for every main cause is initiated, whereby the findings of this process can be used as a starting point or a catalogue of measures for other problem solving methods.[183]

Every major branch of the diagram (see figure 2.15) represents a main category, e.g. equipment, environment, people, machines, materials, methods. These main branches need to be adjusted depending on the problem and are not a mandatory categorization of this tool, although they help as a guideline in the early phase of application.[184]

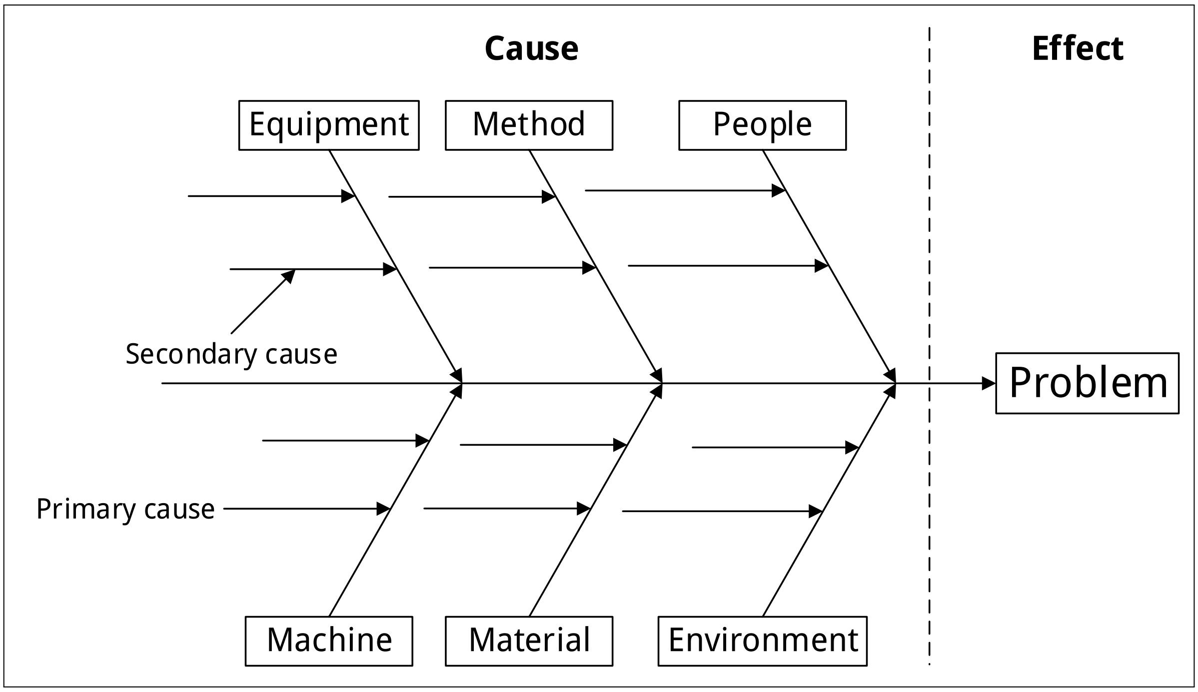


Figure 2.15: Cause and effect diagram[185]

[180] cf. Imai (1993), p. 76.
[181] cf. ibid., p. 281.
[182] cf. Tague (2004), p. 15.
[183] cf. Al-Radhi and Heuer (1995), p. 43.
[184] cf. Herrmann and Fritz (2011), pp. 149-150.
[185] adapted from: Hirano (1996), p. 13

2.4 Summary

Both methodologies, Lean Production and Total Productive Maintenance, are driven by the aim of eliminating disturbing influences within the production process that decrease the value of a product. In this process, the identification of these value-decreasing activities is the most important step in optimizing existing processes. However, it is not unlikely that the proposed actions for improvement are not supported by all employees, as they often see them as an extra burden adding to their normal workload or because they consider the current process to be sufficiently performing and thus see no need for correction. The cultural change of all employees towards the acceptance of value-increasing actions and a raised awareness of wastages of any kind is therefore the most crucial step during and after the implementation of these two methodologies. The management of the first and second level of the company have to convince their coworkers about the benefits of the far-reaching changes in the existing workflow, even if their usefulness is only visible in the long-term.

Of course, this cultural change cannot be realized in a very short time. Necessary tools and methods need to be trained and applied correctly to guarantee long-lasting results of improvement. Therefore, supporting structures should be implemented within the company's organization layout, which supervise and evaluate performed measures and, in cases of negligence, to prevent a fall back to old structures. The rating of performed actions should not just rely only on the outcomes, but more on the efforts taken by the employees. This should encourage and reward their participation on these actions and help to reduce barriers remaining in people's mind. However, the proposed need for continuous improvement related activities is a doubled-edge sword. On the one hand the supervising employees are encouraged to give sufficient time for the implementation and application of new processes or workflows, but on the other hand to address every occurring loss. To prevent an overload, the sphere of influence is needed to be limited, especially in the starting phase of a new-implemented Lean environment, on a selective choice on main topics that are most promising to improve the overall situation.

Instead of relying just on subjective ideas of employees for optimization in general, the selection of improvement activities should be based on data driven reports of the current production process state. The OEE metric system of the TPM methodology is providing hereby a profound and comprehensive data base. Based on the data obtained, it is then possible to narrow the place of the occurring losses whether it is caused by a specific product, machine or workforce. The existence of hidden (indirect) costs within the production process is often unattended, as they are not visible or tangible like defect products. But especially these costs are influencing the profitability and should be therefore reduced as soon as possible. The three single factors of the OEE value are helping to address these disturbances or wastages, whether they are displaying a direct loss (quality, scrap pieces) or an indirect loss like unnecessary downtimes (availability) and non-conformity to standards (performance). To draw a positive effect of improvement actions based on the OEE method hinges on the question regarding the collection of production process data in terms of quality and quantity. It must be borne in mind that the acquisition is not be seen as an exceptional burden or as the means of personal surveillance. Above all should be the aim to improve the situation for all participants of the production process, because only in this case the positive effects of Lean or TPM can be enabled.

3

Sealing Production Process

In the following chapter, an introduction to the company's current production process for sealing products is given. The written description of the items is based on the impression of the author of this thesis and on the statements of the production manager.

3.1 Plant Layout

The company's plant, located in an external industrial area district of Bursa/Turkey, is separated into two main buildings. The departments Business Management, Logistic Management, Purchasing, Engineering and Sales are situated in the administration building, whereas the one-storeyed shop floor is completely reserved for the sealing and anti-vibration production, including inventory stock and work preparation areas. As can be seen in figure 3.1 most of the useable area of the shop floor is reserved for the production of anti-vibration products. The installed infrastructure (electric, pneumatic, ventilation) allows a limited rearrangement of certain machines, but nonetheless it is not possible to extend the sealing production area in general.

The total shop floor area of about 9654 m^2 is separated into:

- **Anti-vibration production:** 3230 m^2
- **Sealing production**: 815 m^2
- **Rubber compound preparation:** 1355 m^2
- **Logistic center (Sealing/Anti-vibration):** 656 m^2
- **Social rooms and transportation space:** 3598 m^2

The cryogenic deflashing machines are situated in an external building on the plant site mainly for safety reasons. The nitrogen needed for this production process is stored in a high-pressurized tank (22 bar). Because of limited production area at the main shop floor it would not be possible to integrate this size (10.000 l) of tank right next to the production line in the future. The single distance between the external building and molding machines is about 110m.

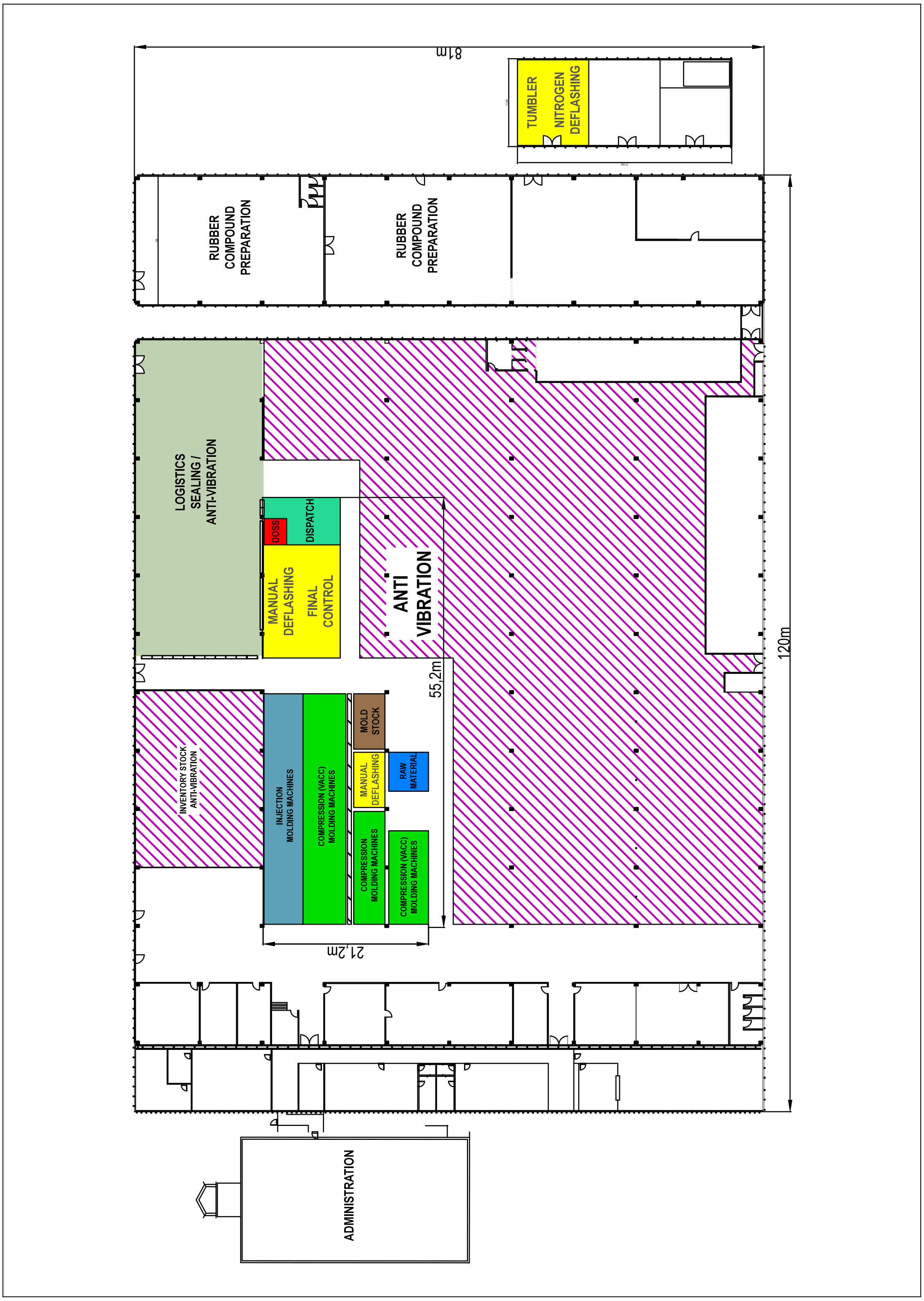


Figure 3.1: Plant layout[186]

[186] own contribution.

Sealing Production Layout

Until the end of March 2013, the complete sealing production line was located at a now abandoned subsidiary factory site approx. 40 km away from the actual plant. This relocation was carried out in order to concentrate the complete production in one place with the aim of saving redundant logistic and management costs. Table 3.1 shows the separation of the sealing production line into the five main areas. Areas marked with (E) are located in the previous mentioned external building, those marked with (S/AV) are sharing their services also with the anti-vibration production segment:

Raw Material	**Molding**	**Deflash**	**Control**	**Logistics**
Manual preparation place	Injection machines	Manual workplaces	Manual workplaces	Dispatch
Rubber compound factory	Compression machines	Nitrogen deflashers (E)	Optical control	Logistic department (S/AV)
	Compression machines (Vacuum)	Tumbler (E)		
	Mold stock Ultrasonic washing machine (S/AV)	Washing (E)		

Table 3.1: Different areas in the sealing production[187]

As can be seen in figure 3.2, a basic flow principle layout of the production process was installed, beginning with the molding machines on the left side and the succeeding processing stations like deflashing, optical/manual-control and dispatching on the right side.

[187] own contribution.

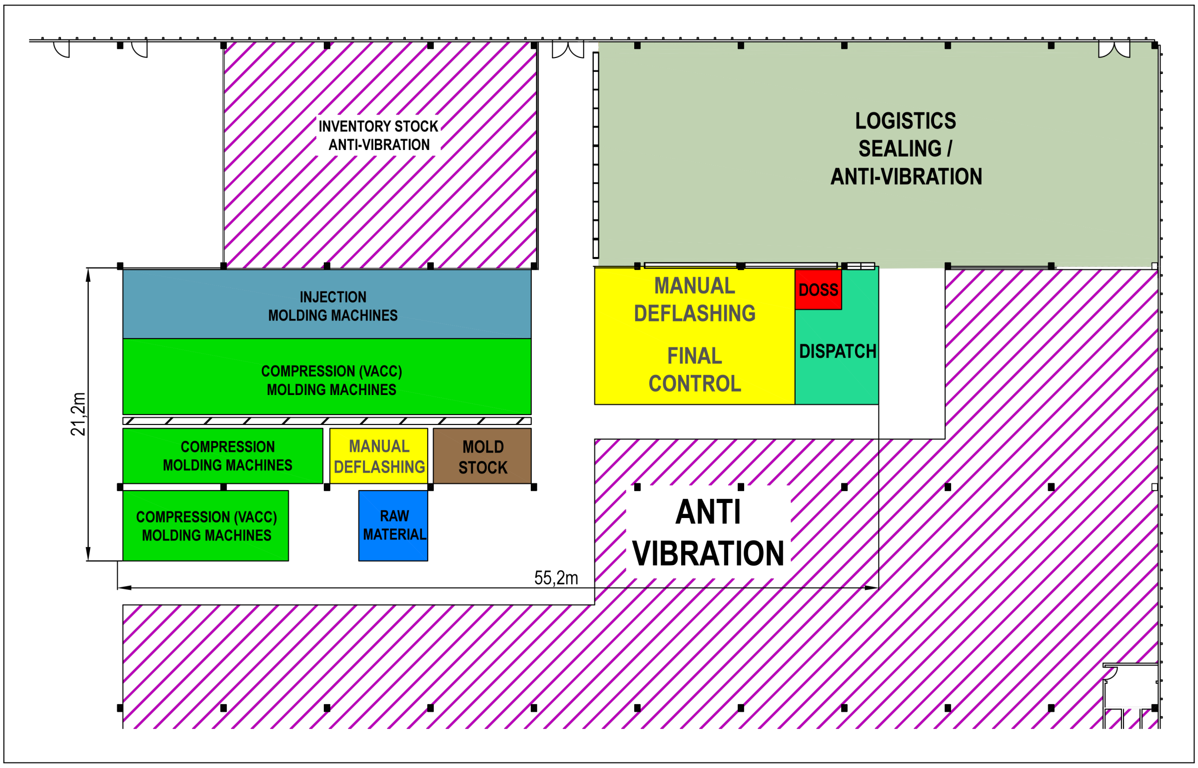


Figure 3.2: Detail view: Sealing production layout[188]

3.2 Machinery and Equipment

The following chapters are providing a quite more detailed overview about the installed machinery and different production process stations. Nevertheless, a complete and technically detailed description cannot be given.

Injection Molding

At the moment four horizontal injection molding machines are installed, which can be used with synthetic rubber compounds (main usage) or with other materials like silicone and EPDM rubber. The heated material is pressed under high pressure through a nozzle into the closed mold. In case of synthetic rubber the machine can be fed automatically by an endless rubber strap, which enables a semi-automatic production. Because of the adhesion of the molded parts to the mold surface, the operator needs to remove the parts by hand after each cycle. This can be also performed by an automatic scrubber mechanism, but this usage is not suitable for every product as for example small and thin pieces could be damaged. During the usage of non-synthetic rubber materials the operator has to manually refill the injection piston with smaller packs of the raw material after several cycles. Due to the different cycle times for each part, the operator can handle up to three machines at the same time without any big

[188] own contribution.

discontinuities.

The injection machines are mainly used for the production of O-rings, as the lead-time between two cycles is tremendously lower than it would be with compression machines. The produced amount of O-rings within each cycle depends heavily on the diameter of one of these rings. For example, the mold of O-rings with an outer diameter of 1 cm features a cavity number of nearly 200 pieces. Special sealing rings with a diameter bigger than 8 cm are produced on compression machines, as the low annual demand for such products would not justify the time-intensive usage of injection machines. The management of the company also granted the investment in three additional machines, which are expected to be installed at the end of the year 2013 and at the end of January 2014, respectively. These new machines are also designated for the production of O-rings.

Maintenance operations are only carried out by the designated maintenance department, machine operators are not integrated into any maintenance activities. The execution of maintenance operations is triggered by the ERP-system based on a periodic plan.

Compression Molding

In total there are 29 compression molding machines in use at the production site:

- 13x Compression molding machines (10x of the same type)
- 16x Compression molding machines; vacuum-supported (14x of the same type)

The main difference (beside the vacuum function) between these two machine types is the maximum molding pressure rate. The vacuum machines can supply a clamping pressure up to 300 bar, whereas the normal machines deliver a useable pressure rate only up to 100 bar. The supplied pressure rate of the machine is important for the size and inner volume of the used mold. Smaller machines can only be used for low cavity-volume molds, otherwise underfilled parts are the result, because the raw material cannot be pressed completely through over the inner surface of the mold. As automatic or semi-automatic usage of these machines is not possible, only products with a low annual demand are produced with this type of machine. One operator can handle up to four machines of this type at the same time. The raw material has to be put into the open molds by hand. A table right next to the machine functions as shelf space for material and molded parts.

Usually the raw material is delivered to the working place in small chunks. The size and weight of one chunk depend on the volume of the final piece. These chunks are fabricated either in the “Raw material preparation”-area by hand or automatically with a designated machine at the “Rubber compound factory” (only in case of synthetic rubber). Heating plates under and over the mold supply the energy for the vulcanization process. The values for the temperature of these plates and the curing cycle time depend on the desired shoe hardness of the final product. Both values are provided by the company’s own rubber laboratory, to ensure a stable quality of the produced compounds.

The vacuum function of the bigger machines is essential for the usage of molds, which feature a high cavity number or a complex geometry. Air trapped inside the mold during the compression cycle can prevent the complete distribution of the raw material. It also occurs that the air gets trapped in the inner part of the final piece, which can result in a bursting or breakdown of the piece during its future usage. Shortly before the compression cycle starts, a chamber covers the mold from the outer environment and sucks out the air.

The vacuum machines also feature a semi-automatic operation mode. The manual work is reduced to refilling the raw material and detaching finished parts from the molds with the support of pressurized air. The easiness of the detaching depends mainly on the surface quality and design of the mold. Often, the operator needs to use extra tools like small picks to separate the sticked molded parts from the mold. Therefore it is not unusual that a high amount of produced pieces are already damaged by these detaching procedures. As can be seen in figure 4.3, the majority of the scrap-related costs arise from the part failures classification “Air trapped” and “Punch”. In addition, the usage of inappropriate tools like picks is likely to damage the inner surface of the mold.

Maintenance activities for all compression machines follow the scheme of the injection machines. It should be added that 14 compression machines with vacuum support are built in a tandem construction, meaning that two machines share a common control unit. In case of malfunctioning control it is not unlikely that both machines are disturbed in their normal operation.

Raw Material Preparation

As mentioned above, several different raw materials are used for the final products. The list of possible materials includes synthetic, silicone based, nitrile and EPDM rubber. Synthetic rubber is produced at the company’s own compound factory. The base material is a polymer synthesized from petroleum side products, which is supplied by Wacker-Chemie or LANXESS. Depending on the desired physical behavior of the final product (shoe hardness, durability, stiffness against loads), the base material is mixed together with coal dust and a variety of active chemical ingredients in a rolling machine. The exact composition ratios of the additives is based on the experience of the company’s rubber laboratory and continuously performed tests (rheometer, salt spray test, durability) of every produced batch. In case of non-compliance of the raw material with the specifications given by the customer, the whole batch will be destroyed.

The synthetic rubber material is delivered to the machine workplace either in the form of ‘endless’ rubber strips (injection machines) or in the form of chunks (compression machines). The final shape of the chunk depends on the produced part and varies from stripes to clumps of different sizes. This action is carried out completely automatically by an extra machine.

Prefabricated rubber chunks are stored in a cooling room until they are needed for production.

Silicone-based or EPDM rubber materials are supplied from certified manufacturers (e.g. Wacker-Chemie). The certification is required by the customers as they want to ensure the adherence of quality compliance across the complete value chain for their products according to DIN/ISO 9000 or ISO/TS 16949. The material is delivered in a cylindrical shape with a weight of 2 kg each. For a more convenient usage at the molding machines the shape of the raw silicone rubber is changed with the help of a semi-automatic piston press, resulting in stripes with a length of approx. 75 cm. Together with a product label (containing part code and expiry date) a pack of 20 single stripes is stored in a shelf. When there is need for replenishment at the machines, the machine operators fetch the packs from its storing area and slice the pack of stripes to shorter pieces, depending on the needed volume for one production piece. In comparison to the synthetic rubber, no extra ingredients can be added to the silicone; therefore the only process parameters that can be altered are the curing temperature and time. The set values are based on experience and measurements from the rubber compound laboratory.

Mold Stock

Currently there exist four different types of molds:

- Injection molds
- Compression molds for vacuum supported machines
- Compression molds for standard machines
- Prototype molds (normally features only one cavity)

Due to their high weight, the two firstly mentioned molds are transported with the help of an electrical pallet truck within the production area. The other two mold types can be lifted by hand, as their weight is considerably lower. After usage, all molds are directly brought back to the mold stock. An optical control of the mold surface or the cleaning of wear (either by hand or in the ultrasonic washing machine) after its daily usage are not mandatory at the moment. This is done only at the behest of the molding shift leader or production leader and by automatic trigger signals, released by the ERP-System. Shift leaders are notified by the ERP user interface when the number of produced quantities reaches a predefined value for each mold.

Manual Deflashing and Final Control

The molding process technology promotes the development of excess material along the parting line of the molds. This excess material, called flash, develops because of leakages of the raw material between the two contact surfaces. Due to deformations of the mold under load, rust, wear material or manufacturing tolerances it is not possible to establish a perfect planar contact of both mold sides. Therefore a defined gap between the two mold surfaces is created in the mold-manufacturing phase around the inner and outer contour of the part. The distance between gap and contour has to be as small as possible in order to create a fine tearing line, which makes it easier to separate flash from the part.

Produced parts with flash are not accepted by customers for optical and technical reasons. Because of that, all parts have to be deflashed manually or in a machine-supported process. Most of the produced parts are deflashed manually by workers with help of tools like scissors, cutters or sand paper. The time needed for this process heavily depends on the contour and size of the piece. Parts created out of new molds are also much easier to handle than parts made out of old or dirty molds. During the deflashing process, the workers also check for faulty parts. The number of controlled and faultless pieces is entered into the ERP-system where the production planning subsystem calculates an additional production demand in order to compensate the lost amount of parts. The material of scrap parts cannot be recycled for a new production cycle as their material is already vulcanized.

Table 3.2 shows the different failure attributes of a produced part and in addition the most probable place of origin of these failures:

	Place of origin		
Defect class	**Molding**	**Deflashing**	**Molding and/or deflashing**
Air trapped	X		
Compound failure	X		
Mixing of unknown material	X		
Mold defects	X		
Mold dirty	X		
Outbreak	X		
Over cure	X		
Rubber not compressed	X		
Stained	X		
Sticking of rubber flash	X		
Thick rubber flash	X		
Unbonding	X		
Under cure	X		
Underfill	X		
Cutting failure		X	
Sandpapering failure		X	
Punch			X
Miscellaneous			X
Hole failure			X

Table 3.2: Origin of defects[189]

Currently 14 work places exist in the production area for deflash and control activities. Pre-produced or supplied items are stored in a buffer shelf right next to the deflashing area until the shift leader distributes the work orders according to the priorities defined in the shipment plan.

[189] own contribution.

Automated Optical Control

Because of their high annual demand, small size and high stringent compliance to customer specifications, O-rings and other ring-shaped parts are controlled with a visual control system, called DOSS LiteD. Featured with a load tray and conveyor loading belt, the machine can operate fully automatically, including counting. The image processing system is capable of checking 12.500 pieces per hour for their compliance regarding dimensions, inclusions, flash, concentricity and several other geometrical properties. Pieces with one of these failures are separated from the faultless parts (tolerances are predefined by the control system) and collected in a scrap bin. The maximum diameter per piece is limited to 25 mm due to the camera and processing system. Pieces provided from external suppliers are also checked by this system.

Nitrogen Deflashing, Tumbler, Washing

As already mentioned, all parts have to be freed from flash and support structures needed for the molding process. In the case of small O-rings (diameter lower than 25 mm and bigger than 5 mm) or pieces with a complex shape, a manual deflashing process would take too much time and labor capacity. To keep the deflash process time for these products as low as possible, the company makes use of cryogenic deflashing machines. The machines use liquid nitrogen to cool the pieces down to $-196\,^{\circ}\mathrm{C}$, where the flash becomes stiff. The actual deflashing is carried out by media pellets made of plastic. Parts and pellets are tumbled together in the rotating inner parts of the deflashing machine. Disadvantages of this method are the low amount of pieces, which can be deflashed in one cycle, and the high cycle time. Nevertheless, the advantages outweigh the disadvantages, as manual deflashing would not bring the desired quality and quantity.

There is also a tumbler machine without any nitrogen function. Work principle here is a vibrating drum full of small ceramic pellets. The flash is scrubbed away due to the vibration-induced movement of the pellets around the part surfaces. This machine is only used occasionally for a certain type of products. Deflashed and tumbled parts are then checked in the “Final control”-area by hand or with the DOSS control system for part failures. A small amount of parts needs to be washed after the final visual control. This is only done on customer request, mainly in cases where the parts are used in an environment with high hygiene requirements

Dispatch, Logistic

Deflashed and controlled items are stored temporarily in the dispatch area, where logistic workers divide them into the correct lot sizes and packaging types.

3.3 Production Process

The Five-stage production process (see figure 3.3) features only a small amount of value-added activities. The raw material preparation and the molding sub process are essential for the manufacturing of the different products, whereas all subsequent processes can be classified as *necessary, but non-value added (NNVA)*. Like mentioned before, these actions are either required by the customer or due to the limits of the production technology (separating, deflashing, controlling). Up to this day, the used production methodology and technology can be seen as state of the art.

The main problem of the actual process is the quick and easy identification of *non-value-added actions (NVA)*. The high amount of manual work and consequently slow work in the deflashing and control process causes hidden wastages in terms of *waiting* and *unnecessary inventory for work-in-progress (WIP) parts* (see chapter 2.1.5). Again, the amount of this wastage depends heavily on the types of produced items, which results in a varying wastage amount from day to day. Although most of the defective parts are created in the molding process, the detection of this wastage only takes place in the deflashing and control section. Therefore unnecessary workload is created for the workers, which causes additional leading times for the products.

It is possible to support the manual deflashing process through investing in new cryogenic deflashing machines or tumblers, this increases the lead times dramatically because of insufficient high cycle times and the limited loading size of these machines. Final control still has to be carried out manually as the optical scan machines cannot detect hidden failures of complex shaped objects. A decrease of the lead-time for deflashing and control can only be achieved if the creation of defective products is prevented in the first place, i.e. within the molding process.

Without doubt, the manual deflashing and control activities are the bottlenecks of the whole production. An increase of the workforce would probably reduce the lead times within in these production steps, but this approach would just alleviate the symptoms, as it doesn't reduce the amount of NNVA. A short-term effect would be the perceived visual reduction of NVAs, but nevertheless the root causes for their existence would not be identified.

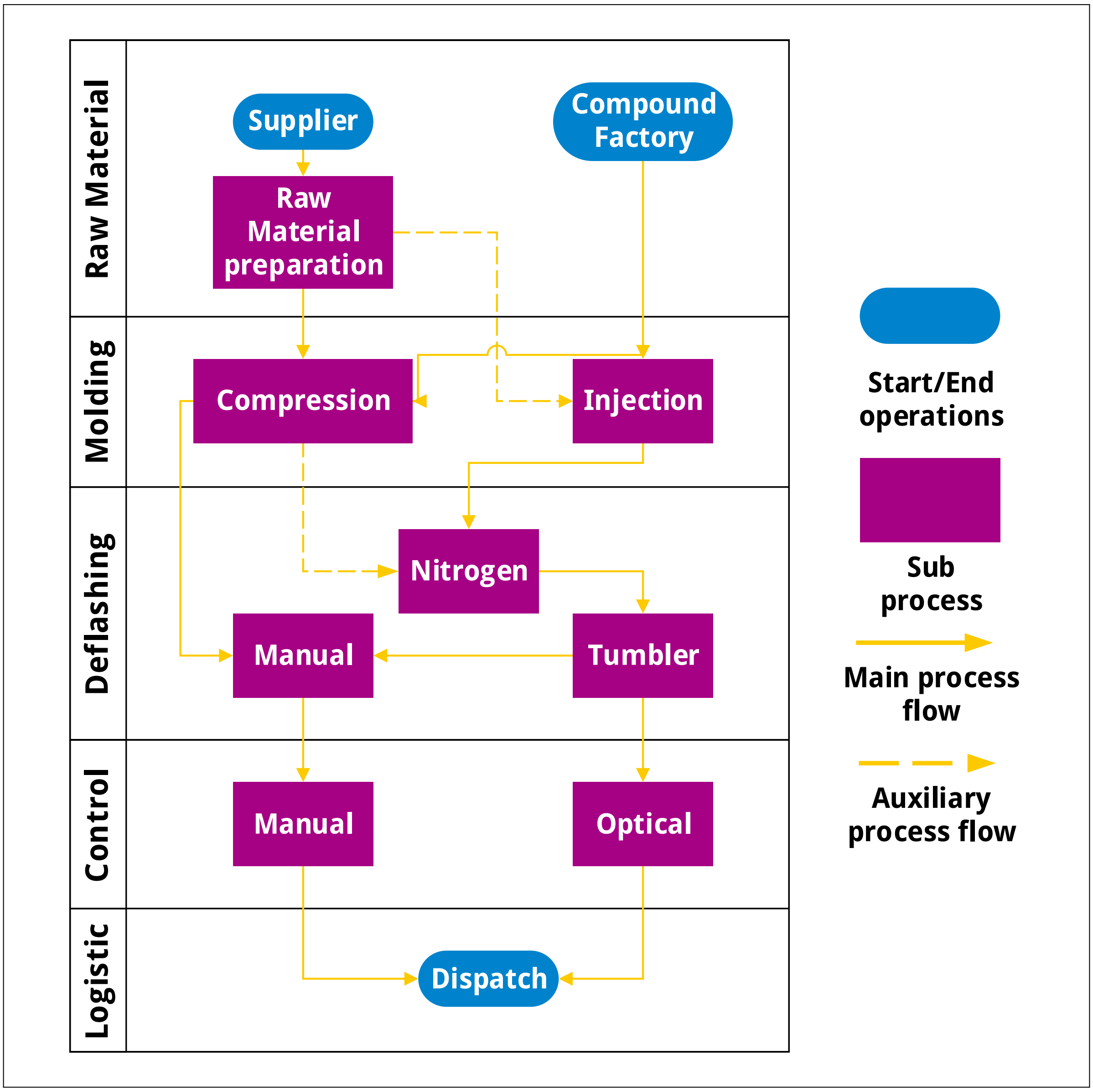


Figure 3.3: Flow chart of sealing production process[190]

3.4 Product Types

In contrast to the anti-vibration segment of the company, sealing products are only produced on customer request. After a successful prototype phase, new products are integrated into an automatic production planning system, which generates the production plan in combination with the ERP-System. A daily meeting group, consisting of production managers and key account managers of the sales office, discuss the proposed plan in order to approve the plan or alter it in cases of urgent deliveries requests.

Currently, the different products can be split up into 16 main product groups (see figure 3.4), whereas five product groups (19%) are responsible for the main share (79%) of the

[190] own contribution.

whole production output. This corresponds to the *Pareto-principle*, which states that nearly 20% of the products are responsible for 80% of the company's revenue. A portfolio strategy for selecting high-profit products or those with a high order quantity is currently under development. The necessity for this selection is also given by the current duration of mold changes and subsequent machine setups (mean value about 80 minutes per change). A high number of different products would cause a tremendous impact on the useable operating time.

As can be seen in figure 3.5, the demand of the different products varies from one month to the next. For three months, an extraordinary decline of produced items can be noticed. The first big gap between production volume and monthly average in the months of February and March 2013 was caused by the relocation of the complete sealing production line to the new plant site now used. The second gap in August 2013 can be explained with seasonal effects of the domestic and international automotive industry. During this time, it is not unusual that manufacturers close the majority of their production sites or even halt their complete production for several weeks, because of mutual company holidays. This month of low production volume (72% of the monthly average) is followed by a period of high demands beginning in September (138% of average demand).

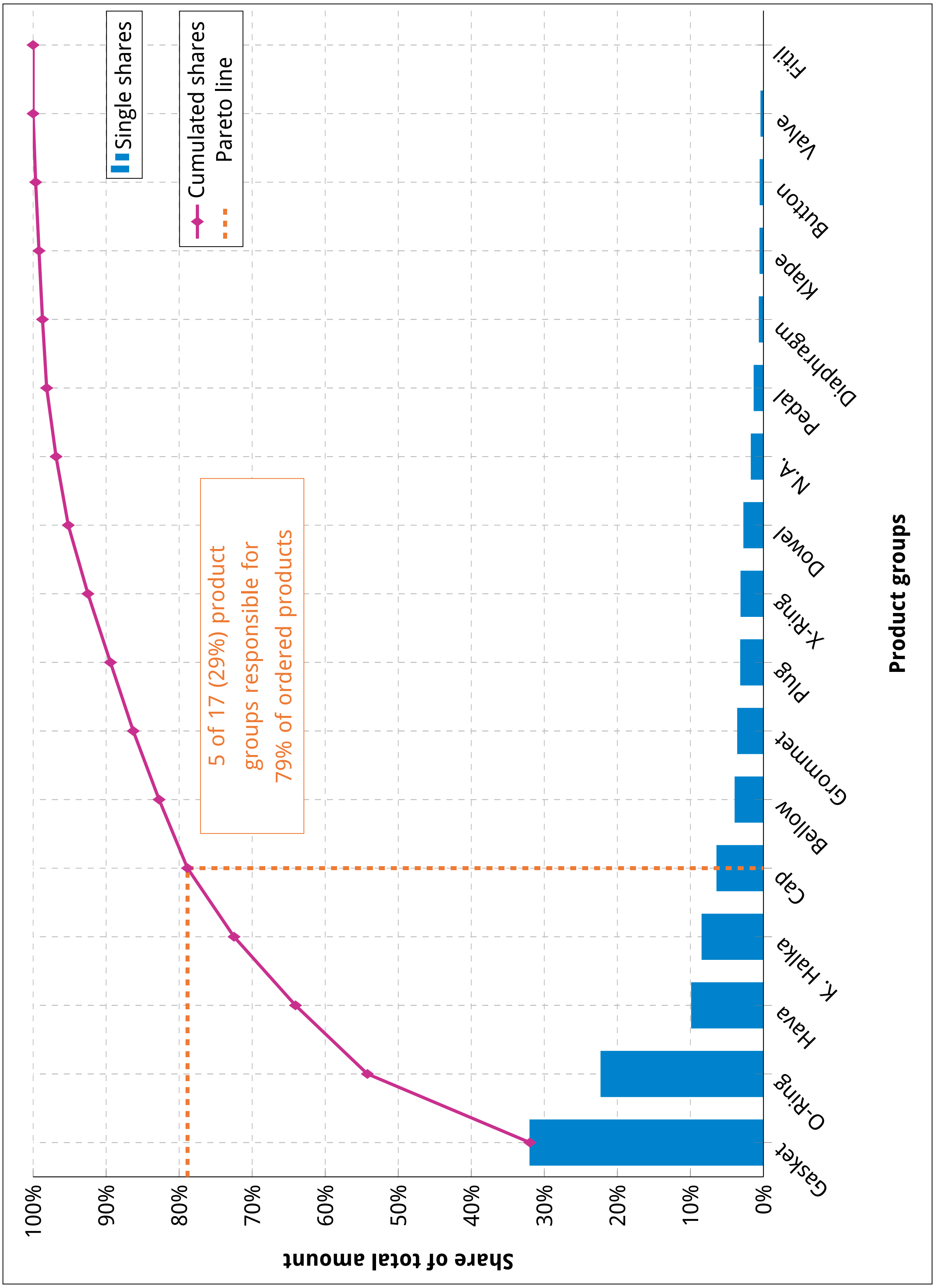


Figure 3.4: Distribution of ordered products from January till September 2013[191]

[191] own contribution.

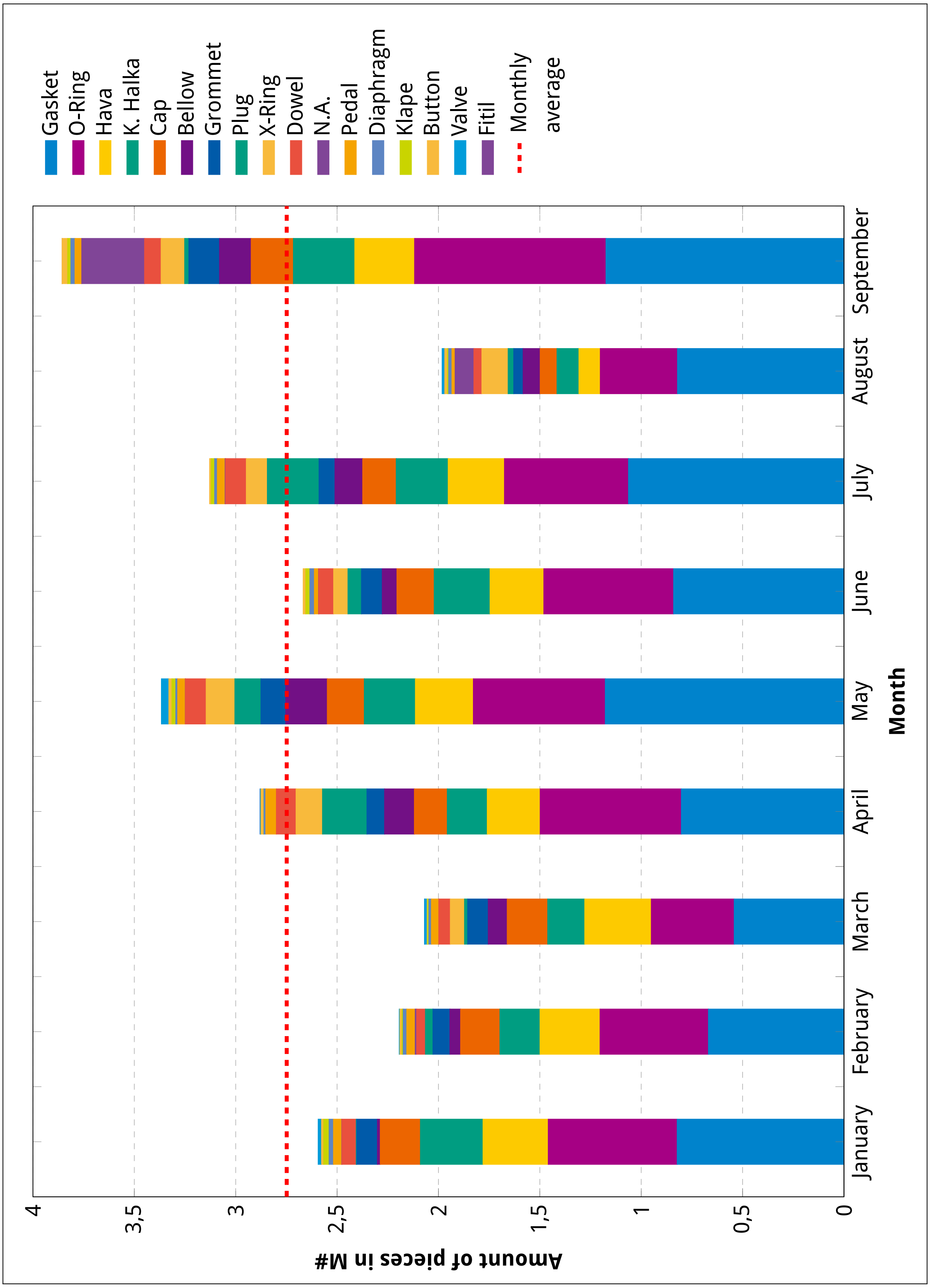


Figure 3.5: Shipped items in 2013[192]

[192] own contribution.

4

Actual Process Deficiencies

In the previous chapter it was shown that the current production process is suitable for the sufficient production of different sealing products, nevertheless the company was not able to operate the sealing production in a profitable way. In the analysis of data obtained from the ERP-System, two crucial issues could be identified.

4.1 Scrap Rate

Based on the production planning feedback system, controlled items with defects will be counted and classified according to the defect scheme in table 3.2. The tracking of scrap reasons was initiated at the beginning of October 2013; previous data sets are unfortunately not available. As can be seen in figure 4.1, the scrap rate varies over the four months (October 2013 till January 2014), far exceeding the targeted scrap rate of 6%. This rate was defined by the management, valueable information about an average scrap rate in the sealing production industry could not be found in the literature. However, following the Lean philosophy, the future goal should be to decrease the actual rate to the lowest possible value (in extreme case 0%) with the help of continuous improvement actions.

The causes for the reduction of the scrap rate in November 2013 and the subsequent fallback in December 2013 cannot clearly be identified. Possible reasons could be the specific type of produced items (shape and contour, complexity) or an unsteady performance in detecting defects. Because of limited availability of data, it would be inappropriate to draw a real trend from this analysis. A reasonable explanation for the increase of produced items can still be given due to the newly installed injection molding machines, which are mainly used for a high-count production of O-rings.

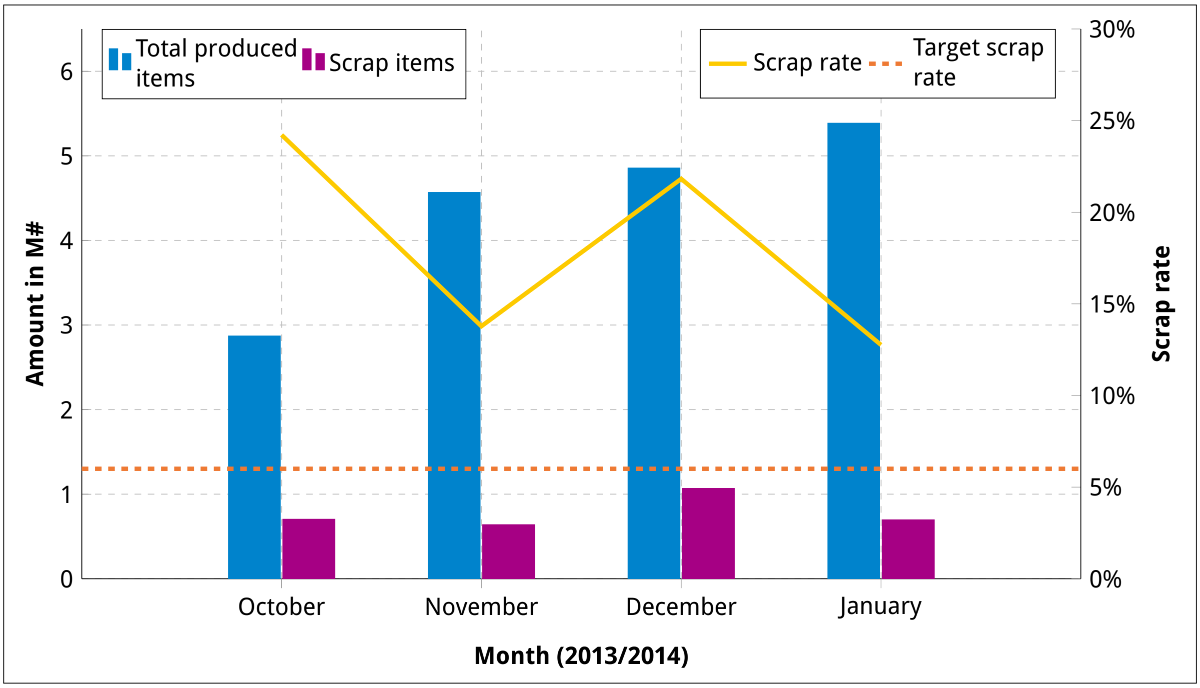


Figure 4.1: Monthly overview of produced and scrap items[193]

Every defective item causes tangible and hidden costs (see figure 2.8), which directly and indirectly influence the company's profit. Since the defective items are mainly detected at the end of the production process (Final control), they create nearly the full costs of production. This includes costs for raw material, but also process costs (molding) and labor costs (deflashing and control).

With the combination of the scrap data and cost structure tables for the different products it is possible to calculate the monthly financial loss caused by defective parts:

	Produced Quantity	**Scrap costs**	**Scrap costs per piece**
October (2013)	3.139.527 #	36.910 €	$1,17 \frac{\text{€-cent}}{\#}$
November (2013)	4.556.866 #	38.235 €	$0,84 \frac{\text{€-cent}}{\#}$
December (2013)	4.845.045 #	45.151 €	$0,93 \frac{\text{€-cent}}{\#}$
January (2014)	5.375.038 #	39.977 €	$0,74 \frac{\text{€-cent}}{\#}$

Product prices converted in Euro for a better comparability; constant conversion rate 1 € = 2,74 TL

Table 4.1: Monthly overview of scrap costs[194]

Without doubt, these numbers influence the profitability of the sealing segment tremendously. Based on the scrap costs of January 2014 (assuming constant production and scrap rate), the direct loss on profit for the company over the whole year amounts to about 471.000 € (see

[193] own contribution.
[194] own contribution.

figure 4.2). If the company manages to reduce the scrap rate by 1 percent per month down to the predefined rate of 6%, the total amount of 172.000 € (only direct costs) could be saved. An even greater reduction by 2 percentage points, would save up to 207.000 € on direct costs.

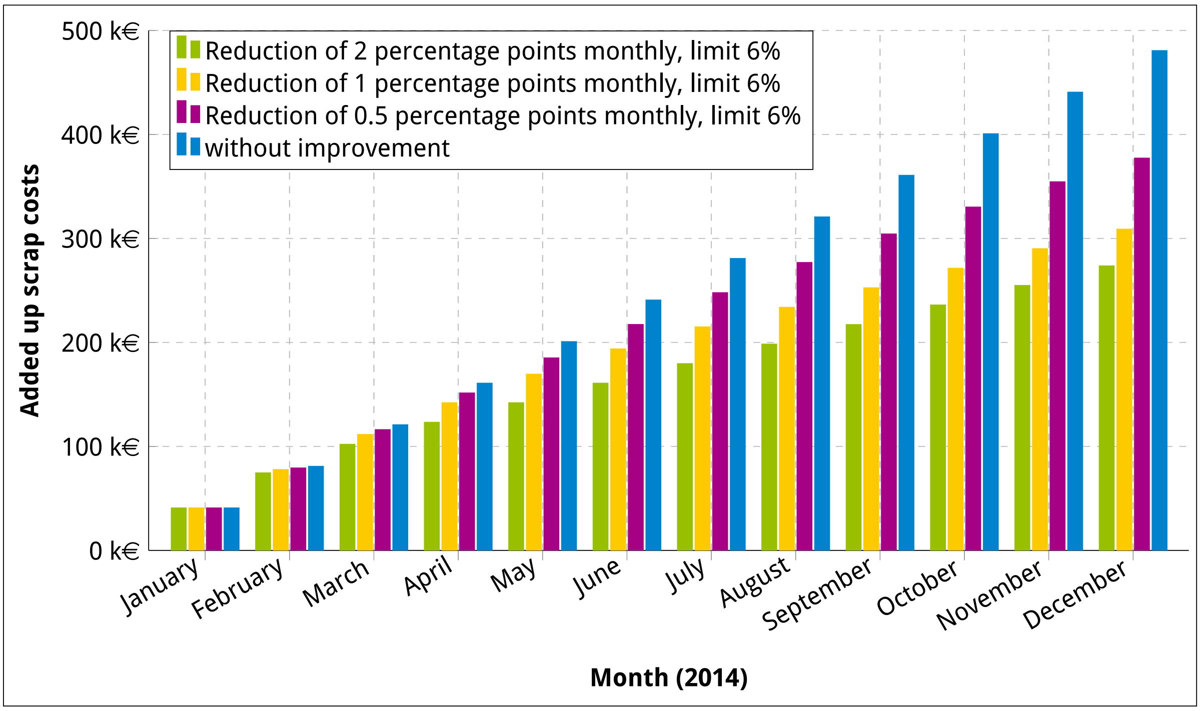


Figure 4.2: Scrap cost interpolation with varying scrap improvement rates[195]

Defective parts do not only generate direct costs, they also cause hidden costs, which are difficult to measure or calculate. The production of scrap parts creates a performance loss of the machines, as the not-useable items need to be produced again in order to reach the amount demanded by the customers. This artificially increased production volume makes it rather difficult to determine the real needed capacity for machines, but also the right amount of workforce. The problem case *Scrap* clearly addresses the waste categories *Overproduction*, *Unnecessary inventory* and *Defects* (see chapter 2.1.5) of the Lean philosophy. The reduction of the scrap rate should therefore be one of the main goals for the future, as currently a high amount of money and time are spent without creating any value for the customer.

With the help of the differentiated scrap data entered into the ERP-System, the origin of defects can be clearly identified. In figure 4.3, different scrap reasons are listed and ranked according to the costs they cause. It is easy to see that particularly high costs are generated by the defect classes *Air trapped* and *Punch*. These two classes are responsible for nearly 60% of the total costs. What is also interesting is that all listed classes (except category "Other") can be related to the molding process (see table 3.2). Possible reasons could be an inappropriate handling of the molding machines and/or insufficient machine conditions. It should also be investigated if the machine maintenance activities and the training of the operators are still adequate to maintain a high process quality.

[195] own contribution.

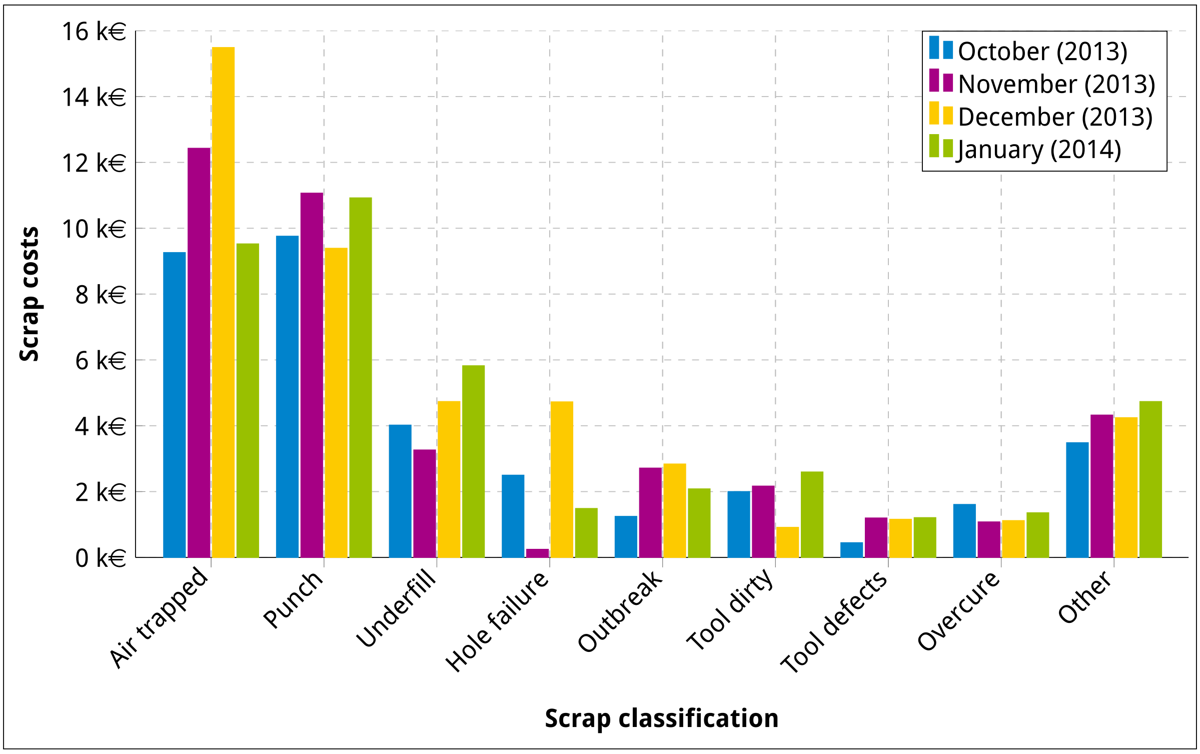


Figure 4.3: Scrap reasons[196]

4.2 Rising Delivery Delays

Another factor that reduces the product value for the customer are the rising delays in punctual deliveries of the final products. Figure 4.4 displays the dispatch situation of the company for one specific customer, based on data on the expected delivery dates and the dates on which the products left the logistic area. Most customers expect a delivery on an appointed date, but some of the company's customers (mainly automotive suppliers) allow delivery up to one or two weeks in advance. At the beginning of the year, the company managed to deliver parts up to 13 days in advance (mean value within one calendar week). After some big fluctuations in the first five weeks, the value for the mean delay stabilized, but with a steady increase during the next 30 weeks. In the low-demand month August (see figure 3.5), the company was able to change the trend in favor of a better delivery situation. However, the delivery times worsened massively between weeks 40 and 45, resulting in a high mean delay. The trend line clearly shows an upward movement with a delay level above zero. This development presents a risk for the essential attribute *Time* for the value of a product (see figure 4.6). Possible consequences of steady delays could be the loss of the manufacturing contract if the customer values punctual delivery rather than a reasonable price.

[196]own contribution.

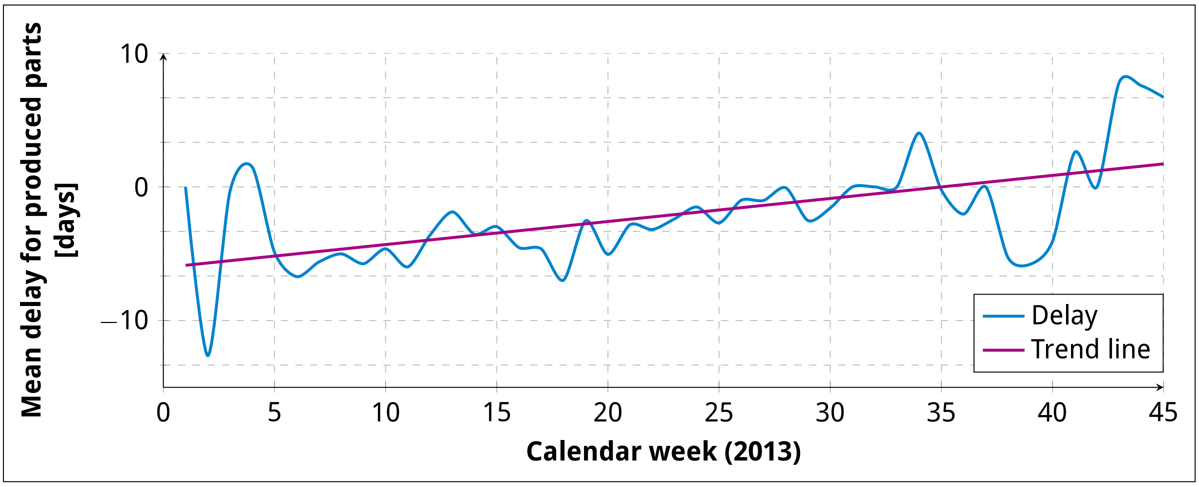


Figure 4.4: Delivery delay[197]

As the company relies on external suppliers for different items, it also needs to be analyzed if the outsourcing strategy affects the delivery situation in a negative way. The product code naming system allows a quick and easy identification of supplied items in the data tables. The blue area in figure 4.5 only displays delivery delay of in-house produced parts, whereas the purple area shows the occurrence of delays for all items, i.e. supplied and in-house production items. It can be seen that delivery delays (positive values) are mainly caused by in-house items, nevertheless supplied items can also be responsible for delays - albeit to a lesser degree. It is also important to mention the fact that supplied items have a significant and positive impact on advance deliveries. An extension of the current outsourcing strategy could help relieve machine capacity in order to improve the delivery situation, but the risks of such a strategy need to be evaluated.

[197] own contribution.

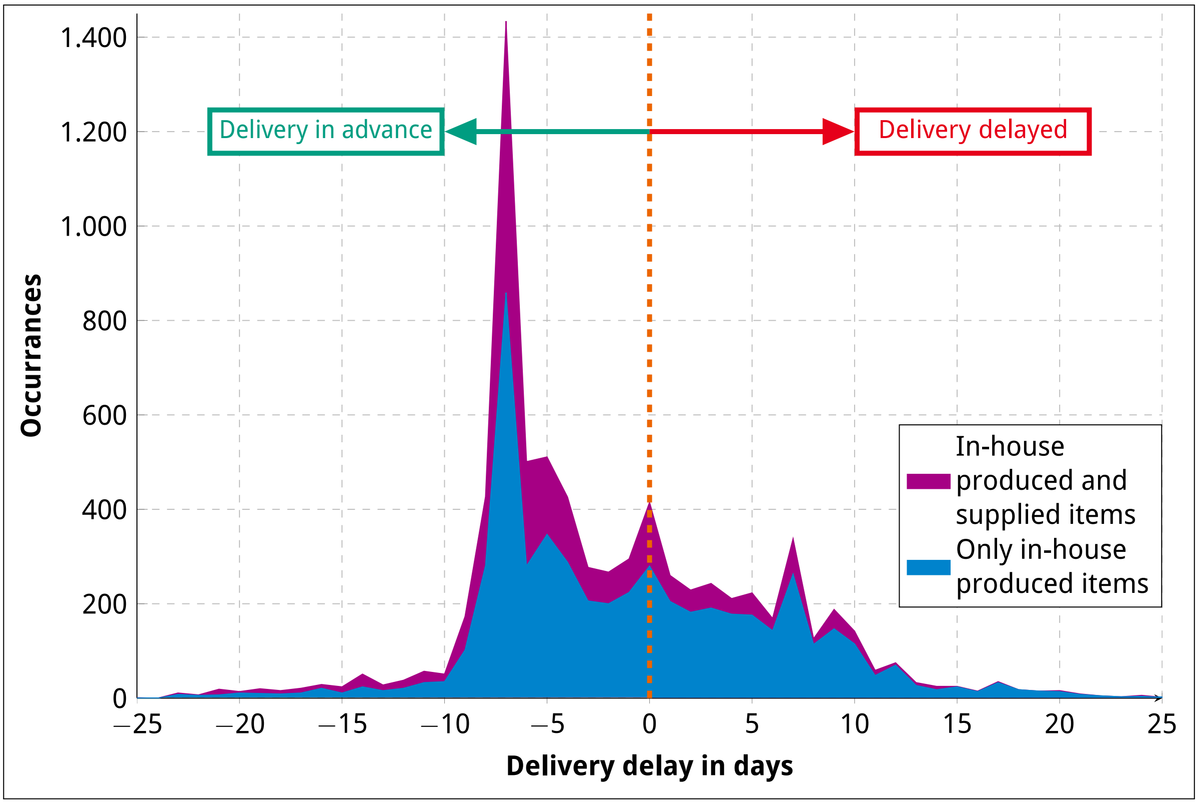


Figure 4.5: Delivery delay occurrences[198]

4.3 Summary

According to the Lean philosophy, the value of a product is defined by the customer in terms of quality, price and time. The aim of the company should therefore be to meet all three objectives and to establish manufacturing processes needed to create this value. Like it was described before, the current production process cannot generate the total value that is demanded by the customers and also impairs the profit of the sealing production. The two problems are directly connected with each other, whereby the creation of defective products can be seen as a root cause as it creates an extra burden for the subsequent operations (deflashing and control; manual and automatic), resulting in higher lead times, which directly affect the ability to deliver products on the desired dates.

[198] own contribution.

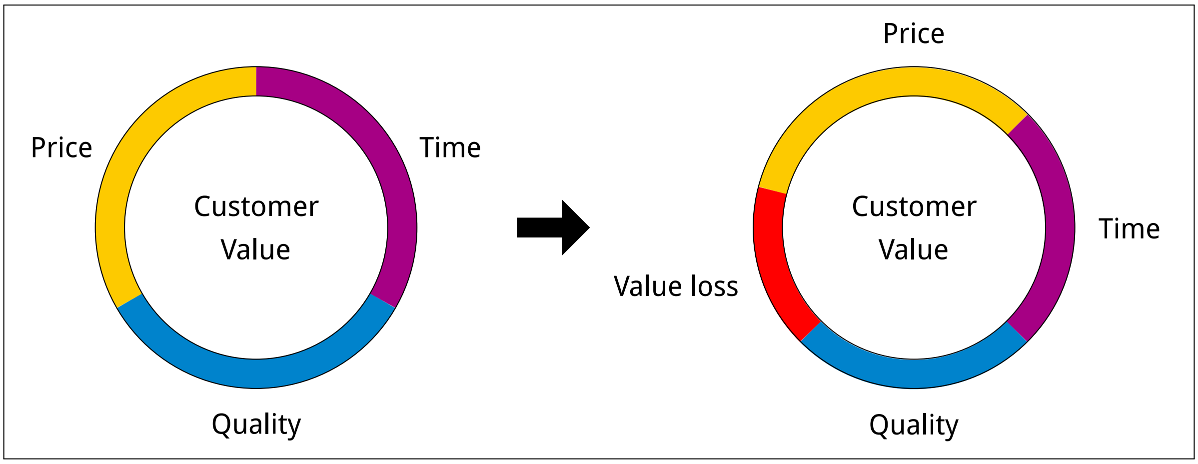


Figure 4.6: Decreased value for the customer[199]

The customers are currently not confronted with decreased quality as the control processes prevent the dispatch of defective items as much as possible. Therefore *Quality* can be seen as an internal value, whereas *Time* relates mostly to the external view of the product value. Nevertheless, the aim of the optimization phase should be the elimination of all value-decreasing activities, whether they are internal or external.

Another issue of the current production process is that it does not display at which place the losses in terms of performance or quality occur but only the total effects (scrap rate, delivery delay). Instead of a trial-and-error approach for optimization, a clear and profound assessment of all influencing factors (machines, operators, process performance) is necessary in order to rate the effect of measures that were taken to improve the situation. Another important question concerns the utilization of the machines. The utilization of 100% (see chapter 1.3) is a clear subjective statement and cannot be backed up by comprehensive data at the moment. The following phase of optimization should therefore verify if the statement is true or not and in addition check if the machining process is either done in an effective way or if the existence of hidden losses prevent an optimal usage.

[199] own contribution.

5

Optimization Phase

The previous chapter showed that two tangible problem cases influence the profitability and ability for complete value production of the sealing segment in a direct (scrap costs) and indirect way (delivery delay). These problems need to be treated as they put the economic future of the company at risk. Therefore a suitable strategy, based on the Lean methodology, has to be implemented in order to quickly decrease the effects of these two issues and thus to prevent the reoccurrence in the long run. The aim of the optimization phase should also be the identification of hidden losses (see chapter 2.2.5) within the production in order to assess which factors decrease the effectiveness. The framework in this regard is provided by the OEE metric system, which presents a transparent and comprehensive view on the current production performance.

It seems that this phase is only focused on the first process steps of production and does not include the steps for deflashing and control, although the Lean and TPM philosophy demand a holistic approach. This focus is based on the inherited error principle, according to which the loss (either performance or quality) is not likely to be caused within the step of error detection, but mainly in the previous actions. As described in table 3.2, the major source of defective items lies in the molding process. An optimization in this area of production would improve all subsequent actions as it reduces the extra burden for deflashing operations, decreases the inventory level of WIP-parts and lowers the total amount of produced parts in the first place. The other reason for this focus is the inability to innovate the deflashing process because of the lack of new technology. An expensive investment in new deflashing machines would probably slightly reduce the working load for the deflashing workforces, but it would not change the time efforts for controlling, which is now carried out in the same step.

5.1 Layout Modifications

Although the possibility of rearranging machines and working places is limited due to the installed infrastructure, several optimizations were made in order to support the manufacturing process (see figure 5.1). The biggest change is the relocation of the mold stock, which is now situated behind the injection molding line. The increased space allows for a higher number of storage shelves and a more convenient access with the electrical forklift. In the previous stock system, molds were stored in single shelves with no special order or arrangement, resulting in unnecessary search times prior to production usage. The new shelve sections can now easily be identified by consecutive labels, which make it easier to find the needed molds. The storage position of each mold is noted in a directory that is managed by the shift leaders. After usage, molds are stored in their designated place. For this new layout, no existing machine needed to be moved as the space was unused before.

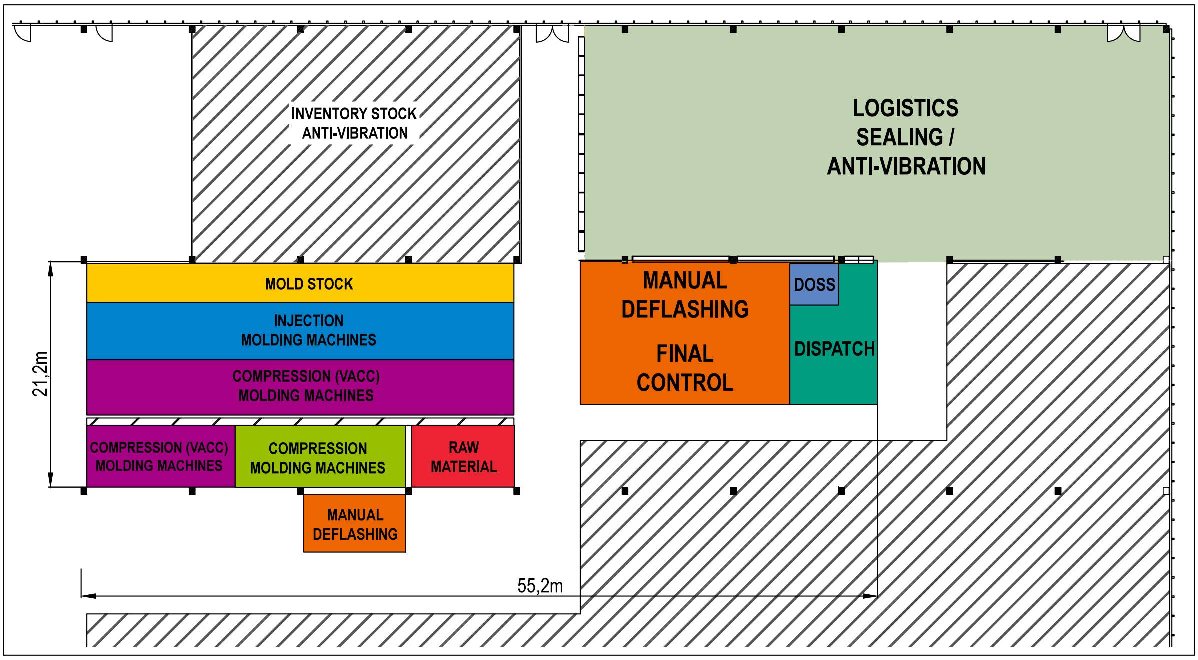


Figure 5.1: Detail view: Sealing production layout (new)[200]

Due to the freed space in the former mold stock place, several compression machines (normal and vacuum supported) could be relocated in order to harmonize the utility space and to reduce the needed footprint. Areas for manual deflashing, final control and dispatch were not modified as a relocation would create the necessity to split up the combined working area and increase the travel distance between final control/dispatch and logistic department. One manual deflashing area (three single workplaces) is still situated near the normal compression machines, as the low output rate of the surrounding machines enables the workers to deflash parts directly after the production cycle and thus decreases the lead time for several products.

As can be seen in table 5.1 the nominal space for mold stock and raw material preparation has increased heavily, whereas the needed space for machines could be reduced. The high number for the mold stock is due to the increased amount of movement area along the shelves. Due to the now easier access to molds, this rise cannot be classified as a real loss, as it enables the operators to reduce the time for waiting and searching. By reducing the space in the different machining areas, the total space saving amounts to nearly 6%. Nitrogen deflashing machines continue to be in the same place as moving them nearer to the main production area of these items is still not possible.

[200] own contribution.

Area	Before	After	Change
Mold stock	28,4 m^2	79,7 m^2	+280,7%
Raw material	25,5 m^2	30,5 m^2	+19,4%
Manual deflashing	271,6 m^2	271,6 m^2	±0,0%
DOSS	9,7 m^2	9,7 m^2	±0,0%
Dispatch	49,7 m^2	49,7 m^2	±0,0%
Compression machines	58,0 m^2	50,7 m^2	−12,5%
Injection machines	148,1 m^2	117,1 m^2	−20,4%
Compression (Vacc.) machines	224,2 m^2	157,4 m^2	−29,7%
Total	**814,9 m^2**	**767,0 m^2**	**−5,9%**

Table 5.1: Changes of production area[201]

5.2 Implementing OEE Metrics

As described in chapter 2.2.6, the OEE metric can make a significant contribution to a transparent view on the production system and helps to detect losses preventing high performance and quality levels. The working principle of the OEE system in this respect follows the mechanism of a PDCA-cycle, which is repeated continuously with the aim of implementing the metric system as a standard management and controlling tool for the company.

The PDCA-cycle (see figure 5.2) for the OEE metric system can be divided into the following phases:

- **Plan:** Data acquisition
- **Do:** Data processing
- **Check:** Data analysis
- **Act:** Definition of action plan and execution

In comparison to the normal PDCA-cycle-oriented processes, the first two actions (data acquisition, processing data) need to be performed at any time as it provides the basic data that is needed for the subsequent actions. Disruptions during the gathering of data would interfere with the aim of the OEE metric system to identify all occurring losses.

[201] own contribution.

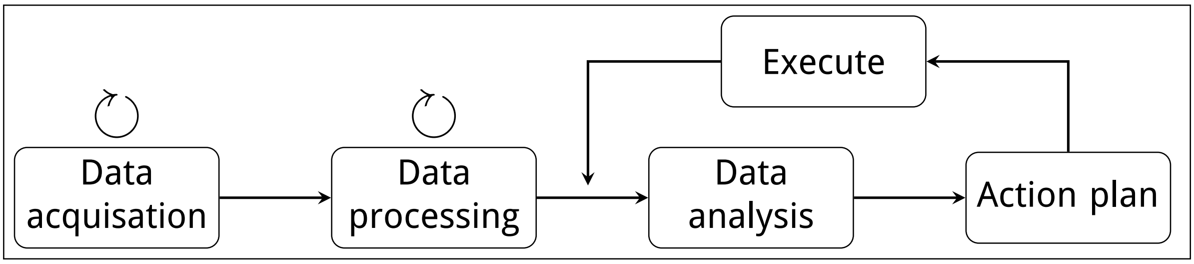


Figure 5.2: PDCA-cycle for the OEE metric system[202]

5.2.1 Plan - Data Acquisition

The company's current ERP-system already features some kind of tracking database for time losses caused by problems with machines, molds or raw material. The initial plan to use this system as a fundament for the OEE calculation had to be abandoned as the quantity and quality of the existing data were not sufficient for a complete and profound evaluation. At this time, the tracking of time losses within the production could not really be considered as mandatory activity, likewise the entry into the ERP-system depended mainly on the ambition of the shift leaders. Quick evaluations with the existing data revealed a completely unrealistic OEE value of about 90%. What added to the lack of data was the lack of knowledge by the operators - some of them being new in the company - of how to measure and report these losses in detail to their shift leader. In addition the old system was not able to track the production performance of a product. Performance goals like desired cycle counts within one shift, if any, were formulated verbally by the shift leader. A profound evaluation of these goals was therefore not really possible.

To obtain all needed information and values for the OEE calculation and evaluation, a "Production Performance Sheet (PPS)" was developed, which is to be used at every machine and has to be filled out by machine operators during their shift. At the beginning, the PPS will only be introduced in the sealing segment, but the aim of the management of LPAP is to also use this kind of performance evaluation in the anti-vibration segment of the company. Therefore additional time loss classes and additional fields are already included on this sheet. The disadvantage of this manual data collection is the extra burden for the operators. Of course, an IT-supported automatic acquisition would considerably simplify this process, but cause much higher costs for the implementation. Thus, the traditional sheet version also functions as a feasibility analysis for a possible upgrade towards IT-driven systems. The PPS can be divided into three main parts (see figure A.1 in appendix A): Basic information, performance graph and time-losses field.

[202] own contribution.

5.2.1.1 Basic Information

This part of the sheet contains all information that is needed to clearly identify every manufactured product within one shift. For this purpose, the operator has to fill in the current date and shift he or she is working in, along with product related attributes such as "Product Code", "MPS[203] and Batch number" and "Mold condition[204]". What is then added to this data is the name and the personal ID of the operator and the number of the machine used for the production. Whenever possible, the operator can simply mark the value field with a cross to make it more convenient to fill out and prevent missing or wrong information.

5.2.1.2 Performance Graph

The basic idea behind this graph is a quick and easy visual representation of the achieved production performance within one shift. With the help of cycle counters installed on every machine, the operators should mark the amount of produced items and connect the different dots every hour of their shift. In the ideal case, the single dots define a straight line with a constant gradient (theoretical maximum of cycles per hour). However, disturbances, either planned ones like breaks or unplanned ones like machine failures that occur during the production may cause an unsteady development of the performance line. In case of such a disturbance, the operator should mark the beginning and the end of the disturbance in the graph, resulting in a horizontal line. The grid separation into five-minute-cells should facilitate the marking for the operators.

5.2.1.3 Time Losses Field

In this sheet section, operators should note down different losses within a grid. In cases of a machine stoppage caused by internal or external reasons, the corresponding cell needs to be marked. As this section and the performance graph feature the same time resolution, their information can be linked, whereby the direct linkage aims at two targets: Data integrity and cause-and-effect display.

A profound OEE analysis based on the noted data is only possible if all influencing factors are completely recorded. A negative deviation of the achieved production rate from the theoretical maximum rate needs to be justified by one or more stoppage reasons in the corresponding time cells. Negative deviations in the graph without reasonable explanation are not allowed. Should such cases happen anyway during the application of this sheet, two possible reasons can be indicated. Either the operator needs to be supported with the application of this sheet, or he does not perform at the expected working level. In both cases, selective training can be applied in order to remedy these deficiencies.

[203] Manufacturing Planning System
[204] Total amount of cavities/usable amount of cavities

In compliance with the existing classification scheme, following stoppage reasons were defined (reasons marked in blue are only suitable in the anti-vibration segment).

Supply of raw materials:

- **EKS1:** Waiting for material (Metal)
- **EKS2:** Waiting for material (Bonding application)
- **EKS3:** Waiting for material (Rubber compound)
- **EKS4:** Waiting for material (External supplier)

Quality of raw materials:

- **HMD1:** Quality issues (Surface)
- **HMD2:** Quality issues (Rubber compound)
- **HMD3:** Quality issues (Metal)

Mold related issues:

- **KPD:** Mold change
- **KLT:** Mold cleaning (Manually or mechanical)
- **KLP:** Mold problem
- **THS:** Mold modification (Metalworking shop)
- **TIB:** Waiting for test
- **OLC:** Dimension control

Machine related issues:

- **MKK:** Machine failure
- **MAK:** Machine setup
- **MM:** Machine maintenance
- **ENR:** Power failure

Undefined or planned:

- **Other**
- **Break**

5.2.1.4 Production Performance Sheet

Figure A.1 (see appendix A) displays the second version of the Production Performance Sheet PPS, which is currently used in the sealing production. Red colored text and lines show sample data, which needs to be recorded by the machine operator at the beginning and during the shift. After several days of tracking with help of the first sheet version it was noticed that the operators had problems to fill in the values right properly. Therefore the sheet was redesigned to accommodate the operators, resulting in a reduction of the amount of fields and text to the lowest possible grade.

5.2.2 Do - Data Processing

Production Performance sheets are collected daily and also rated for completeness and accuracy. The tracking for accuracy should grant higher data quality and allow to detect operator deficits in data acquisition so that affected persons can be notified. Because the obtained data cannot be integrated into the existing ERP-system, a self-built Excel-based system is used as an interim solution. Nevertheless the complete integration of the OEE metric system into the ERP-system will be pursued as it better ensures data integrity. The daily production protocol, written by the shift leaders, also serves as a secondary information source if single values are missing.

The company's management is aware of the difficulties arising from the tracking of personal IDs of the machine operators, as it directly allows conclusions about their personal working performance. Nevertheless, this measurement is necessary in the early phase of the OEE metric system in order to analyze how the performing level is distributed across the whole workforce and how it influences the performance in general.

5.2.2.1 Availability Factor

As described in equation 2.2, the availability factor consists of two time-based values. The first one (planned operating time) describes the time within a shift, i.e. time in which the production can theoretically be running; the second one (downtime) displays the sum of all time losses that occurred during the production itself and prohibited a normal usage of the machines.

The planned operating time for the company is calculated by:

	480 min.	60 minutes x 8 hours per shift
−	5 min.	1st Tea break
−	25 min.	Meal break
−	5 min.	2nd Tea break
=	445 min.	Planned operating time

Table 5.2: Calculation of the Planned operating time

Other planned production standstills are not known. National or religious holidays are not considered in this calculation as they are depend on national regulations and cannot be avoided. It is possible to integrate these non-production times into the OEE calculation, resulting in a metric value called "Total Productivity". Nevertheless this method is not very common and will not be considered, also because of the fact that the company is already using a 3-shift system (thus operating 24 hours per day). Because of the significant role of religion in the employees' social life in Turkey, an additional break time for prayers of about 35 minutes on Fridays is not considered as downtime. On these days, employees can decide on whether they extend their normal lunch break or not.

The sum of the various time losses can be categorized as:

$$\text{Stoppage planned} = \text{MM}$$
$$\text{Setup} = \text{KPD} + \text{TIB} + \text{OLC} + \text{MAK}$$
$$\text{Organisation} = \text{EKS1} + \text{EKS2} + \text{EKS3} + \text{EKS4} + \text{HMD1} + \text{HMD2} + \text{HMD3} + \text{KLT} + \text{Break}$$
$$\text{Failure} = \text{KLP} + \text{MKK} + \text{ENR} + \text{THS}$$
$$\text{Other} = \text{Other}$$

Equation 5.1: Calculation of the single downtime losses

The total downtime loss is thereby:

$$\text{Downtime} = \text{Stoppage planned} + \text{Setup} + \text{Organisation} + \text{Failure} + \text{Other [min.]}$$

Equation 5.2: Calculation of the total downtime loss

The loss class "Break" is here also integrated in the calculation, but only a timespan of more than 35 minutes is counted, as the regular downtime for breaks is already considered in the "Planned operating time". Although the loss classes HMD1, HMD2 and HMD3 describe a quality issue (therefore actually a loss of quantity), they will be considered as a time loss (time between first occurrence of defective items and restart of normal operation assuming that all produced items of one cycle are defective). Single defective items will be counted during the final control anyway.

The final OEE availability factor in this respect is:

$$\text{OEE}_{\text{Availability}} = \frac{\text{Planned Operating Time} - \text{Downtime}}{\text{Planned Operating Time}} \; [\%]$$

Equation 5.3: Calculation of the OEE Availability factor

5.2.2.2 Performance Factor

Based on a predefined cycle time for each product, the maximum throughput in production can be calculated per hour or per shift. Negative deviation from this maximum value can be caused by two problems:

1. **Insufficient performance of machine operator:** Lead time for one production cycle is either increased due to unnecessary inactivity timespans of the operator or because the workload of having to operate too many machines simultaneously is too high.
2. **Mold condition:** The total number of cavities which can be used in one cycle of production is reduced because of damages to the mold.

So far, there is a list of measured and convincing cycle times for 170 products. In this case, this information is used for the calculation of the "Target Production Rate (TPR)". In cases with missing cycle time information the TPR is based on the highest differential value of the performance line within the PPS. As the evaluation of the cycle time is an ongoing process, the information is combined from time to time.

The performance loss caused by the insufficient mold condition is calculated by:

$$\text{Performance}_{\text{Mold}} = \frac{\text{Number of functioning mold cavities}}{\text{Total number of mold cavities}} \; [\%]$$

Equation 5.4: Calculation of mold condition performance loss

If a predefined and measured cycle time for a certain product exists, the performance factor is calculated according to equation 5.5.

$$\begin{aligned}\text{Performance}_{\text{Operator}^1} &= \frac{\text{Achieved production rate}_{\text{Shift}}}{\text{Theoretical production rate}_{\text{Shift}}} \; [\%] \\ &= \frac{\text{Achieved production rate}_{\text{Shift}}}{\frac{445 \text{ min.}}{\text{Duration of one cycle}}} \; [\%]\end{aligned}$$

Equation 5.5: Calculation of operator performance loss, variant 1

In cases of missing information regarding the cycle time, the performance loss induced by an underperforming machine operator is calculated according to equation 5.6.

$$\text{Performance}_{\text{Operator}^2} = \frac{\text{Achieved production rate}_{\text{Shift}}}{\text{Maximum production rate}_{\text{per hour}}} \; [\%]$$
$$= \frac{\text{Achieved production rate}_{\text{Shift}}}{8 \cdot \max \frac{\text{cycles}}{\text{hour}} \cdot \frac{\text{445 min. (8 hours per shift minus breaks)}}{\text{480 min.}}} \; [\%]$$

Equation 5.6: Calculation of operator performance loss, variant 2

The decision of which operator performance factor to use, is made by an automatic query within the Excel sheet. If both performance values can be calculated ("Maximum production rate per hour"-value is always assessed from the sheet), the factor with the lowest value is used for the ongoing calculation. Reduced operating time for machine operators due to several downtime causes is taken into account so that the decreased timespan does not interfere with operators' performance value. The final OEE Performance value is then calculated within equation 5.7.

$$\text{OEE}_{\text{Performance}} = \text{Performance}_{\text{Mold}} \cdot \text{Performance}_{\text{Operator}^{1,2}} \; [\%]$$

Equation 5.7: Calculation of OEE Performance factor

5.2.2.3 Quality Factor

The OEE factor for quality is the sum of all controlled parts which meet the specifications and are free from defects, divided by the total amount of produced parts within the working shift. Due to the workload of the operators at the machines, controlling cannot take place directly after the molding process; also the existence of flash would prohibit an accurate checking for defects at this point. Therefore the check of the products has to be carried out in the subsequent process steps. As said before, damaged or insufficient parts are counted and reported to the ERP-system. This data (itemized by the corresponding production date) is then used for the calculation of the OEE quality factor (see equation 5.8).

$$\text{OEE}_{\text{Quality}} = \frac{\text{Produced Quantity} - \text{Defect Quantity}}{\text{Produced Quantity}} \; [\%]$$

Equation 5.8: Calculation of the OEE Quality factor

5.2.2.4 OEE Factor

As shown in equation 2.1, the OEE factor is the product of the three single factors availability, performance and quality. The assessment and evaluation is currently based on a single product and not directly on the machine, as the production equipment is not specifically tied to the production of a certain product. In cases in which the machine is not producing throughout the whole shift (unavailable employee, no production planning), wildcard data is used for the data entry (Product code: XXX-XXX; Machine operator ID: 20000). Instead of entered time losses, the “Achieved Production Rate (APR)” is set to zero, resulting in a performance and total OEE factor of 0%. Based on the single factors, the total OEE factor can be calculated according to equation 5.9.

$$OEE_{Total} = OEE_{Availability} \cdot OEE_{Performance} \cdot OEE_{Quality} \; [\%]$$

Equation 5.9: Calculation of the total OEE factor

5.2.3 Check - Data Analysis

The data collection comprises 3777 single data entries obtained in the time between 19th February 2014 and 28th March 2014 (37 days). The total daily amount of returned performance feedback sheets varied during the collection phase, also the quality and quantity of information was not always 100% satisfying. Nevertheless, the data collection can be seen as comprehensive, as the majority of operators participated well during this phase.

Figure 5.3 displays the amount of returned feedback sheets per day and the average values of the achieved quality. Based on the count of installed machines (35 machines, three shifts daily), a maximum value of about 105 returned sheets was expected. Five machines were not in use for production purposes during the collection phase, which reduced the maximum value down to 90 pieces. This means that the difference between this value and the amount of returned sheets in the figure is caused by performance sheets that were not completed. As for missing sheets, no specific reasons for their absence could be found. Operators were made aware on this issue, but the problem still exists. In the case of missing sheets, the production protocol served as an auxiliary source of production data, whereas no specific operator ID was connected with the corresponding data entry (ID 10000 was used for the integrity of data). The grading system ranged from zero to three, whereas zero defines a missing sheet, one an existing sheet with a lack of important information (missing stoppage reasons or hourly production rates) and three a properly completed sheet containing all necessary information.

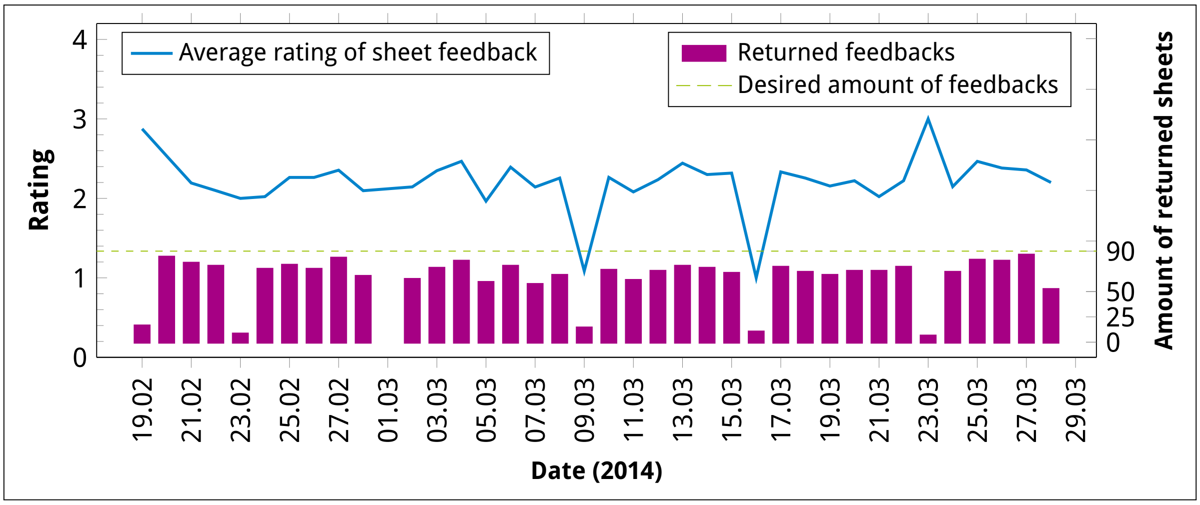


Figure 5.3: Performance sheets feedback[205]

The average rating stabilized during the collection in the range between 2 and 2.5, representing a sufficient level of data quality. Also the number of returned sheets can be considered as steady. The big decreases on 23rd, 16th and 9th March and 23rd February can be be attributed to a dramatically reduced production plan on Sundays. On 1st March, no production was planned at all.

Based on the equations proposed in the chapters 5.2.2.1 to 5.2.2.4, the different OEE factors are calculated in order to display (see figure 5.4) their shares of the total production time. The area plot only represents the values of machines, where production was planned within the shifts, whereas the line plot displays the total plant OEE level that includes all machines, whether they were used for production or not. This value is lower than the normal OEE factor, as it also comprises the unused machines with a corresponding performance factor of zero. The reason for the importance of displaying the area and line plot within one single diagram is the previously mentioned missing statistical linkage of the OEE metric system. The validity of the OEE factors is only granted if the number of producing machines is known.

[205] own contribution.

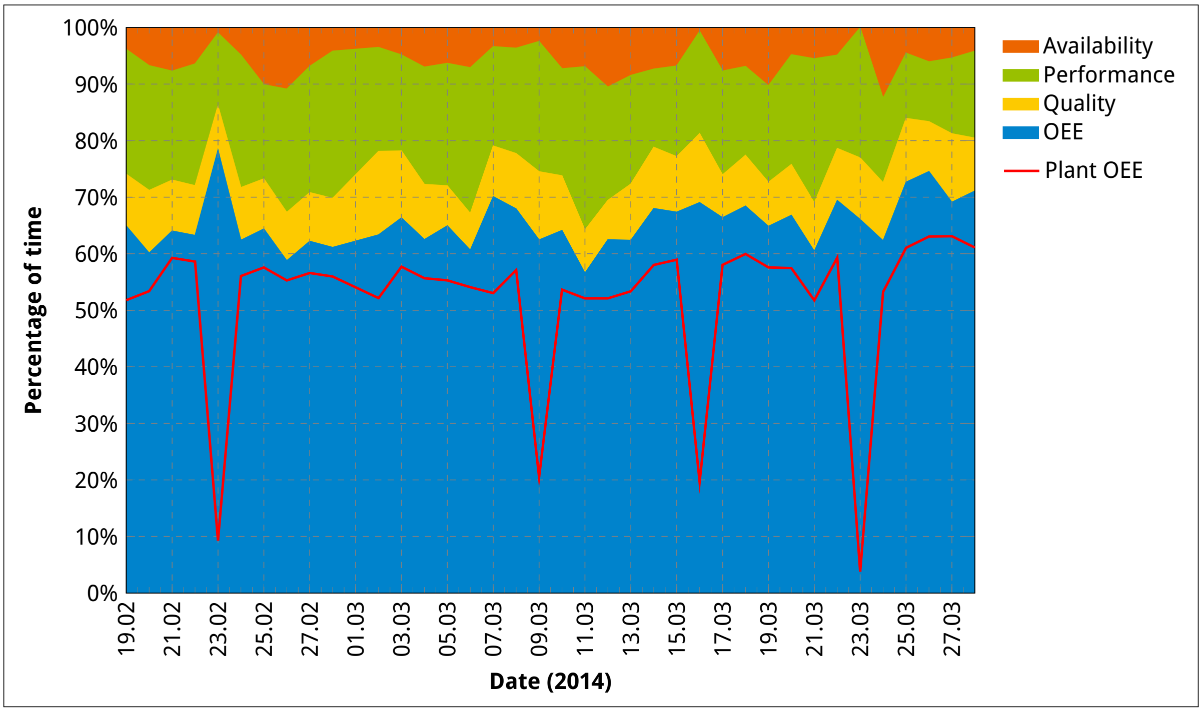


Figure 5.4: Development of OEE and its single factors[206]

Based on the temporal development of the OEE factors in figure 5.4, the ratios for availability and quality can be considered as almost stable. The performance factor, however, is not only prone to higher variability; it also makes up for the largest share of all three loss categories.

Although the achieved OEE level (mean value for the whole timespan 65%) is close to the average value of about 60% for the manufacturing industry proposed in 2.4, the real level is presumably lower, as not all losses in terms of availability and performance could be recorded because of the previously mentioned missing performance sheets. Nevertheless, the figure shows the capability of the OEE metric system to assess and evaluate direct and indirect losses within the production. In the next steps, the reasons for the existence of these losses need to be investigated in detail.

Figure 5.5 displays the development of the OEE factor (only producing machines) by shift. What is interesting are the high deflections of each shift around their common average value of 65%.

[206] own contribution.

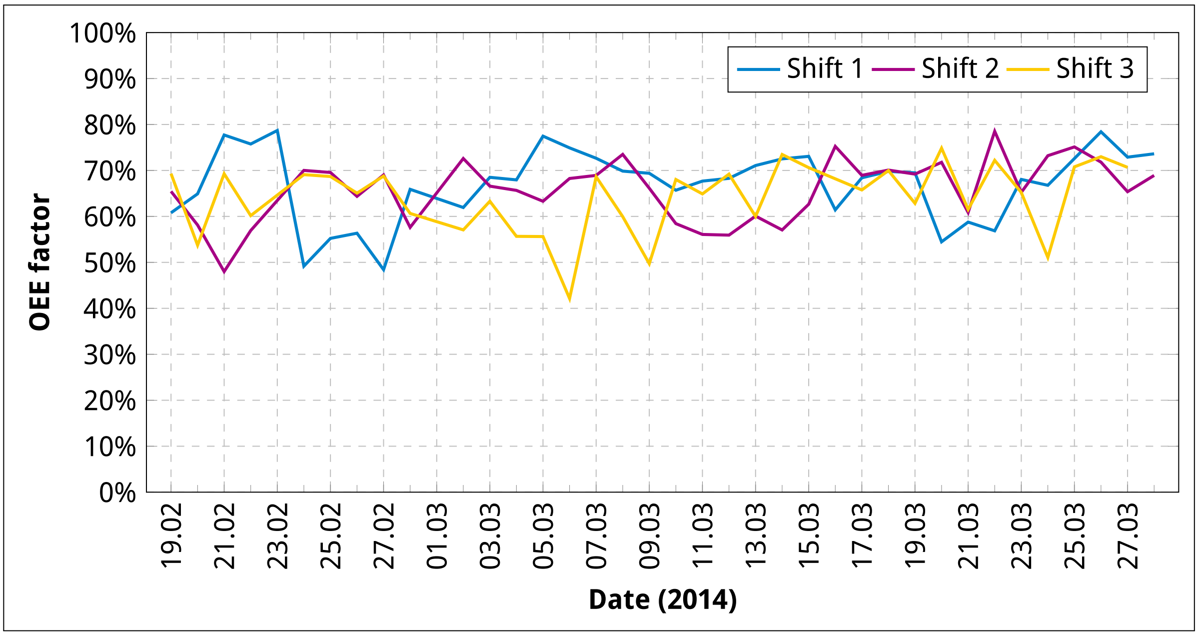


Figure 5.5: Development of OEE factor of each working shift[207]

5.2.3.1 Influencing factors and their relation to each other

The current production consists of three different protagonists (machine, operator and product) that are responsible for the creation of valuable goods. Indirect or direct losses occur whenever one or more protagonists are not operating or functioning at 100% of their predefined feasibility level. Each protagonist can thus directly influence one category of loss within the production: downtime of machines decreases the factor of availability, whereas operators are responsible for the achieved performance during their shift. The direct connection between products and quality is due to the recognition of faulty parts during final control, although other parameters could be responsible for the existence of good or bad parts.

Figure 5.6 displays the direct connection between the three protagonists and the losses of production, but it is conceivable that there also exist indirect influences beside the direct causations proposed by the OEE metric system and its equations. In the following chapters it is evaluated whether these indirect connections exist and how they influence the existence of the three losses.

The displayed figure can also be seen as a deviation from a "Cause and Effect"-diagram, which tries to include all related factors of a given problem. In this case, the low profitability of the sealing segment is defined as the problem, which needs to be decreased by using the OEE metric system as an intermediate tool for assessing and evaluating of the current production parameters.

[207] own contribution.

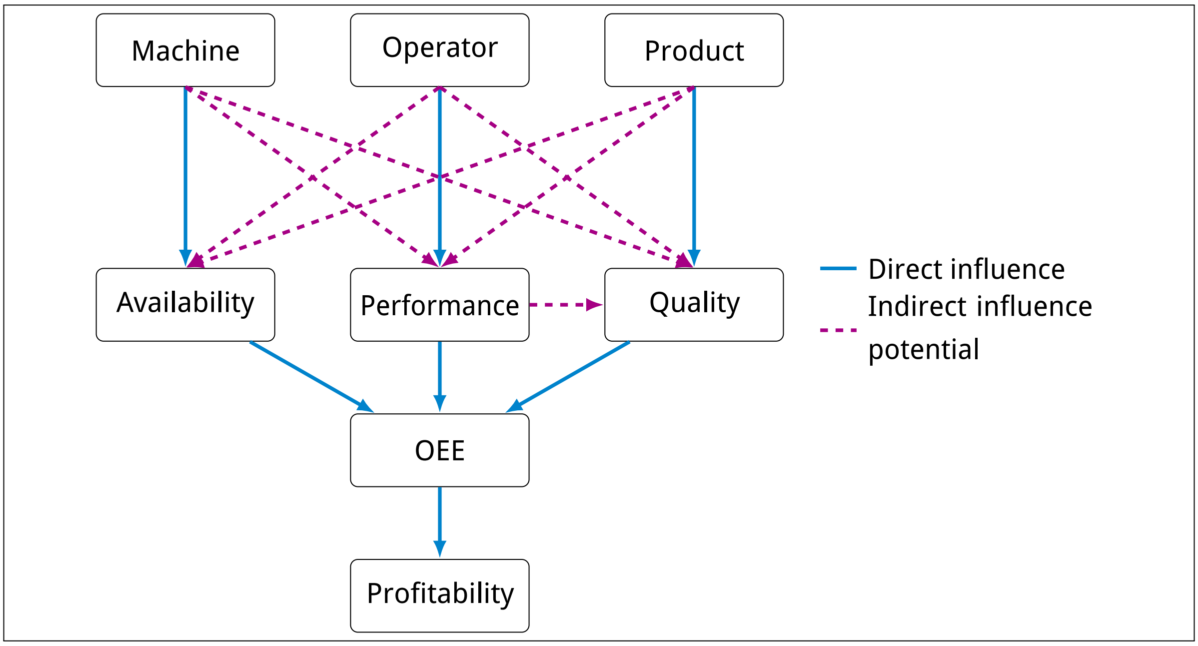


Figure 5.6: Connection between production factors[208]

5.2.3.2 Direct Influence: Machine - Availability

Figure 5.7 shows the variations of the availability factor depending on the type of molding machine. Normal compression machines have, according to the obtained data, the highest average rate of availability with 95,1%, but it has to be added that the machines KPA08-1 to KPA08-5 were not, despite some few exceptions, used for production. The level for vacuum-supported machines with 94,3% is slightly lower, but still higher as the value for injection machines with 89,8%. This group also shows a high degree of deviations from their average value (up to 6 percentage points).

[208] own contribution.

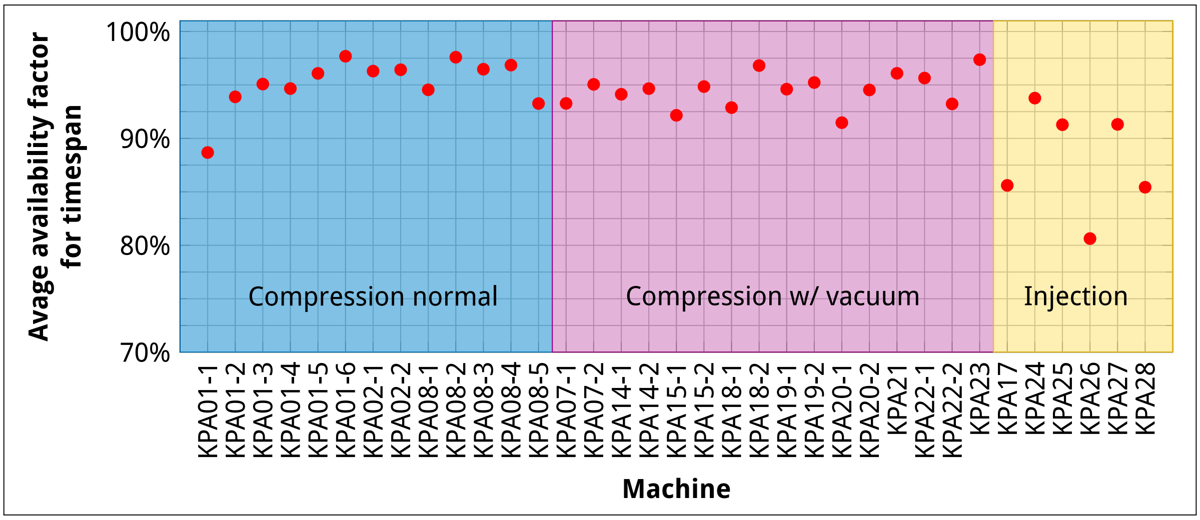


Figure 5.7: Availability factor, separated by machine[209]

Figure 5.8 displays the distribution of availability-decreasing reasons that occurred during the collection phase. The category "Other" was used during the data recording whenever no reasonable explanation for an underperforming production state could be provided. Because of its catchall function, it is conceivable that this downtime is normally generated by the other predefined factors, but without comprehensive information it is not possible to categorize them according to their original causation. The usage of the production protocol for a accurate identification of downtime causation was also not always possible.

[209] own contribution.

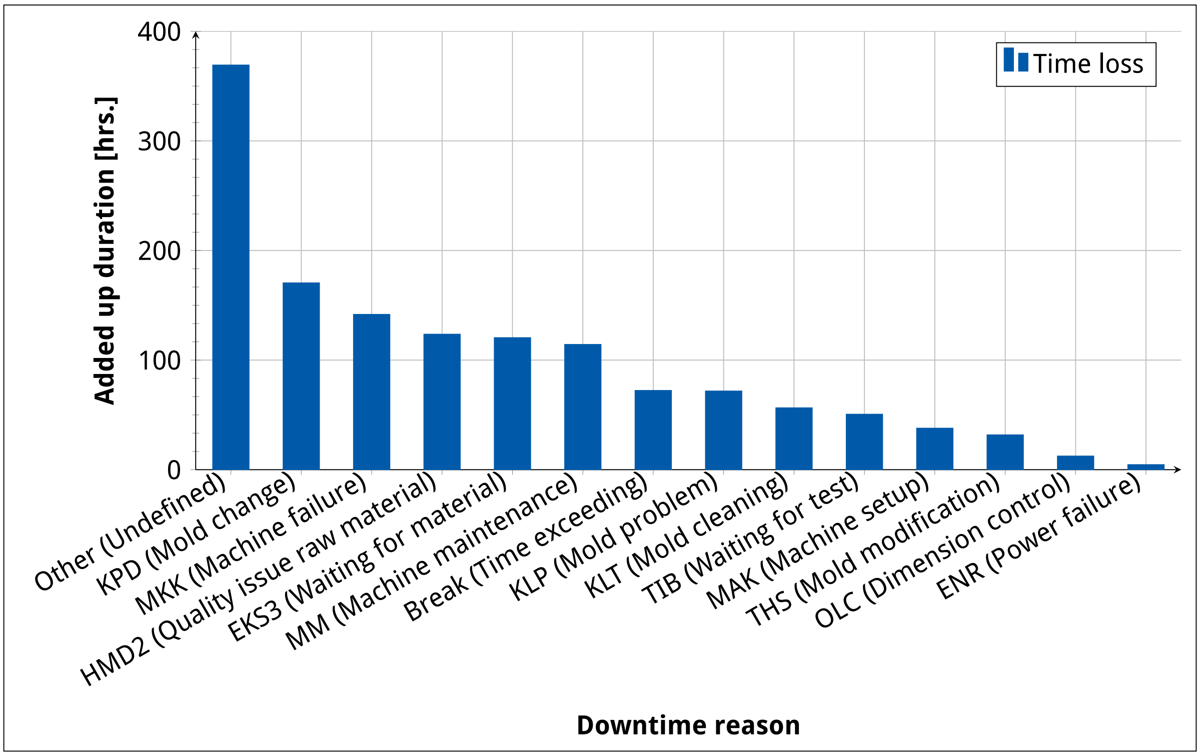


Figure 5.8: Total amount of downtime, categorized by its reasons[210]

The high value for mold changes (KPD) is considered as justified, as during the collection phase 284 different molds were used for production. A typical mold change for vacuum and injection machines takes between 60 and 90 minutes, whereas the change for normal compression machines is considerably easier (no fixtures or clamps) and takes only a few minutes. The majority of mold related downtimes (TIB, MAK, OLC) are accompanied by frequent mold changes in order to guarantee the compliance with the specifications. Surprisingly, high values for machine failures (MKK) and raw material related issues (HMD2, EKS3) are visible.

Table 5.3 displays the mean time and amount of occurrences of each downtime reason. The cause “Break” stands out in this table because of its high occurrence value of nearly 850 times. As mentioned before, this classification is used whenever an operator exceeds the normal break time of 25 minutes. Later on it is clarified whether this is a general problem concerning the entire workforce or whether it just happens to a few people. At the moment it is unclear why the raw material-related issues (EKS3 and HMD2) display such high mean values. In any case, it should be investigated how the planning of raw material preparation and quality checks can be improved in order to reduce these big ratios of unnecessary downtime. What is more, it should be examined whether the actions occasionally carried out after a mold change (TIB, OLC) can be improved in terms of duration. Downtimes caused by mold problems (KLP, THS) are mostly not predictable and therefore hard to prevent. A preventive checkup prior to production use could help to minimize these issues, although this would imply additional handling procedures that should not pause or delay the normal production.

[210] own contribution.

Downtime reason	Sum [min.]	Mean [min.]	Occurrences [#]
Other (Undefined)	22.095	131, 5	168
KPD (Mold change)	10.170	73, 7	138
MKK (Machine failure)	8.445	159, 3	53
HMD2 (Quality issue raw material)	7.360	160, 1	46
EKS3 (Waiting for material)	7.171	159, 4	45
MM (Machine maintenance)	6.800	75, 6	90
Break (Time exceeding)	4.281	5, 1	853
KLP (Mold problem)	4.250	184, 8	23
KLT (Mold cleaning)	3.330	85, 4	39
TIB (Waiting for test)	2.979	102, 7	29
MAK (Machine setup)	2.215	96, 3	23
THS (Mold modification)	1.850	205, 6	9
OLC (Dimension control)	690	43, 1	16
ENR (Power failure)	220	73, 3	3

Table 5.3: Downtime reasons and their sum, average and occurrence values[211]

As mentioned, the data show a high ratio of machine failure-related (MKK and ENR) stoppages. According to the TPM methodology, breakdowns should be avoided completely with the help of steady maintenance activities. According to table 5.3, these activities (MM) were performed, but its high average value creates the impression that normal maintenance work was not always applied. Figure 5.9 displays the distribution of downtimes caused by MKK, MAK, MM and ENR for the single machines. It has to be added that the machines KPA26, KPA27 and KPA28 have been brought into service recently and that a higher amount of machine-related downtimes is not unusual during their startup phase. In contrast to that, there are several machines which have already been used for a longer period of time in the company, and which show a high amount of serious mechanical breakdowns. The complete stoppage time for Machine KPA01-1 was generated within three subsequent shifts and is therefore not actually comparable, as it is treated as a one-time incident. Regarding the other affected machines, the use of methods like 5-Why should be considered in order to identify possible root causes for these issues, even if this would stop the normal production usage for a certain time. Otherwise, the frequent stoppages are likely to appear all over again. Energy supply related downtimes occurred, but only three times and mainly for one machine.

[211] own contribution.

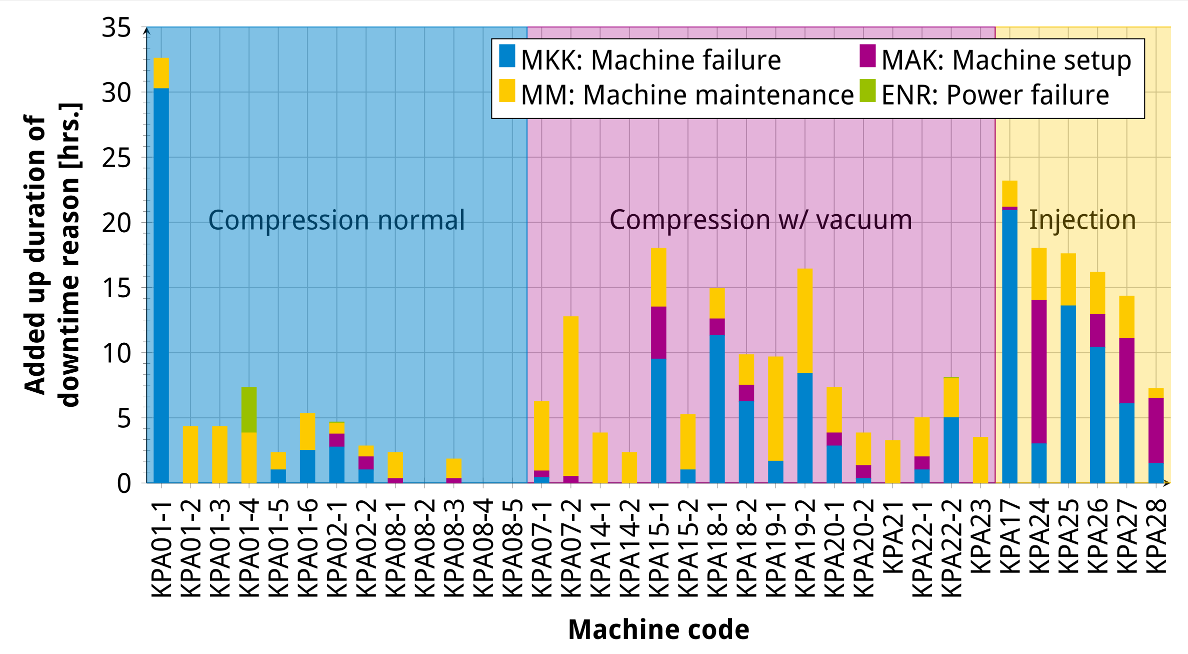


Figure 5.9: Decreased availability because of machine related downtime reasons[212]

Figure 5.10 displays the daily availability factor of each shift. Remarkable are the high differences between these days for which no reasonable explanation can be given. Every shift shows a high degree of volatility, although shift 1 (24:00 to 08:00) stabilized during the collection phase.

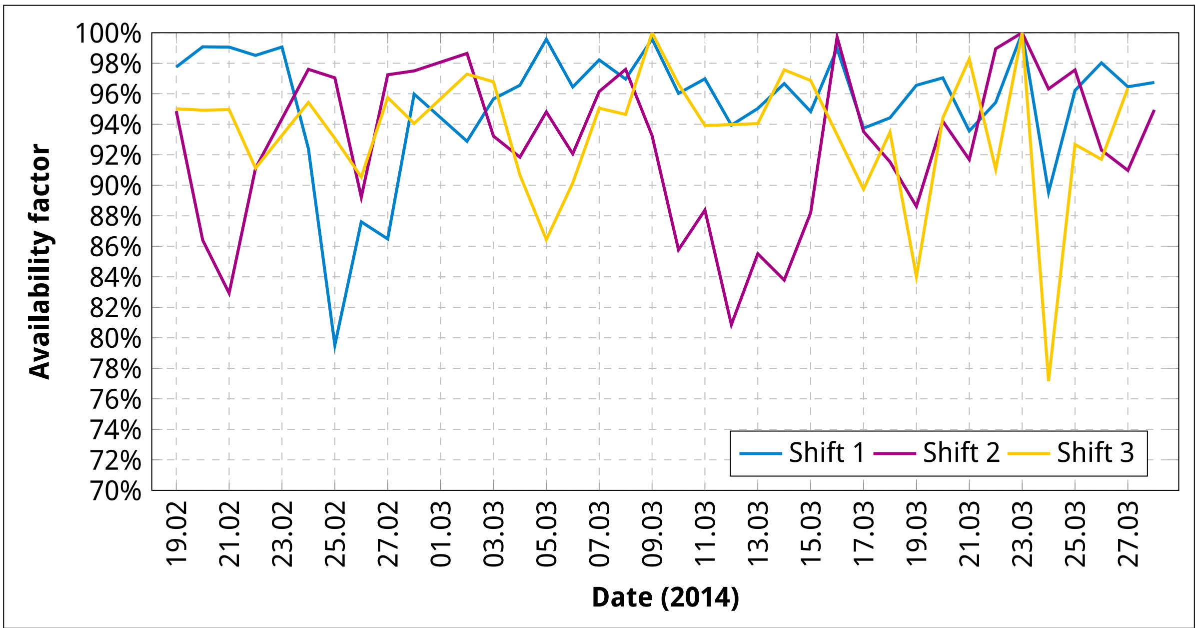


Figure 5.10: Development of availability factor of each working shift[213]

[212] own contribution.
[213] own contribution.

5.2.3.3 Direct Influence: Operator - Performance

Figure 5.11 displays the distribution of achieved working performance of the whole workforce. The majority of operators show a performance factor in the range between 80 and 86%, although a few operators managed to outperform this average value. Nevertheless, others performed quite poorly in comparison to the majority. The operators 12306 and 12315 are newly hired, which explains the lower performance factor. As mentioned before, the risk of personal performance tracking exists, but it is useful information to identify best-practice workers that are able to support their colleagues in terms of training or handling procedures. In addition, underperforming employees should be paid attention in order to support or train them additionally to achieve higher performance rates in the future. Raising the general performance is more difficult and should be part of focused continuous improvement actions

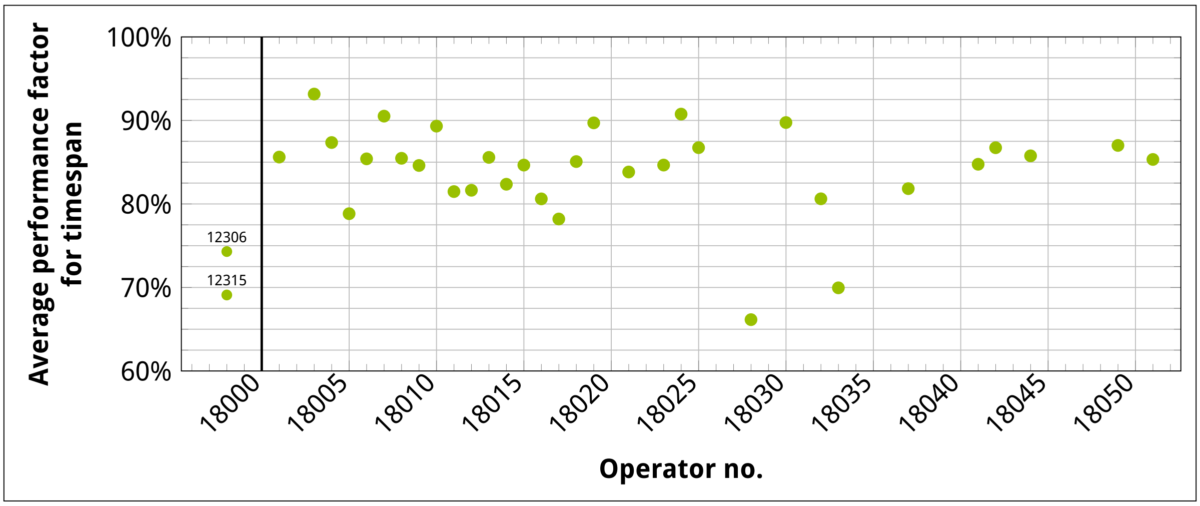


Figure 5.11: Performance factors of operators[214]

Like in the shift diagram above (see figure 5.11), the performance factor varies between the working days (see figure 5.12), but this time to a much a higher degree (up to 35 percentage points). The composition of the teams of workers within one shift is normally not changed during the week; therefore no reasonable explanation of this behavior can be given at this moment. A follow-up review will be carried out to check if this situation of high volatility still exists and which measures for a more equalized performance between all shifts should be taken.

[214] own contribution.

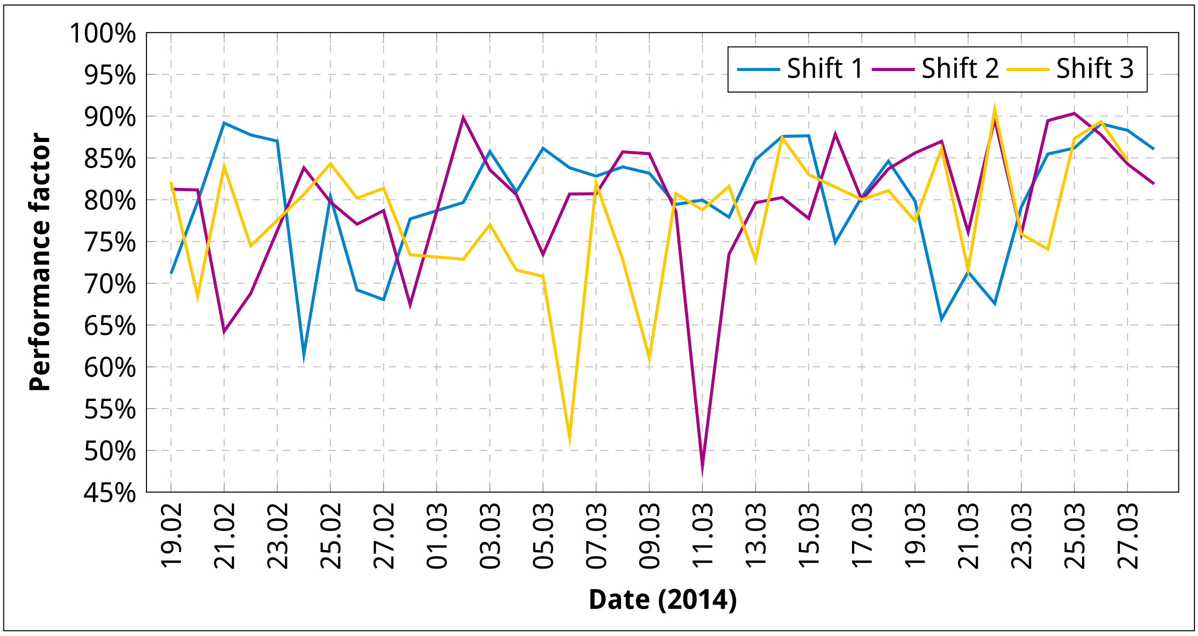


Figure 5.12: Development of performance factor of each working shift[215]

5.2.3.4 Direct Influence: Product - Quality

Based on the ERP data, the direct loss caused by scrap pieces could be calculated (see table 5.4). In these 37 days a total loss of 52.000 € was created because of the production of defective items, which corresponds to a monthly (30 days) loss of 42.800 €. This value is still high but in comparison to the quality-related losses which occurred in February (43.604 €, 5.694.217 pieces), it shows a decrease on costs per piece, as the amount of produced parts increased by 7,8% within one month. Thus, the scrap costs per piece have lowered from $0,765\frac{\text{€-cent}}{\#}$ down to $0,696\frac{\text{€-cent}}{\#}$. The increase of produced items is due to the commissioning of a new injection machine during the days of data tracking, which is mainly used for the manufacturing of high-count products like small O-rings. Nevertheless the information about the Top 10 cost drivers in terms of quality is useful for the selection of ongoing improvement actions, as they are responsible for 31% of all occurred scrap costs.

[215] own contribution.

Product	APR [#]	QF [-]	Scrap pieces [#]	Price per piece [€]	Monetary loss [€]
TMC-1654	798.795	0,87	105.027	0,05	4769,63
LMC-1195	246.680	0,55	111.067	0,04	4381,72
9L-0436	23.832	0,57	10.230	0,20	1971,53
TMC-0955	125.570	0,74	32.226	0,06	1872,38
TMC-1453	18.648	0,92	1.446	1,07	1587,22
TMC-0609	177.694	0,85	27.343	0,06	1539,41
TMC-1620	15.234	0,86	2.152	0,56	1171,45
2L-0096	87.248	0,94	5.383	0,18	1146,87
TMC-1538	69.353	0,65	24.413	0,04	1024,17
TMC-1614	14.184	0,84	2.238	0,40	892,67
Other (274x)	6.165.602		630.118		31.688,48
	$\sum$ **7.472.840**		$\sum$ **951.543**		$\sum$ **52.045,54**
per month (30 days)	$\sum$ **6.143.323**				$\sum$ **42.784,74**

APR: Achieved production rate
QF: Average quality factor

Table 5.4: Quality losses directly related to products[216]

Unlike the other shift diagrams, the quality factor diagram (see figure 5.13) shows only low or no deviations on these days. The differences occurring throughout the month can mainly be explained by the selection of products from the product plan.

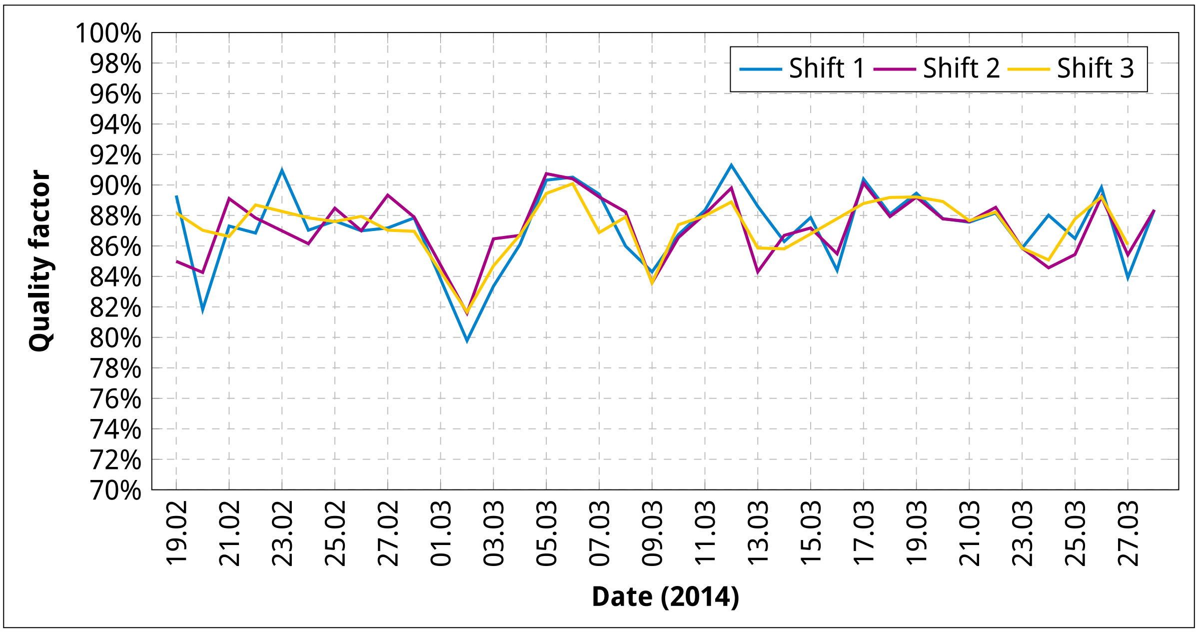
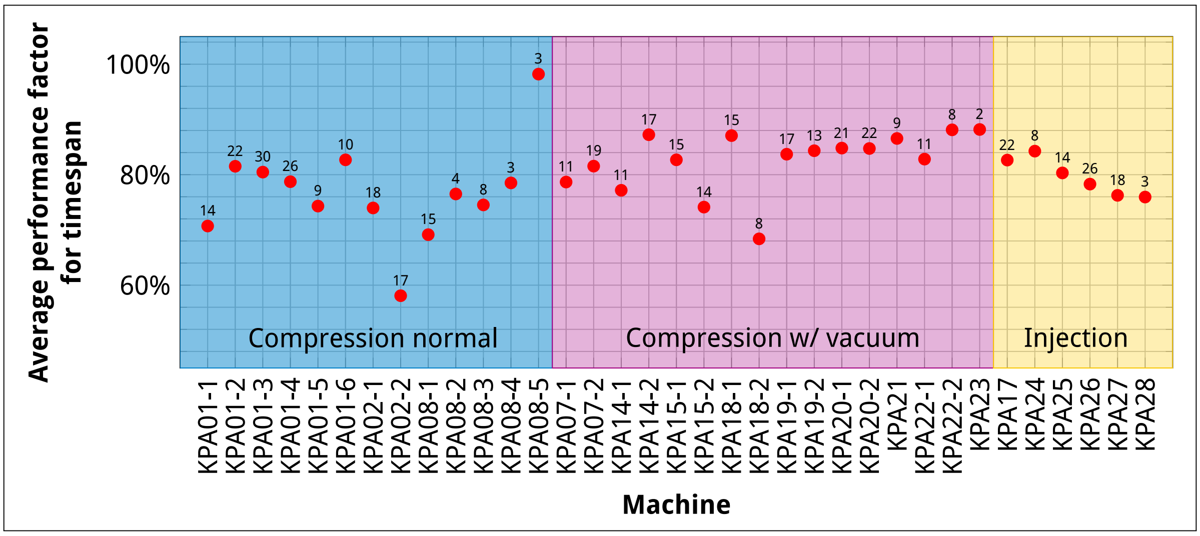


Figure 5.13: Development of quality factor of each working shift[217]

[216] own contribution.
[217] own contribution.

5.2.3.5 Indirect Influence: Machine - Performance

Figure 5.14 displays the average performance factor of each machine and the corresponding number of different manufactured products produced on this machine. In this figure, the normal compression machine shows a quite uncommon distribution. During the data entry it was noticed that every submachine in one major machine arrangement (KPA01, KPA02 and KPA08) showed the same achieved production rate per shift, which is mainly caused by the subsequent handling for loading and deattaching by the operator. The data of performance factors shows that on these machine arrangements products with highly different cycle times are produced at the same time. The common performed cycle time is given by the product with the longest cycle time and therefore increases the lead-time of all other products. In general, the average performance level of the normal compression machines is the lowest of all types, as all procedures have to be conducted manually by the operator, whereas the other types of machines support the user in many ways by an automatic opening and closing of the molds. Regarding the vacuum-supported machines it must be investigated why there are such big differences between several sub-machines (KPA14, KPA15, KPA18). The other vacuum machines show less deviation. Unexpected are the low performance rates of the new injection machines (KPA26, KPA27 and KPA28), whereby the average performance factor of KPA28 only relies on three different products and is therefore not directly comparable with machines, which feature a higher number of different manufactured products. One possible explanation for the differences between the machines could be that the new machines have not yet been optimally programmed, which opens room for improvement in the future.



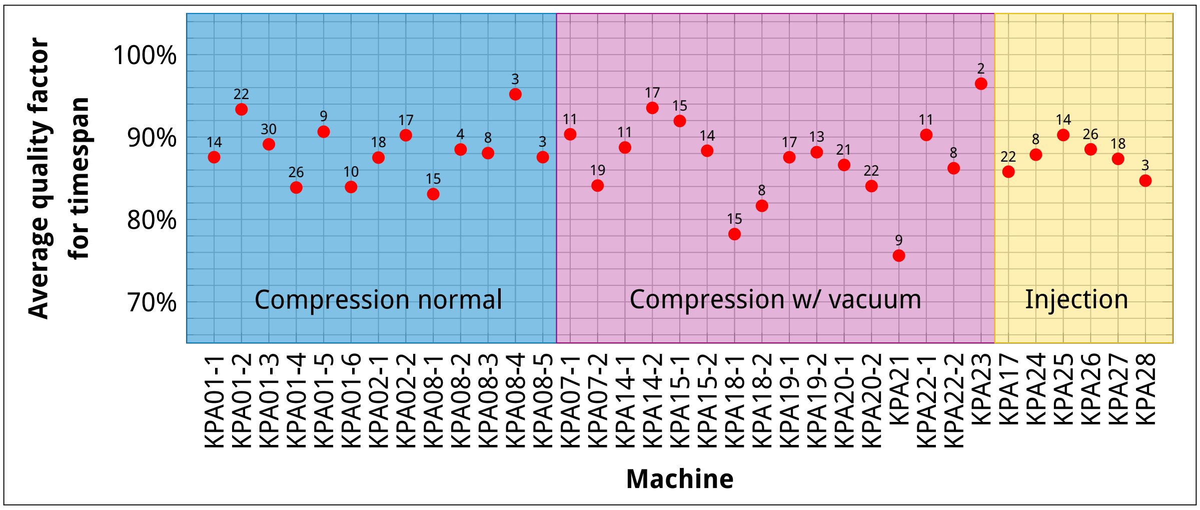
Labels above marks indicate number of different produced products on the corresponding machine

Figure 5.14: Performance factors of machines[218]

[218] own contribution.

5.2.3.6 Indirect Influence: Machine - Quality

The quality factor distribution for the machines shows a more uneven composition (see figure 5.15). Again, it should be checked if the differences within each major machine arrangement are caused only by selection of manufactured products or if the maintenance level is inappropriate for the production of value-added goods. A convincing statement about a machine-dependent quality factor can only be made after a longer period of data tracking, although these machines, which currently have a low quality factor, could be selected for an additional overhaul inspection in a timely manner.



Labels above marks indicate number of different produced products on the corresponding machine

Figure 5.15: Quality factors of machines[219]

5.2.3.7 Indirect Influence: Operator - Availability

As could be seen in table 5.3, the downtime reason "Break" has a big share of the total availability factor. Figure 5.16 displays its place of origin across the whole workforce. It can be said that the break times are frequently exceeded, though in a small scope. The management needs to decide if and how they should react to this problem. An enforced tracking and direct communication of these break extensions bears the risk of decreased motivation on part of the employees, but this availability loss should still be measured and evaluated to prevent a negative development of this value. It has to be added that break extensions on Fridays are not included in this calculation because of the extra granted break time for prayers.

[219]own contribution.

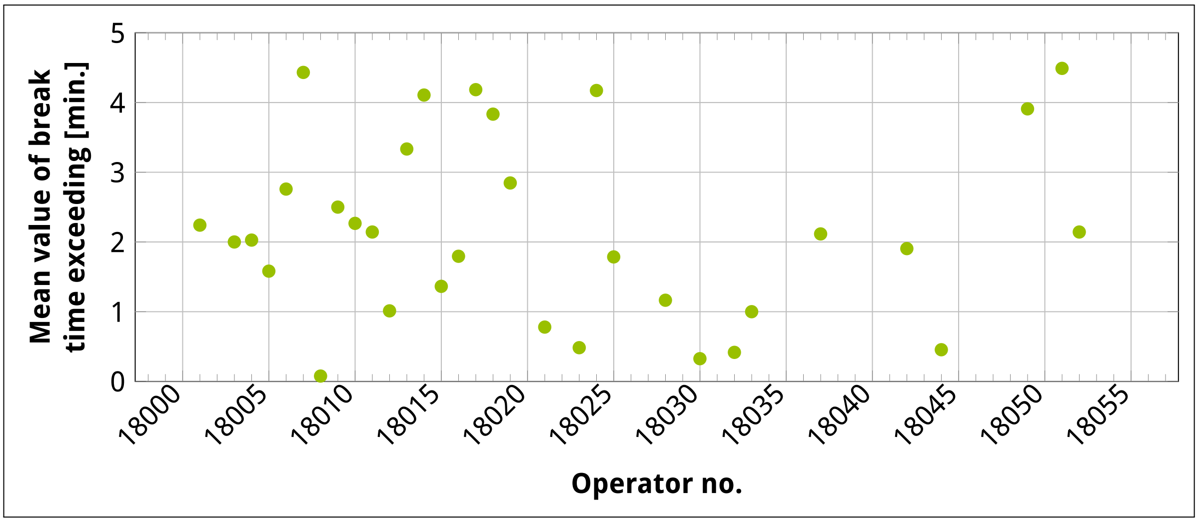


Figure 5.16: Availability losses due to exceeding break times[220]

Without doubt, the existence of the category "Other" is ambivalent due to its catchall function and the deception of the original causes. But nevertheless, it can be seen as a metric for the state of OEE tracking implementation. High values for this category can point to deficiencies in the knowledge transfer between shop floor employees and superiors regarding the purpose of the OEE tracking, whereby ongoing trainings and greater exchange between them should minimize these deficiencies. An extension of downtime categories to document the loss origins in greater detail is also thinkable, but the risk of a complication is given. Figure 5.17 shows which operator was prone to filling in the feedback sheets incorrectly or insufficiently, but the usage of this information should serve as an indicator for possibly badly transferred knowledge and not as tool for penalization.

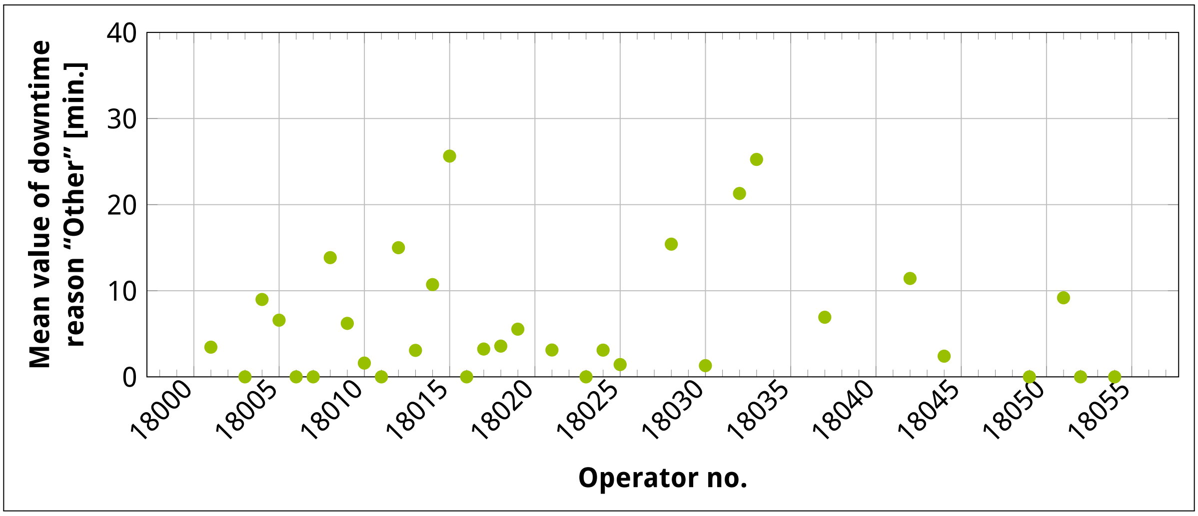


Figure 5.17: Distribution of downtime cause "Other" dependent on operator[221]

[220] own contribution.
[221] own contribution.

5.2.3.8 Indirect Influence: Operator - Quality

What is also likely to conceivably influence the quality of products are the working and handling procedures of machine operators. Figure 5.18 displays the average quality factors of each operator. As can be seen, no high deviations from the average value about 87,4% can be observed for the whole workforce, which means that there is no great influencing potential. The quality factor mainly depends on the product itself

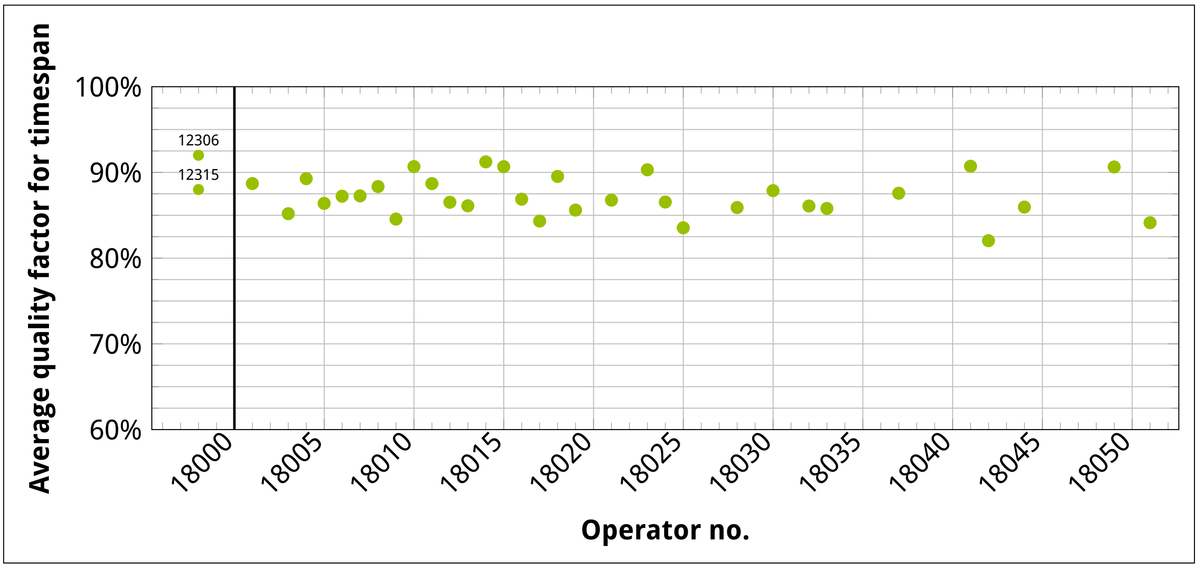


Figure 5.18: Quality factors of operators[222]

5.2.3.9 Indirect Influence: Product - Availability

As could be seen in figure 5.8 and table 5.3, product-related downtime categories have a big influence on the total availability factor. In this respect, it is important to distinguish, as some stoppage occurrences should be evitable at any stage of the production process. This list includes the categories EKS3 and HMD2, whereby the reasons KLP, THS, TIB and OLC are either non-predictable or necessary due to mold changes (KPD). Table 5.5 summarizes the stoppages in relation to the respective corresponding product and displays the high amount of evitable time losses, which are responsible for 41% of the total sum. Interestingly, within the evitable loss structure the insufficient provisioning of raw material (quantity and quality) for only ten products caused 53% of these time delays.

[222] own contribution.

Product	EKS3	HMD2	KPD	KLP	THS	TIB	OLC	Time loss	Evitable time loss
	Evitable		Inevitable						
	[min.]	[min.]	[min.]	[min.]	[min.]	[min.]	[min.]	[hrs.]	[hrs.]
TMC-0881	420	930	-	-	-	60	-	23,50	22,50
9L-2768	770	60	60	-	-	20	-	15,17	13,83
TMC-0609	625	60	60	360	-	324	-	23,82	11,42
TMC-1635	220	460	-	-	-	-	-	11,33	11,33
TMC-0872	405	240	-	-	-	-	-	10,75	10,75
LMC-1746	-	600	-	-	-	-	-	10,00	10,00
2L-0096	-	565	750	-	-	300	60	27,92	9,42
3L-5003	260	200	90	-	-	30	-	9,67	7,67
1L-0232	445	-	30	-	-	-	-	7,92	7,42
9L-2965	-	445	-	-	-	120	-	9,42	7,42
Other (274x)	3.786	3.800	9.180	3.890	1.850	2.125	630	421,02	126,43
							$\sum$	**570,50**	**238,13**

EKS3: Waiting for raw material
HMD2: Quality issues raw material
KPD: Mold change
KLP: Mold problem
THS: Mold modification
TIB: Waiting for test
OLC: Dimension control

Table 5.5: Availability losses due to product related downtimes[223]

Due to the high ratio of raw material-related stoppages, there is a need for a more detailed analysis of the extent to which the type of material plays a role for this availability decrease in order to see if the problem rather relates to the internal material preparation of rubber (compound factory) or to the supplied materials from external suppliers (silicone based rubber). In both cases it also needs to be checked if the time delays (EKS3) for supplying the machines are arise from internal miscommunication or from non-availability of materials caused by disturbances in the order chain. The same analyses need to be performed regarding the quality of raw materials (HMD2). In this respect, it needs to be determined whether a different sourcing strategy can minimize the occurrence of this problem.

[223] own contribution.

5.2.3.10 Indirect Influence: Product - Performance

As stated in equation 5.7, the condition of molds directly influences the OEE performance factor. 254 out of 284 (89,4%) molds used for production show hardly any loss due to non-usable cavities. The other 34 molds feature a performance factor in a range between 0,6 and 0,98 (see table 5.6)

	Total	Mold performance factor									
		1-0,99	0,99-0,98	0,98-0,97	0,97-0,96	0,96-0,92	0,92-0,88	0,88-0,84	0,84-0,80	0,80-0,76	0,76-0,60
Mold count	284	254	4	4	2	7	3	5	1	2	2

Table 5.6: Distribution of mold performance factors[224]

The need for an intensive checkup of the partially usable 34 molds arises from the fact that these are responsible for a high amount of lost production time (see figure 5.7). The time loss is calculated based on the values of "Achieved production rate", "Mold performance factor" and "Cycle time". The average operating performance factor for each product achieved during the collection phase reinforces the loss, resulting in the total time loss. In cooperation with the production planning department, the question of whether the expected upcoming demands for the single product would justify the costs of a complete overhaul or a newly made mold should be decided on. The table data also shows that even molds with a high performance factor (0,98-0,99) are generating a significant time loss due to their high count of achieved production cycles. The improvement of mold handling and checking procedures is strongly recommended together with a checkup of the usage of inappropriate deattaching tools, which would aggravate the decline of the mold performance.

Product	APR	MPF	Cycles lost	Cycle time	Time loss	Time loss	OPF	Total time loss
	[#]	[-]	[#]	[min.]	[min.]	[hrs.]	[-]	[hrs.]
TMC-1137	736	0,63	276	14,78	4.080,20	68,00	0,90	75,35
LMC-1195	1.762	0,77	409	4,00	1.636,14	27,27	0,89	30,48
LMC-0490	706	0,86	101	9,83	991,76	16,53	0,93	17,81
TMC-1166	610	0,93	41	12,75	518,50	8,64	0,56	15,35
2L-0062	374	0,76	91	5,53	503,38	8,39	0,59	14,25
TMC-0830	395	0,86	55	10,70	587,01	9,78	0,84	11,69
TMC-0608	1.116	0,98	25	11,88	297,27	4,95	0,43	11,43
TMC-0888	1.192	0,98	29	10,93	319,42	5,32	0,72	7,43
LKH-0465	218	0,80	44	5,58	243,43	4,06	0,78	5,21
TMC-0668	4.321	0,99	26	10,00	256,85	4,28	0,83	5,15
Other (17x)								27,58
							$\sum$	**221,73**

APR: Achieved production rate
MPF: Mold performance factor
OPF: Average operating performance factor

Table 5.7: Performance losses due to mold cavity erros[225]

[224] own contribution.

5.2.3.11 Indirect Influence: Performance - Quality

A correlation between high performance rates (mold performance factor is excluded from this calculation) and low quality, or vice versa, could not be detected based on the data obtained. The cluster of points (see figure 5.19) shows no significant decrease in quality at increasing performance rates.

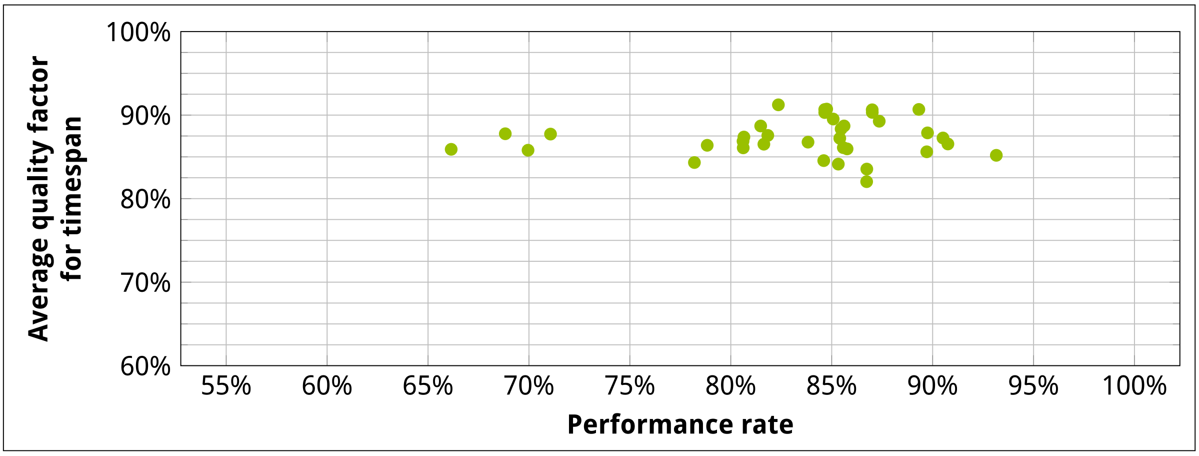


Figure 5.19: Correlation between production rate and quality[226]

5.2.4 Act - Definition of Action Plan and Execution

Except from the quality loss, every other direct and indirect influence case showed a time loss. Thus, based on the initial situation outlined in chapter one, it is more important to assess the occurring losses from a monetary point of view. The calculations needed for this are based on the company's calculation tables for fix costs of each machine type. This is possible, as the occurring delays, whether caused by downtimes or underperformance, virtually increase the needed machine capacity. In an ideal case, the complete fix costs of a machine are covered by an ideal (i.e. without any disturbances) production setup and the subsequent sale of items to the customer, but in situations with no or a smaller amount of produced items, these costs have to be compensated for by the company. Table 5.8 provides a summary of all indirect and direct losses, whereas figure 5.20 shows their temporal development during the collection phase. It has to be added that the indirect loss value for non-productive machines used also includes uncovered costs (total sum: 14.941 €) for those days, where no or tremendously low production was planned.

[225] own contribution.
[226] own contribution.

Loss type	Loss category	Total amount [€]	Amount per month (30 days) [€]
Indirect	Availability loss	8.654	7.115
Indirect	Cavity performance loss	1.286	1.057
Indirect	Operating performance loss	18.645	15.328
Indirect	Machines with no production	26.241	21.572
Sum indirect		**∑ 54.826**	**∑ 45.071**
Direct	Quality loss	52.046	42.785
Total sum		**∑ 106.872**	**∑ 87.856**

Table 5.8: Indirect and direct losses occurred during the collection phase[227]

The analysis of the OEE tracking data shows that in addition to the known quality-depending direct costs, nearly the same amount of indirect costs arise in current production, which together decreases the profitability of the company. Based on these numbers, quality losses are responsible for 49% of all costs and thus a serious issue. Problematic, too, is the fact that the identification of the root causes is a time-consuming process. On a few occasions in the past, special meetings were held in order to specify and execute special improvement actions for a limited amount of products causing high monetary losses. This PDCA-oriented approach is probably the only method that can improve the situation in small steps. A more frequent organization of these meetings could generally improve the situation in the long run.

The improvement of performance-related losses is also quite difficult. The first step should be the analysis of repair possibilities for molds, which feature a high total time loss or a low mold performance factor (see table 5.7). The monetary improvement effect is limited, as the costs are comparatively lower in comparison to the other categories. Nevertheless, the checking procedures could reveal similar defect origins that can be tracked back to harmful handling procedures during the molding process or mold changes. This information could also minimize further mold damages, although they are not completely preventable.

Regarding the question of the general improvement of the operator's performance, it is necessary to foster the exchange between operators and their superiors in order to identify the performance-limiting causes. A temporary increase of workforce within one shift on selected machines could show if a limitation is due to the amount of simultaneously handled machines for one operator or to the measured cycle times not being suitable, which would mean that they need to be adjusted towards more feasible times. In addition, operators with a below-average performance rate should addressed directly concerning the question of how they could be supported in order to raise their personal performance level.

An easier and faster way to reach improvement is the decrease of evitable downtime reasons. There is need for a detailed value chain analysis about the provisioning of raw material, as the categories HMD2 and EKS3 are responsible for up to 42% of product-related downtimes (see table 5.5) and generate more than 17% of the total availability costs (see table 5.9).

[227] own contribution.

What is more the stoppages caused by mechanical failures (MKK), energy shortages (ENR) and exceeding break times have to be seen as evitable. MKK and ENR can be prevented by means of a comprehensive maintenance system that also includes preventive treatment. This also concerns the high amount of exceeding break times. If possible, the management of the company should try to convince the operators to use this timespan for easy and quick maintenance or cleaning activities, which can help establish an autonomous maintenance system. The high amount of the category "Other" is due to the fact that this metric system is still just being established, which explains why some deficiencies in application exist. Thus, these shortcomings should be seen as starting points for improvement and can help determine the required level of detail of this system.

Reason	**Costs of Downtime** [€]	**Ratio** [%]
Other (Undefined)	2.256,68	26,08
KPD (Mold change)	1.068,60	12,35
MKK (Machine failure)	860,63	9,94
HMD2 (Quality issue raw material)	763,97	8,83
EKS3 (Waiting for raw material)	722,68	8,35
Break (Time exceeding)	644,52	7,45
MM (Machine maintenance)	611,75	7,07
KLP (Mold problem)	453,56	5,24
KLT (Mold cleaning)	405,08	4,68
TIB (Waiting for test)	355,89	4,11
MAK (Machine setup)	278,16	3,21
THS (Mold modification)	174,73	2,02
OLC (Dimension control)	48,02	0,55
ENR (Power failure)	10,12	0,12
	$\sum$ **8.654,39**	**100,00**
Evitable (MKK, HMD2, EKS3, Break, ENR)	$\sum$ **3.001,91**	**34,68**

Table 5.9: Breakdown of availability costs[228]

As can be seen in table 5.8, a high amount of indirect losses are generated by uncovered fix costs due to machines not used for production. Excluding the days with no or a low production plan, it is remarkable that the nonuse of several normal compression molding machines caused an indirect loss of about 8660 €, whereas vacuum-supported and injection machines created a loss for the same reason of about 1170 € and 1470 € respectively. It is up for discussion if the future production plan should allow for a higher utilization rate of the normal compression machines, at least to compensate for steadily occurring fix costs. Another option for cost-cuttings within this scope could be the decommissioning of one of the three major machine arrangements (KPA01, KPA02 and KPA08) in favor for an extended outsourcing strategy. This measure is also justified by the high under-performance levels observed for this type of machines

[228] own contribution.

The action plan is summarized in table 5.10.

5.3 Results

The application of the OEE metric system in the current sealing production segment has revealed that, despite the previously known quality loss, a high amount of indirect losses exists, which has a dramatic impact on profitability. Through the constant usage of this tool, production managers can directly detect bottlenecks in the molding value-chain. This comprehensive and transparent view on losses also allows for a better selection of specific improvement activities likely to effectively reduce occurring time losses and, more importantly, activities which can decrease the monetary losses. Using such a production tracking system is not only necessary to select improvement topics, but also to evaluate the effectiveness of these measures after their implementation.

The company is aware that at this stage of implementation of the OEE metric system deficiencies still exist, which is not uncommon, as this scope of production parameter tracking has never been done before. An important milestone for the company concerning the future usage of this system is an increased awareness of losses and wastages of any kind, which makes it easier to correctly identify their origin and increase the level of data validity for the subsequent analyses. The use of paper-based evaluation sheets presents two important disadvantages. First, the extra paper work for operators creates an unnecessary burden and distraction from their actual job, even if the amount of needed information is reduced to a minimum level. What is more, the level of detail of the documentation mainly depends on the attitude of the operator and bears the risk of important occurring losses not being assessed correctly. Secondly, the data entry and evaluation is carried out completely manually and unnecessarily uses working power. The integration of the OEE metric system into the company's ERP-application is therefore highly recommended as the majority of the production parameters applied is already being stored or assessed independently from this OEE tracking project. An additional benefit is a higher degree of data integrity.

In addition to the pure tracking of data it is necessary to provide a steady feedback about the current status of production for the main users of this system, i.e. the operators. This should encourage a stronger participation and also introduce a bit of healthy competition among the workforce, which have positive effects if it is used to motivate employees, e.g. by rewards for good participation or above-average performance levels. The most convenient way of feedback is the graphical representation of data analyses similar to those used within this chapter. Monetary losses should be emphasized within these feedbacks, because they have a higher force of expression than time based values.

[229] own contribution.
[230] own contribution.

Category	P	Action
General	S	• Providing of feedback to the users of the system about the ongoing status and achievements
	M	• Determine the need for additional downtime categories
	L	• Rising the awareness of operators for the correct assessment of occurring time losses
Machine - Availability	S	• Value chain analysis for the correct provisioning (Quantity and Quality) of raw materials
	S	• Root cause analysis for repeating mechanical failures
	M	• Check of possibilities to decrease the average time of mold changes and accompanied sub processes
	L	• Establishing of autonomous maintenance activities
Operator - Performance	S	• Knowledge transfer between operators and production management to determine performance decreasing factors
	S	• Additional support and training for operators showing a performance level below average
	S	• Profound measurement of cycle times and check for their feasibility
	M	• Time limited trial of workforce increase during one shift in order to determine positive effects on the performance factor
Product - Quality	S	• Increase of frequency for PDCA-cycle oriented meetings regarding the selective improvement of products, which show a high ratio of monetary losses
Machine - Performance	S	• Check on machine parameters and conditions, which prevent a higher performance
	M	• Selection of products for major machine arrangements based on their common cycle time, especially on normal compression machines
Machine - Quality	S	• Check for actual conditions of machines, which feature a low quality factor
	S	• Measures against rising dirtiness and an increase of cleaning activities for a quicker and easier detection of slow developing machine failures
Operator - Availability	M	• Decrease of non value-added activities during production time or transforming into value-added ones (for e.g. maintenance)
Operator - Quality	S	• Prohibiting of handling procedures that could damage the surface and general condition of molds
Product - Availability	S	• Improved provisioning of raw materials
	L	• Check of possibilities for a different sourcing strategy
Product - Performance	M	• Check for mold condition and possible overhauls
	L	• Determination of root causes that lead to these damages, either through production usage or by mechanical design
Performance - Quality	-	• No measures necessary, but the correlation between these production parameters should be checked from time to time

P: Time priority for realization
S: Near-term
M: Medium-term
L: Long-term

Table 5.10: Summary of proposed action plan[229]

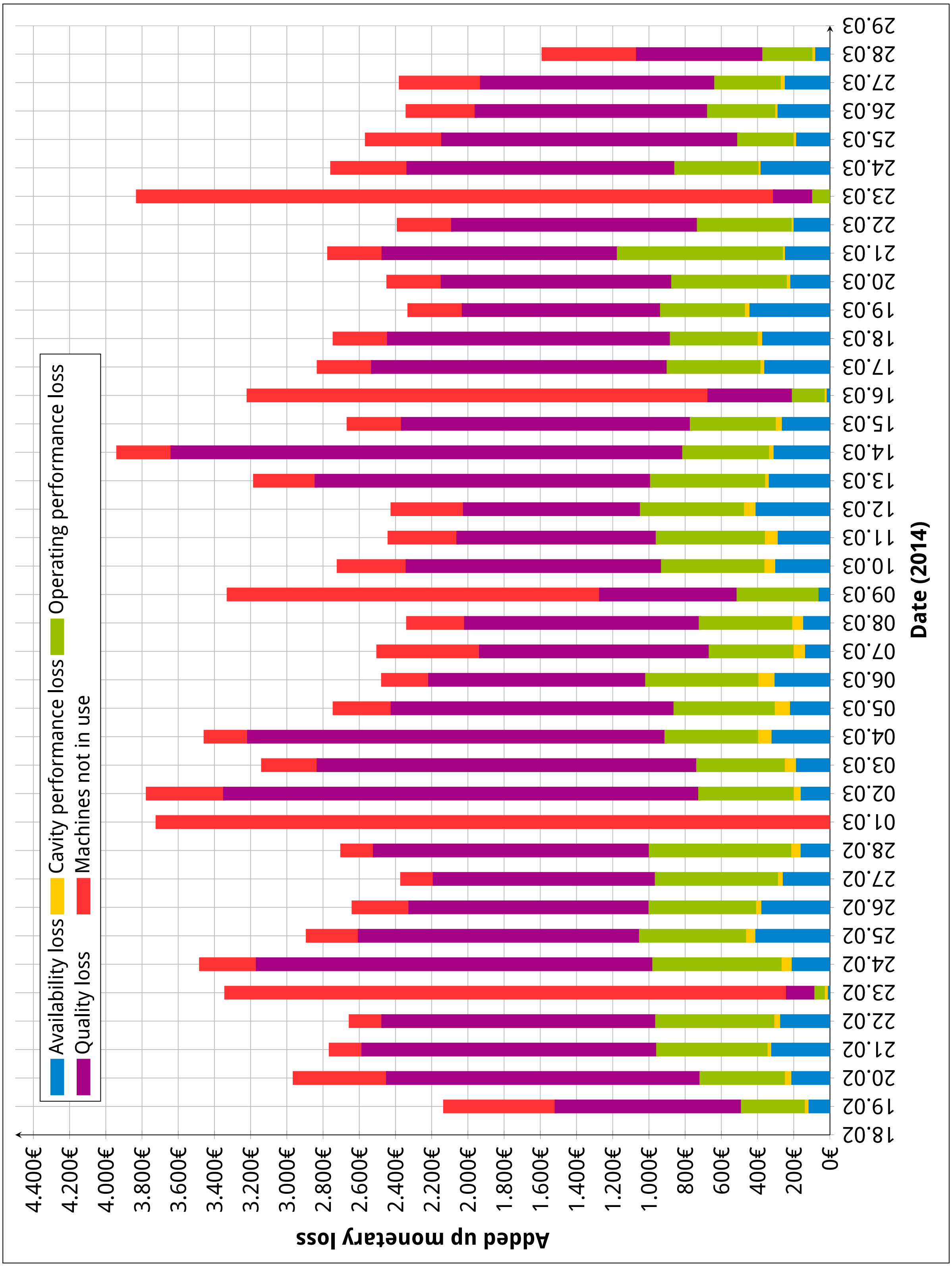


Figure 5.20: Daily amount of direct and indirect losses[230]

6
Summary and Outlook

The usage of the OEE metric system makes a helpful contribution for the transformation of an existing production process into a process in which its fundamental principles are driven by the ideas and convictions of the Lean manufacturing methodology. It supports the objective discovery of time and monetary losses in the value-chain, which haven't been tangible or visible before, as the vantage point regarding the effectiveness of a production is often valued just on the pure outcomes (good parts versus bad parts). Many times it is forgotten that the performance and quality of every subprocess inside the manufacturing chain tends to decrease through over time. Aggravating is the fact, that this creepy behaviour is not recognized by its users as long there is no need to concern oneself with this issue. The necessity for change is then often triggered by the realization of occurring monetary losses.

The following process of optimization is often accompanied by the unperceived resistance against change, as bad habits cannot be abandoned within in a short time period. The company should be aware that especially in the beginning of transformations hard challenges have to be faced that could put the whole project on risk. Fundamental condition is the broad communication of the superior goal, which should be followed in order to leave the deficiencies behind and establish an environment for a value-added production. At the present time, there are no fundamental new technologies available that could reduce the current problems of the company without any big efforts, therefore the improvement needs to be done step by step with the intensive participation of all concerning employees. This time consuming way will have the advantage that correct root-causes for existing issues can be detected and knowledge is transferred through over the whole workforce, whereas the innovation based approach is more likely to obscure deficiencies. Above all is the establishing of a corporate culture that fosters the identification of losses of every kind within the production process. Production managers or superiors are not able to observe every detail of production at any time, therefore the burden of assessment for occurring losses relies mainly on employees that are directly related to the production process itself.

This results in a need for an ongoing training of methods and tools that either helps for the identification of losses or for the decrease of those. The organized and efficient detection should always remain in the foreground, as the risk of wasting time on auxiliary activities is given. Production managers should select the topics of interest, but nevertheless be always open for suggestions of employees and reward their effort of participation. The selection of improvement topics is needed to be based on objective metrics that provide a holistic overview about the current situation and its deficits. Hereby relies the severity to track the correct amount of production parameters in order to generate meaningful analyses. The actual paper based method showed the capabilities of this metric system, but it is believed that this manual approach will always show shortcomings in the field of assessment and evaluation as it distracts in a certain way every user of their original duty.

Providing a remedy could be the implementation of a factory wide data acquisition boxes that are directly connected to the machines and the ERP-system. Main benefits are the reduction of operator interventions to a minimum and a high level of data validity. It is also believed that the manual tracked losses within this collection phase are not reflecting the real value, as the awareness for them is still developing and it is therefore not unlikely that the amount of time and money losses will rise during the following continuation of implementation. The company needs to be aware of the long-lasting time between improvement steps taken and visible results and should not value the whole effort on short-dated targets. Furthermore it is more important to set the right basis parameters like the previous mentioned cultural change and support for employees.

An useful pillar of the TPM methodology, the autonomous maintenance, was not implemented within this project as important premises for the correct implementation and application are missing and a rough and limited approach would bring only unwanted disturbances to the current environment. Nevertheless, the implementation is seen as mandatory, as we have seen that evitable machine failures occurred. Steady maintenance, in this specific framework, needs to be seen as a value-added activity. Here again relies the factor for success in the identification of the employee with his work and the utilities he is using to produce value. Of course, the transition of responsibility bears the risk for production managers in loosing control over many aspects within the production, but it is necessary. Thereby comes the OEE metric system back into play, as it should be used also to detect incorrect behaviours or developments that are showing fall backs into bad habits.

The optimization of an existing production is a long-lasting process that bears more risks than success, but nevertheless it is necessary as the deficiencies just do not disappear suddenly. The success of this transition is depending on all participants, regardless in which department or hierarchy level they are working in and is characterized by an open-minded exchange of opinions.

Figures

Tables

Equations

List of abbrevations

APAG	Angst+Pfister Group
APR	Achieved Production Rate
BM	Breakdown Maintenance
CEO	Chief Executive Officer
CIP	Continuous Improvement Process
CM	Corrective Maintenance
DIN	Deutsches Institut fur Normung
EBIT	Earnings before Interest and Taxes
EPDM	Reliability Centered Maintenance
ERP	Enterprise Resource Planning
GDP	Gross Domestic Product
IMVP	International Motor Vehicle Program
ISO	International Organization for Standardization
JIPM	Japan Institute of Plant Maintenance
JIT	Just In Time
KPI	Key Performance Indicator
LPAP	Laspar Angst+Pfister Advanced Industrial Solutions A.S.
MIT	Massachusetts Institute of Technology
MPF	Mold Performance Factor
MP	Maintenance Prevention
MTBF	Mean Time Between Failure
NNVA	Necessary, but Non-Value-Added
NVA	Non-Value-Added
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OPF	Average Operating Performance Factor
PDCA	Plan-Do-Check-Act

PM	Preventive Maintenance
PPS	Production Performance Sheet
RBM	Risk Based Maintenance
RCM	Reliability Centered Maintenance
SDCA	Standardization-Do-Check-Act
TMC	Toyota Motor Company
TPM	Total Productive Maintenance
TPR	Target Production Rate
TPS	Toyota Production System
TS	Technical Specifications
VA	Value-Added
WIP	Work In Progress

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Appendix

Figure A.1: Production Performance Sheet[231]