Evaluating Organizational Structures using Modeling and Simulation.

A Decision Support System for Maintenance Operations of Audi Hungaria Motors.

Master´s thesis

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In cooperation with:

AUDI HUNGARIA Zrt.

Audi
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Kurzfassung

Industrie4.0, die große Evolution der Vernetzung, führt zu einer Vielzahl von neuen Möglichkeiten, aber auch zu einem enormen Anstieg an Komplexität. Diese komplexe und dynamische Umwelt führt zu neuen Herausforderungen, wie dem Treffen richtiger bzw. guter Entscheidungen im wirtschaftlichen Umfeld. Manager und andere Entscheidungsträger müssen immer weitergreifendere Einflüsse und Auswirkungen berücksichtigen um am Ende die angestrebte Verbesserung für das Unternehmen zu finden. Ein bereits älteres Konzept, das aufgrund der computerunterstützen Möglichkeiten wieder an Bedeutung gewonnen hat, ist die Verwendung von Decision Support Systems, zu Deutsch Entscheidungsunterstützungssysteme. Diese Systeme können Entscheidungen zwar nicht selbst treffen, aber gewisse Aspekte der Entscheidungsthematik genau durchleuchten und damit die für diesen Teilbereich optimierte Lösung aufzeigen. Für die große Gesamtentscheidung wird diese Aufschlüsselung herangezogen und gemeinsam mit anderen Gesichtspunkten vom Entscheidungsträger zu einer Lösung verschmolzen. Somit muss sich dieser nicht mehr gänzlich auf seine Intuition verlassen, sondern kann einzelne Beschlüsse auf quantifizierte Empfehlungen stützen.

Diese Arbeit beschäftigt sich mit der Vorgehensweise zur Erarbeitung eines solchen Decision Support Systems für die Auswahl der geeigneten Organisationsstruktur eines Unternehmens basierend auf einem individualisierten Simulationsmodell. Diese Vorgehensweise wird anschließend in einem Anwendungsbeispiel für die Evaluierung verschiedener Szenarien der Instandhaltungsorganisation der Motorenproduktion der Audi Hungaria Zrt angewandt. Speziell soll die Frage der Zentralisierung-Dezentralisierung hinsichtlich der Steuerung, aber auch physischen Platzierung getestet und optimiert werden. Die Resultate weisen in Richtung einer zentralisierten Steuerung aufgrund einer deutlichen Harmonisierung der Instandhaltungsmitarbeiterauslastung. Dies wiederum führt zu verbesserten Reaktionszeiten sowie erhöhten Produktionszahlen. Die physische Platzierung zeigt eine gegenläufige Tendenz in Richtung Dezentralisierung aufgrund der enormen Größe des Werkes und der damit einhergehenden hohen Reisezeiten der Instandhalter zu den ausgefallenen Maschinen. Dies führt auch zur Empfehlung einer zentralisierten Kontrolle mit dezentralisierter Platzierung der Instandhalter an den Linien, allerdings rein auf die Simulationsergebnisse gestützt, ohne qualitative Faktoren wie notwendige Schulungen, Change Management oder ähnliches zu berücksichtigen.

Abstract

Industry4.0, the great evolution of interconnection, led to an explosion of possibilities, but also complexity. In this dynamic and fast changing environment the question of how to make good decisions becomes more and more important. Being a good manager has changed in terms of how many things have to be considered when making responsible decisions. This new challenge leads to the search of new solutions that shall support the decision makers. One rather old paradigm, that gained new importance, is the usage of Decision Support Systems. These tools' aim is the review of certain aspects of a complex problem. Decoupled from the holistic view they screen a specific part of the problem and deliver optimized options for solutions. Based on these supportive results the manger can make decisions that are quantitatively based rather than intuitively.

In this work an approach of how to develop a decision support for organizational structures through modeling and simulation is introduced. This approach is applied for the evaluation of different possible scenarios of the organizational maintenance structure of Audi Hungaria Zrt. The question of centralization-decentralization regarding control but also physical placement is tested virtually based on key performance indicators and worked out in form of a report that shall help the CEO of Audi Hungaria Zrt. The results show a tendency of control centralization due to the harmonization of maintainers utilization which leads to higher production outputs. The physical placement, however, shows better results with decentralized units (or solutions such as scooters which lower the travel times to the machine errors) due to the huge size of this engine production. In the end the scenario with a centralized control and decentralized physical placement is suggested, not considering qualitative factors such as effort of change, training and the like.

Foreword

This thesis was written at the institute of Mechanical Engineering and Business Informatics under the supervision of Univ.-Prof. Dipl.-Ing. Dr.techn. Siegfried Vössner in cooperation with AUDI HUNGARIA Zrt. in Györ after a six month lasting internship from September 2016 to March 2017. The purpose of this thesis was the evaluation of different organizational maintenance structures for the CEO of the engine production, Herbert Steiner.

I want to thank all my supporters, especially Markus Schulemann, my supervisor and mentor at Audi. Furthermore, I would like to thank Nikolaus Furian, Dietmar Neubacher and Clemens Gutschi for the supervision, brainstorming sessions and support during the process of developing my thesis. The biggest thanks goes to my family, Tobi, Anna, Lena, mum, dad: "*Es ist geschafft!*" Last but not least I want to thank my relatives, especially my grandparents, friends and my girlfriend; for accompanying me and making this time so special.

Table of content

1 Introduction

The industrial environment is in a continuous process of change and as the last years of development show, this process speeds up tremendously. Due to the new interconnecting evolution of Industry4.0 our world explodes in terms of possibilities and complexity. Obviously this dynamic increase of complexity also asks for assimilated, as well as complex solutions as it is manifested already in 1957 in Ashby's Law. This, in the System Theory rooted principle, is not just relevant for the value-added site of a company but also its organizational "*inner*" site. The question that arises is how can managers face this challenge. How can they keep up with this fast changing environment and still make the right – or at least a decent – decision for the company? Also Gerard Lewis and Neil Stewart (2003, p. 31) consider making good decision the biggest future challenge, interpreting Ashby's Law as follows: *"An implication of the law for business organizations is that they must develop sufficient information management and decision-making capacity to cope with the complexity in the environment in which they operate."*

The approach that this thesis will take is the old paradigm of Decision Support Systems (DSS) that recently see a boost of importance due to the new possibilities of Information Technologies. The main aim of a DSS is the vetting of certain aspects of a complex situation and the delivering of an apportioned, as well as supportive report on which the decision maker can base his/her decision. As Gregoriades and Karakostas (2004, p. 307) put it: *"Change, however, is risky because it encompasses unpredictable behaviours. Organisations, in order to minimize this risk, employ decision support systems (DSS) techniques that enable predictions to be made".*

DSS can be used for all kinds of decisions. In this work the main focus will be laid on a rather undiscovered field: The use of modeling and simulation as basis for a DSS to evaluate organizational structures. This rather new approach of quantitatively measuring the performance of organizations is a revolutionary tendency in the field of General Management and Organization.

1.1 Goals of this thesis

The main goal of this thesis is the development of an approach that enables the quantitative evaluation of organizational structures using modeling and simulation. This step by step guidance shall develop a useful decision support that helps managers and other decision makers to find the right organizational solution for them. To also test this approach in practice, a use case will be added to this work. In this example different organizational structures for the maintenance operation of the Audi Hungaria Zrt. will be evaluated.

1.2 Field of research

The main focus of this work will be laid on modeling and simulation with the focal point of modeling organizational structures and its processes. Moreover the subject of general management and organization, maintenance management and some aspects of production management will be of importance.

1.3 Delimitation

One important issue that will not be part of this work is the simulation which will be just briefly described and used as a black box that gets defined inputs and returns outputs. The exact proceeding, the source code or other informatics related topics will not be part of this work.

The implementation will also not be part of this work. The paper ends with the evaluated organizational structures. Change management will therefore not be part of this work either.

1.4 Structure of this work / approach

This thesis is divided in three main parts. The relevant theory from literature, the step by step approach in chapter 5 and the Use Case with Audi Hungaria in chapter 6.

Firstly the main aspects of maintenance with some important definitions, strategies, philosophies and key performance indicators (KPIs) will be expounded. Afterwards the subject of sociotechnical systems will introduce a paradigm that gives a holistic view on working systems. The closely related subject of decision support systems will also be part of this chapter. The next chapter, the main theory of modeling and simulation, will be explained with special attention to the conceptual modeling approach of Robinson.

Chapter 5 will deal with the development of a general stepwise approach which deals with the abstraction, simulation and evaluation of organizational structures. Some established frameworks like the ARIS framework (architecture of integrated information systems) and the conceptual modeling framework of Robinson will be part of this guidance.

Concluding this thesis will introduce a Use Case that applies the approach of chapter 5 on the evaluation of different organizational maintenance structures of the engine production of the Audi Hungaria Zrt.

2 Maintenance

The aim of the use case of this work is the evaluation of different maintenance structure under certain restrictions. To better understand the nature of terms such as maintenance, TPM, maintenance strategies and the like, a brief overview will be provided in this chapter. As Audi is an OEM from Germany, the VDI guidelines as well as the EN and DIN standards will be consulted mostly in this chapter.

2.1 Definitions

The first question that arises is: what is maintenance? There are several definitions, one summarized version is given by the DIN standard, which defines maintenance as *"combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function*". So maintenance is operatively and administratively linked to the item, which is also called maintenance object ("*target assigned and accepted for the maintenance activities*"). The main parts of maintenance are further described in chapter 2.2. To really focus on all the processes and structures, a wider context is necessary. Therefore the term maintenance management is of importance. The aim of maintenance management is to determine its maintenance strategy among other important maintenance subjects. The exact definition reads as follows: *"all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics"* (DIN EN 13306, p. 6)

As mentioned the strategy is part of the maintenance management, it is the *"management method used in order to achieve the maintenance objectives"* (DIN EN 13306, p. 4) To conclude the main definitions it can be said that maintenance management is the umbrella term for all the responsibilities of a holistic maintenance operation. Terms like the strategy, objects and others are parts of the maintenance management which define specific sub-areas or terms.

2.2 The fundamentals of maintenance

As Figure 1 shows maintenance is built upon four pillars. These pillars are inspection, service, repair and improvement. Even though these terms are often mixed or used wrongly, the main tasks differ.

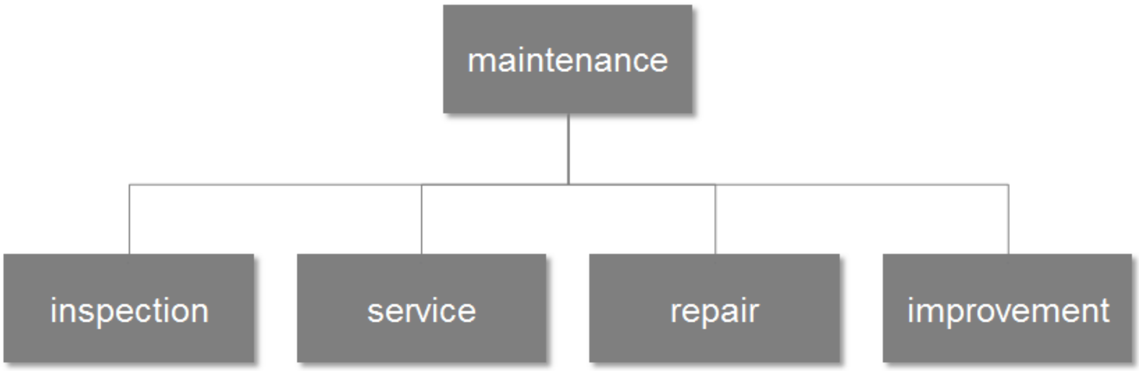


Figure 1: The four fundamentals of maintenance (adapted from DIN EN 31051, p. 4)

Inspection:

Inspection includes all actions that delay the wear of the maintenance object. Examples for these actions can be (DIN EN 31051):

- Analyzing the content and documenting the instruction
- Compiling an inspection plan
- Preparing of the tasks

These, mainly administrative, predetermined tasks are of high importance to keep the unplanned machine errors low. The same goes for the next fundamental, the service.

Service:

Service is all the actions that help determining the status quo, determining the cause of the wear and deriving using guidelines for the future. These actions are among others:

- Error analysis
- Feedback
- Decision for a solution which could be a repair or other actions

In comparison to the first two parts, the repair has no administrative components, but just operative tasks.

Repair:

Is a physical action that refits the function of a defected object. These actions can be:

- Execution itself
- Functional checks

The repair is the main part that most people think of when talking about maintenance. It includes the “firefighting” part when a machine breaks down and the maintainer has to come to restore it. In order to avoid the same error the next time, improvement is a very important task.

Improvement:

This can be technical, administrative as well as management actions that increase the reliability and/or the operational safety of the maintenance object without changing its primary function. Examples are:

- Feedback
- Functional checks
- Report of fulfillment

2.3 Maintenance objectives and strategies

As in chapter 2.2 described, the objectives and targets of maintenance are way more than just repairing machines that broke down. Their main objective is the attainment of the production goals by securing the needed availability of the producing units. (Strunz 2012) This means their responsibility lies beyond firefighting. As Leidinger (2014) put it lapidary, the unit shall be safe, available, reliable and stable regarding its remaining lifetime. So it can be summarized that the most important objectives are:

- Safety
- Availability
- Reliability
- Stability

The maintenance strategies define what issue triggers a maintenance task. In literature they are often listed differently. Some of them are not always mentioned. In this work Michael Schenk (2009) approach will be used in a slightly adapted form. He claims that a strategy can either be reactive, or preventive. If it is preventive, three different possibilities have to be considered; the time-based, the condition-based and the predictive strategy. The strategy which Schenk calls time-based will be defined more generally here as predetermined maintenance. This predetermined strategy is time-based or unit-based. Out of this theory Figure 2 is formed.

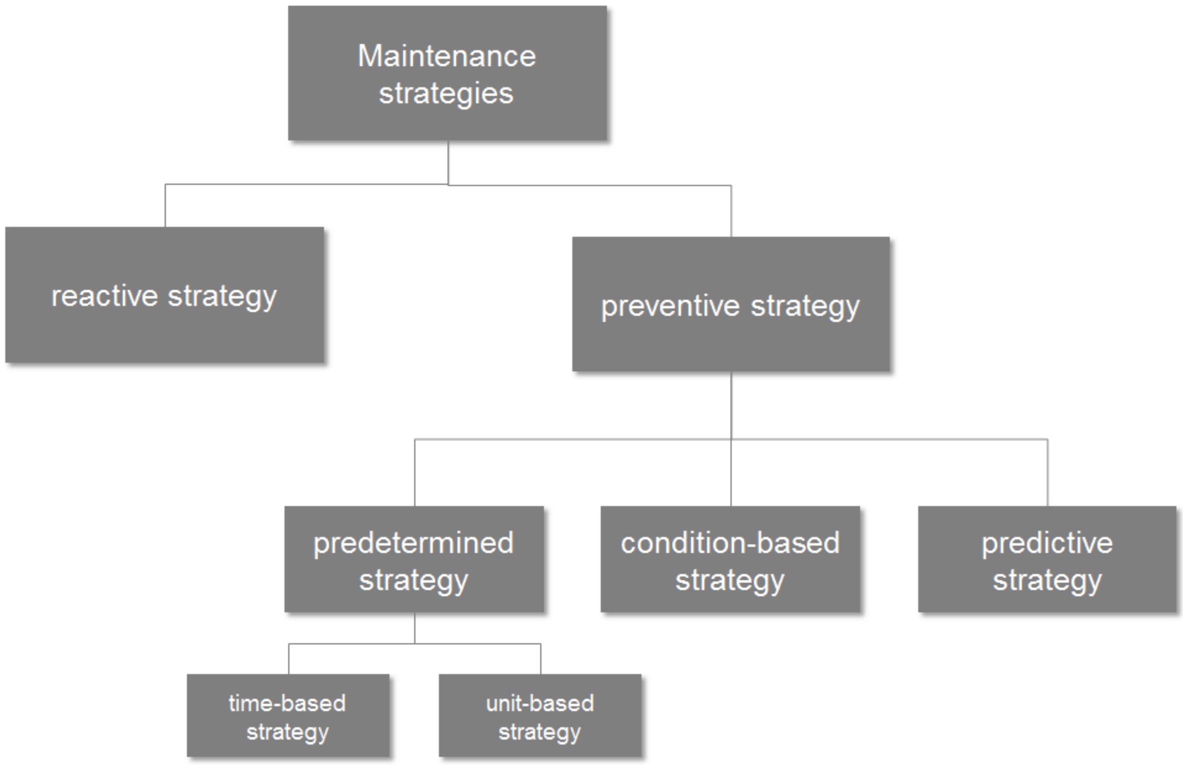


Figure 2: Maintenance strategies (adapted from Schenk 2009, p. 27)

The reactive strategy is also called corrective maintenance strategy. Corrective maintenance is defined as *"maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function"*. (DIN EN 13306, p. 23) Hence, this strategy follows the rule of waiting for malfunctions and reacting to them. A frequently used metaphor is firefighting, which works upon the same principle. The problem that asks for the reactive maintenance operation is the breakdown of a maintenance object. The preventive strategy's purpose is to not even let the object break down. This is not always possible, but important to keep the production as stable as possible.

As Figure 2 shows, preventive strategy is just a collective term for other strategies. Its aim is *"(…) to reduce the probability of failure or the degradation of the functioning of an item"*. (DIN EN 13306, p. 22) Its first part is the predetermined strategy, which is defined as *"preventive maintenance carried out in accordance with established intervals of time or number of units of use but without previous condition investigation"* (DIN EN 13306). This very commonly used strategy does not take any measures or signals into account. The threshold is usually set once according to the user manual and mostly not changed as long as it works out. In comparison to that the Condition-based strategy is a *"preventive maintenance which include a combination of condition monitoring and/or inspection and/or testing, analysis and the ensuing maintenance actions"* (DIN EN 13306, p. 22). One very good example for condition monitoring is diagnostics. A sensor can continuously check the condition of a machine part and warn the maintainer as soon as the measured objects/components reach a critical state. A related strategy that focuses more on historical data as well as diagnostics measures and also other available data, is the Predictive maintenance strategy. It is defined as *"condition based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item"* (DIN EN 13306, p. 23). This strategy is nowadays getting more and more important due to the possibilities of operating data logging ("Betriebsdatenerfassung") and even newer approaches like digital twins. The maintenance strategies are closely related to the management philosophies, which mainly determine how the strategies shall be applied.

2.4 Management philosophies

Within the last decades a lot of different management concepts were established. One that will be further described here is called Total Productive Maintenance; the others are just listed here without deeper insights (Pawellek 2016):

- Total Productive Maintenance (TPM)
- Lean Maintenance
- Total Lifecycle Cost Strategy
- Reliability Centered Maintenance
- Knowledge Based Maintenance

Fundamentals of Total Productive Maintenance:

This team-based, proactive concept's aim is the maximization of equipment efficiency and reliability. It includes the whole organization (not just the maintenance units) and is built upon the principle of zero accidents, breakdowns and defects. (Hawkins, Smith 2004)

As Schröder (2010) concludes the fundamentals of TPM:

- Optimization of the efficiency of all production units to a maximum
- Building an extensive, productive system over the whole lifecycle of the unit
- Integration of all organizational units from top management to the shop floor
- Motivating management through autonomous groups

As mentioned one important fundamental principle of TPM is the integration of all departments through interfaces to the maintenance. This includes the specialty that machine operators acquire certain smaller maintenance tasks. Furthermore, their job is to continuously pay attention to the machines they are working on, in the interest of preventively recognizing possible machine errors. (Pawellek 2016)

The five pillars of TPM:

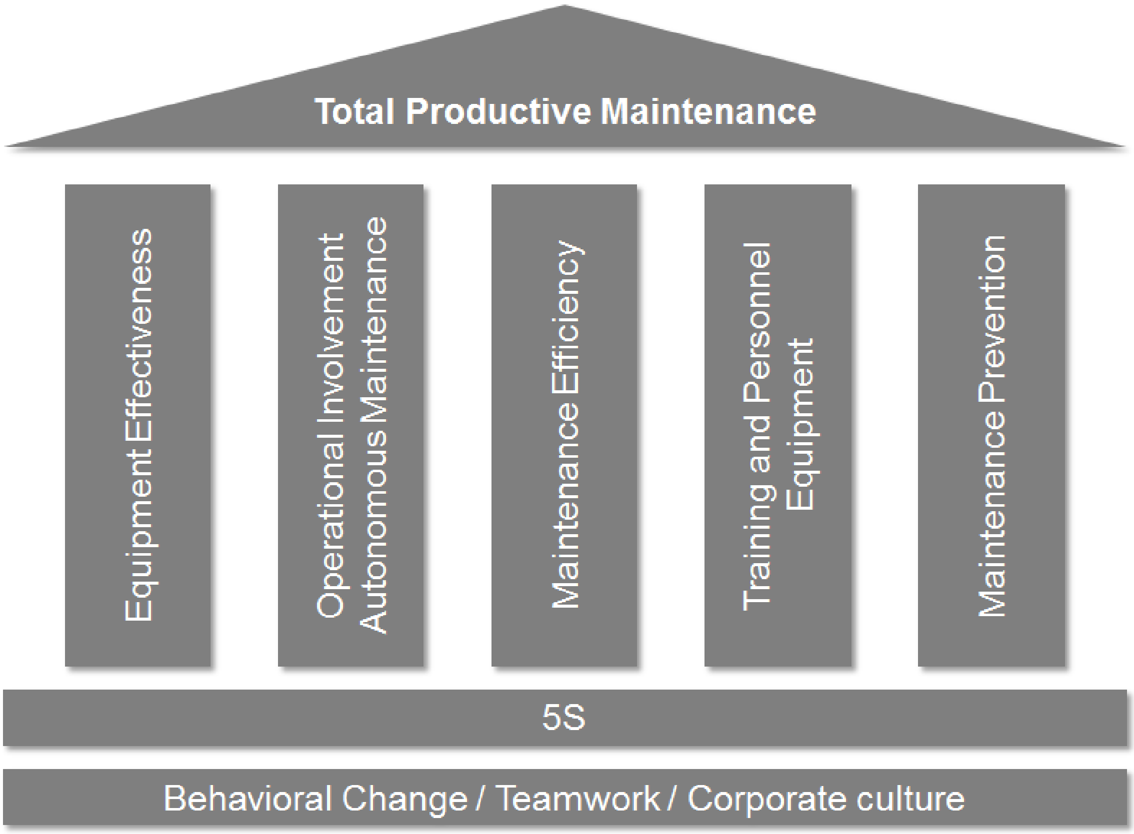


Figure 3: The five pillars of TPM

As Figure 3 illustrates, the five pillars of TPM are built on cultural values and the 5S methodology (sort, set in order, shine, standardize, sustain). The pillars are, next to the already mentioned fundamental-principals, also maintenance prevention and training as well as personnel development.

The TPM philosophy is a complex concept that many companies nowadays try to *live by*. But problems such as too high expectations, no support of the management, resistance against cultural change and the like prevent the high possible success it can obtain. (Schröder 2010)

2.5 Key performance indicators (KPIs)

Since maintenance is a very wide, complex and important fundamental of the production, it is important to somehow plan and control it by numbers. These numbers are so called key performance indicators (KPIs) which shall enable the abstraction of maintenance operations into numbers. In this chapter the nature of

KPIs will be explained. Secondly a few of the most important KPIs for this work will be listed and explained according to the literature especially the VDI2893.

2.5.1 The fundamentals of KPIs

Key Performance Indicators are measurements which purpose is the clear and fast instruction of the interested user. Usually they gain their full benefit in comparison with other KPIs of comparable events or systems. Their main responsibilities are (Werner 2014):

- Valuation: They rate the corporate objectives
- Stimulation: They can detect problems and quantify the reason of the divergences
- Objectives: KPIs support the process of defining success measures
- Management: Management objectives
- Controlling: KPIs enable nominal-actual comparison

Indicators can be classified into three domains (VDI 2893):

- Technical KPIs
- Costs KPIs
- Administrative KPIs

It is further important to distinguish between basic numbers, which are absolute numbers and indicators which mostly are ratios (quotients).

2.5.2 Important KPIs

There are hundreds of KPIs with thousands of names. However, the name is not the important part, but the calculation, definition and unit. In this chapter, a table lists the relevant KPIs for this work. The first column shows the used abbreviation, while the second one shows a short description. The third column features the calculation, in case it is an indicator, and the last column exhibits the unit.

MTBR	Mean time between repair	$\frac{average\ time\ between\ repairs}{number\ of\ failures}$	h
MTBF	Mean time between failure	$\frac{MTBR + MTBF}{number\ of\ failures}$	h
MTTR	Mean time to repair	$\frac{total\ time\ of\ failures}{number\ of\ failures}$	h
RT	Reaction time between the occurrence of the failure and the start of repair	$\frac{sum\ of\ the\ reaction\ times}{number\ of\ failures}$	h
DOC	Degree of decentralization	$\frac{Sum\ of\ decentral\ units}{Sum\ of\ all\ units} * 100\%$	%

OEE	Overall equipment effectiveness	See description below	%
A	Availability	$\frac{total\ producing\ time}{planned\ producing\ time} * 100\%$	%
P	Performance	$\frac{actual\ output *\ producing\ time}{planned\ output * planned\ time} * 100\%$	%
Q	Quality	$\frac{total\ output - faulty\ output}{total\ output} * 100\%$	%

Table 1: Selection of important KPIs

The overall equipment effectiveness OEE:

The OEE defines the availability of a machine or more generally said of a production unit. It takes failures, set-up times, adjusting times, total machine breakdowns and decreased cycle times into account. It is formed out of availability, performance and quality. (Strunz 2012)

$$OEE = Availability * Perfomrance * Quality * 100\%$$

Formula 1: Overall Equipment Effectiveness

The calculation of the OEE in Formula 1 shows that in the very best case the OEE is 100%. In reality the three variables Availability, Equipment and Quality lessen the OEE. In case of the Availability, all the downtimes due to problems with the production unit cause this decrease. The performance is mainly reduced by causes such as cycle time reductions. The third variable, the Quality is affected by the outcome’s condition. If the produced unit has to be disposed of or some rework is necessary, this variable will be lowered. In many companies this is the main KPI that helps keeping track of the production units.

3 Sociotechnical systems (STS) and Decision Support Systems

In this chapter the complex nature of an organizational structure will be examined. A meanwhile common approach to understand and work on organizational structures is the holistic view of sociotechnical systems. As early as the 1950s, the awareness of the inseparability in the observation of social and technical systems arose within the coal mining industry. Even though it had been an under-appreciated domain until the 1980s, it still grew to a complex system with important practical- and theoretical approaches. In this chapter, these approaches, together with all the theories and definitions that grew around this subject, will be explained. Afterwards, this theory will be applied to the topic of organizational management. (Trist 1981; Hettinger et al. 2015)

3.1 Definitions for STS

As a first step the terms socio and technical will be depicted briefly. Afterwards, their combination as sociotechnical system will be defined more closely. In contemplation of a common understanding the term sociotechnical system will be used throughout this work representative for the different notations that are used in literature as for example sociotechnical theory and sociotechnical system theory.

“Socio” and “technical”:

Walker, Stanton, Salmon and Jenkins explain the two terms briefly in their article “A review of sociotechnical systems theory: a classic concept for new command and control paradigms”. Socio is explained as *“(…) of people and society (…)”* and technical as *“(…) of machines and technology (…)”* (Walker et al. 2008, p. 479).

Socio is originated from the Latin word *“socius”* which means companion, ally associate, fellow or sharer (Dictionary.com).

Technical is originated from Greek *“tekhne”* which means art or skill craft and can be narrowed down to the sense of *“being associated with the mechanical arts”* (Dictionary.com).

Sociotechnical system:

“The concept of a sociotechnical system is derived from the premise that any production system requires both a technology, a process of transforming raw materials into output, and a social structure linking the human operators both with the technology and to each other.” (Rousseau 1977, p. 19) Rousseau further claims that a sociotechnical system is a unit that has to accomplish a common goal or at least

task. The unit in this matter is a composition of a social and technical subsystem. E. Mumford (2000) defined it more abstractly in the way that in the design process of a new work system, the social and technical issues are given the same importance.

According to Hettinger, Kirlik, Miang Goh and Buckle (2015, p. 600), a sociotechnical system is a theoretical framework *"(…)that focuses on the interactive influences of social-organisational and technical factors (…) as they impact the design and performance of complex operational systems."* Social-organizational factors in this context are all attributes that influence the organizational structure and personnel characteristics. The technical factors are attributes that support work-related activities and technical processes. Mumford (1994, p. 314) put it that way: *"(…) if a technical system is created at the expense of a social system the results obtained will be sub-optimal."* Furthermore she stated *"(…) that when work is being designed the goal must always be the joint optimization of the social and technical systems."*

A brief explanation is also given by Appelbaum (1997), who states that a work unit, or more commonly said an organization, is the combination of social parts as well as technical ones. Since it evolved out of system theory it can further be said that it is open to its environment.

It can be summarized that a sociotechnical system:

- Is the holistic view on both: the social- and technical factors
- Is used to design and optimize work systems, especially organizational structures and technical processes
- Mostly consists of optimizes one of the two issues (social or technical issues), which is not the optimum for the joint consideration
- Is open to its environment

3.2 Why and how to build STS?

As shown in 3.1 STSs take the social and technical view into account. This is essential for organizational development (OD). Due to the STS theory a framework is given that enables successful changes in the organizational structure while still not neglecting technology. When thinking about an organizational change to obtain OD, STSs are the key to successful planning. This planning is mostly done theoretically first to minimize the risk of introducing a bad change in the existing organizational structure. (Appelbaum 1997)

This gives rise the question of how to build such a sociotechnical system to reach the goal of successfully changing the organization. Mumford (2000) therefore formulated a step by step problem solving guide:

- The total picture: Before starting to build a STS model, the whole problem in every dimension (technical, organizational, social and economic issues) and its interaction needs to be understood.
- Strategy development: Each step within the design process requires its own appropriate strategy. These strategies should also fit together to work as operational guidelines.
- Taking action: Design a mission statement that includes clear definition of the objectives, the design process and the major tasks.

3.3 Design principles for STS

Mumford (1994) declared, next to the problem solving guide from chapter 3.2, seven general design principles which do not focus directly on the model building, but on the most important points which have to be considered during the evolvement of a new work organization:

- Minimize critical specifications: Simply tell the employees what, but not how to do it.
- Control the variance: Try to solve problems as close to the root cause as possible.
- Multiskilling: Always give the employees a combination of routine and challenging tasks rather than one of the two alone.
- Boundary management: Make sure to have clear boundaries, in order to assure that products pass smoothly from one transformation stage to another.
- Information flow: Information should always go directly to the source that originated it.
- Design and human values: Reach for a high quality of life at work. Your employees want to learn, they want to be challenged, they want to feel save.
- Incompletion: Design is an ongoing process, make sure the employees know that.

In addition, more general principles are formulated by Bullinger (1996):

- The group is responsible for so called primary tasks.
- The primary task is the system’s purpose which is defined by the input-output transformation.
- The group’s main aim is the fulfilling of tasks.
- Self-control and self-organization are main principles for the groups.

The nature of sociotechnical systems were explained in this chapter. Some main principles for problem solving and new organization building were introduced too. In the next chapter, the more concrete topic of organizational management will be described.

3.4 Organizational management

The theory of STS answers the question of how to look on the complex nature of organizations in their interactions. In this chapter the question of which scenarios exist will be answered. Since the topic of organizational management is an old, well known and very wide paradigm the focus in this work will be on the operational and organizational structure.

3.4.1 What is an organization?

The first question seems obvious and easy to answer, but beside the definition of the word itself, a wider view will ask for the necessity, the demands, targets and other fundamental characteristics of an organization.

Definition of organization and organizing:

The “BusinessDictionary” defines this term as follows: “*A social unit of people that is structured and managed to meet a need or to pursue collective goals. All organizations have a management structure that determines relationships between the different activities and the members, and subdivides and assigns roles, responsibilities, and authority to carry out different tasks. Organizations are open systems-they affect and are affected by their environment.”* (Dictionary.com)

Stefan Vorbach (2015) defines it by its task as the enablement of a target-oriented collaboration that provides the structure rules for working on complex challenges.

According to Bergmann and Garrecht (2016) the term organization, in the context of a business unit, can be specified and characterized into three dimension:

- The institutional dimension: The business unit *is* an organization (the organization as target oriented social system).
- The instrumental dimension: The business unit *has* an organization (Organization as structure of a system).
- The functional dimension: The business unit *gets organized* (Organization as activity “organizing”).

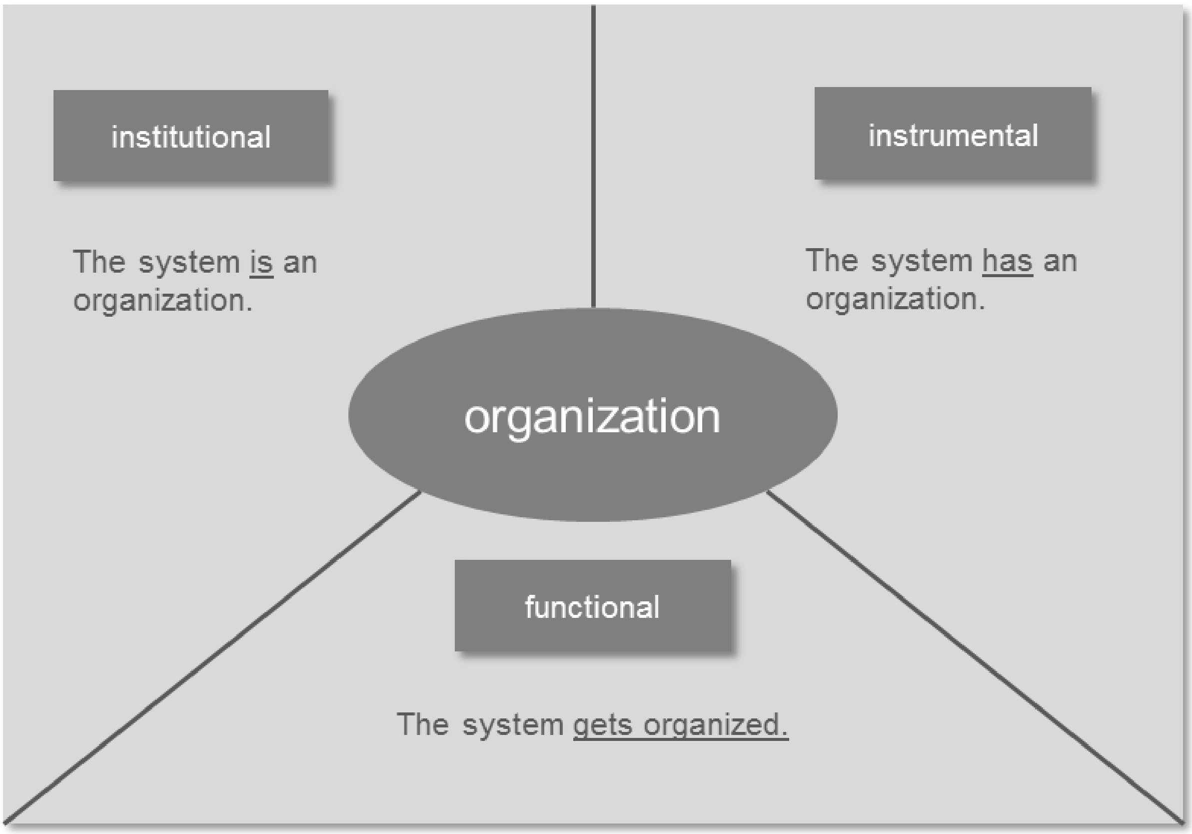


Figure 4: Views on organizations (translated from Bergmann, Garrecht 2016, p. 3)

Organization as a sociotechnical system:

Löffler, Westkämpfer and Unger (2012) describe an organization (to be exact a factory) as a complex system in which elements operate through interaction. Furthermore, they define the structure of a system through this network of elements and their relationships. Those systems are usually built on subsystems, which, in the case of the factory, could be products and the production. Other elements in this operating network will be shown below.

Elements of an organization:

- Workers: The main element of every organization is its worker. This is also the smallest unit from a general and reasonable point of view. The worker combines certain aspects like attitude, skill-level, experience and the like.
- The organizational unit: This central element is a time-independent (as long as the organization is not changed) construct which consist of workers and/or other organizational units. Moreover, it contains a leader, who is responsible for this organizational unit.
- The workgroup: The workers of a workgroup can belong to different organizational units. The purpose of a workgroup therefore is an over-organizational unit which performs its tasks throughout different organizational units. A good example can be expert-groups which are limited in time like a

quality-taskforce which helps stabilizing a production process that essentially dropped its quality standard. (Leodolter 2015)

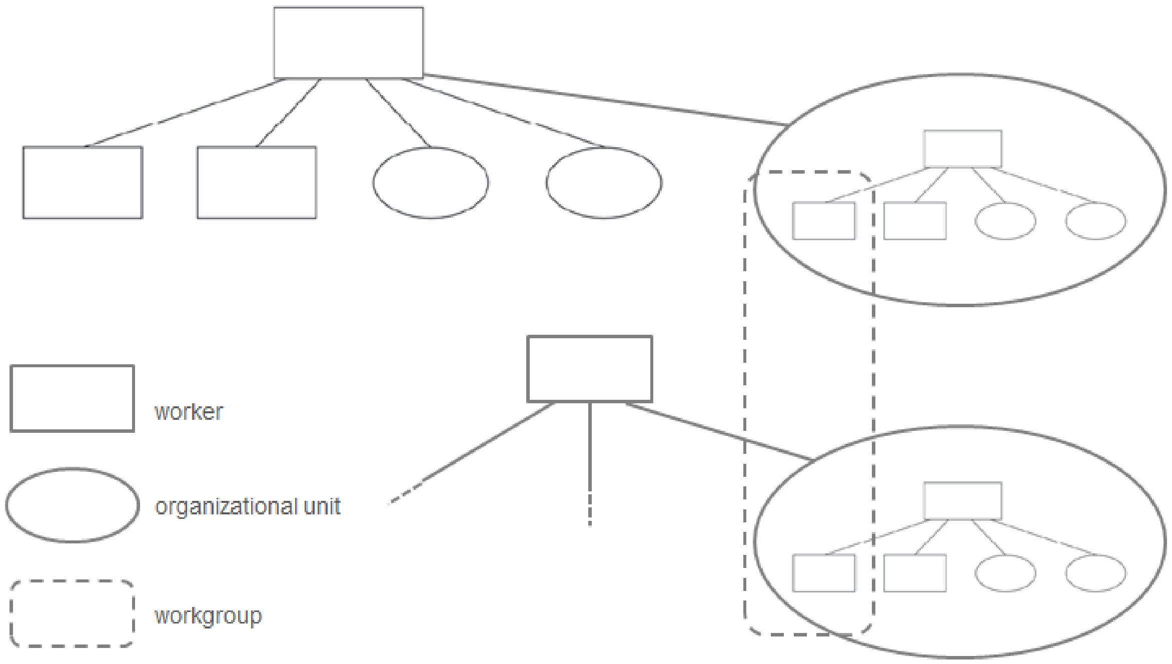


Figure 5: Interaction of workers, organizational units and workgroups (adapted from Leodolter 2015, p. 78)

General requirements to organizations:

Organizations are dynamic and complex systems which are influenced by many factors like the geographical spread, its used technologies, stakeholder influences, its environment and many more. Hence, it is important to bear in mind that under all circumstances there is never a best solution. Instead, there are appropriate and non-appropriate solutions depending on the situation. So the question now is how can we evaluate whether it is an appropriate solution or not? To evaluate an organization consequently, four criteria are formulated which, on the one hand, are related to the superior common goal of the organization and, on the other hand, help to rate the different structures separately. These criteria are (Hungenberg, Wulf 2007):

- Market orientation: An organization has to support the organizational culture regarding market competition and customers' needs.
- Efficiency of resources: Personnel and financial resources have to be kept at a minimum.
- Qualification and motivation: An organization should help to tap the full potential of the management.
- Flexibility: The organization should always be agile in order to react to environmental changes.

The characteristics and objectives of organizations:

The organizations as sociotechnical systems are characterized by the following elements (Vorbach 2015):

- An organization is target-oriented: Their purpose is always the accomplishment of a purpose.
- An organization has formal structures: They are built upon certain rules and criteria to obtain efficient collaboration.
- An organization is an open system: It depends on the interaction with its environment.

The interrelated tradeoffs or opportunities:

When structuring an organization, some interdepended constraints are unavoidable:

- Stability vs. flexibility
- Centralization vs. decentralization
- Delegation
- Formal and informal aspects

Usually it is the management's job to take all the stakeholders into consideration to find out how the organization should be shaped.

Stability vs flexibility:

One main goal of an organization is stability to stay plannable, predictable and efficient. On the other hand, flexibility becomes more and more important due to fast changing boundary conditions such as environment, customer needs and the like. Since stability and flexibility constitute the two poles of a continuum, an organization can never be stable and highly flexible at the same time.

Centralization vs. decentralization:

These attributes are closely linked to stability and flexibility. One main characteristic of a centralized system is stability. Whereas a decentralized system is indicated by flexibility. The question of centralization vs. decentralization is moreover related to history. Like the swing of a pendulum, organizations switched between these two philosophies.

Delegation:

By delegation, the shifting of discretionary competences to subordinated hierarchical layers is meant. Also, this aspect of an organization is linked to stability and flexibility. Stability in this frame of references is linked to authorities on the very top of the hierarchical pyramid, while flexibility is linked to more autonomous self-organized units.

Formal and informal aspects:

Formal and informal aspects are all the allegedly small characteristics which in sum have a great influence on organizations. These formal and informal aspects are among others routines, group behavior, organizational culture, task and role definition, hierarchy and the like. (Bergmann, Garrecht 2016)

Functions and targets of an organization:

Dividing work is an essential principle of organizations. Within these divisions, different people with different knowledge and targets act. To bring these targets efficiently towards the direction of one main common goal, organization is inevitable. Therefore the organization is the instrument which sets the rules and interfaces that are necessary to assure an aligned fulfilment of tasks.

According to this background, two main aspects arise. One shapes the institutional structure of the working units, which is called *organizational structure*. The second one, which coordinates the temporal and special structure, is called *operational structure*. By means of these two views on the nature of organizations, a deeper insight into this subject will be given. (Hungenberg, Wulf 2007)

3.4.2 Organizational structure

The organizational structure represents the respective architecture of the units. All of the existing types of structures exhibit different advantages and disadvantages. Which type fits the organization best depends on many factors. For example the corporate strategy. It is important to keep in mind that due to the high complexity of organization one single best solution will never exist. (Bergmann, Garrecht 2016)

The main types are:

- Single-line system
    - The functional structure
    - The divisional structure
- Multi-line system
- The matrix structure
- Hybrid structures

Single-line system:

The functional and divisional structures are single-line systems. A single-line system is a clear hierarchical organization system where every worker has one defined connection to the next higher hierarchical layer. Within this next higher hierarchical layer one superior is responsible for the worker and vice versa the worker has to explain him/herself directly to just this superior. (Saaman 2012)

Advantages of this system are:

- A clear and easy structure
- Clear information paths and responsibilities
- No conflicts of competences
- Easy to control for the superior
- Clear instructions to the worker
- Highly reliable system
- Clear division of tasks and competences

Disadvantages are:

- Inflexible, long connections (instructions-/information channels)
- High workload for the superior
- Danger of high bureaucracy and "over-organization"
- Lack of motivation sublayers
- No responsibility-taking along the instructions
- No identification
- No room for creativity and innovation

The functional structure:

In this type of organizational structure, the second hierarchical layer is divided into the organization's functions (R&D, production, purchase,…). The advantage of this structure lies in the high specialization which can cause increases in productivity. One disadvantage is the horizontal coordination, which means the coordination of the functions. (Lippold 2016)

Figure 6 shows a very trivial example of a functional structure.

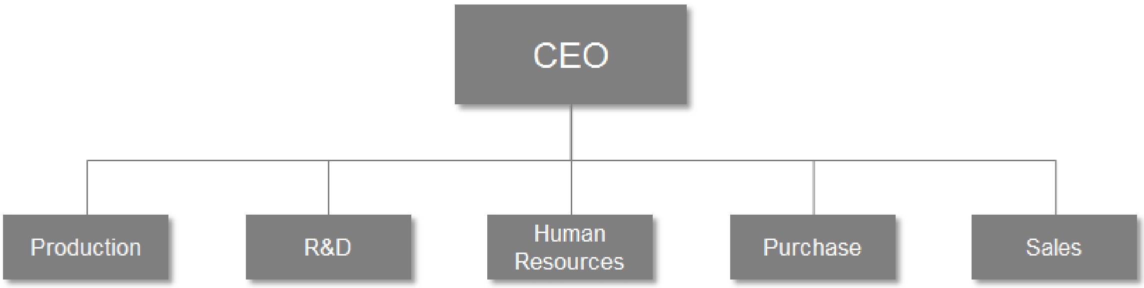


Figure 6: Organigram of a functional structure

The divisional structure:

In this type of organizational structure, the second hierarchical layer is divided into objects. These objects can be business units, product groups, regions and other criteria. In bigger companies a divisional structure with more layers is also possible.

As an example, a company could divide their business into regions and within these regions a structuring by product groups is made. Advantages of this model are the discharging of the management as well as easier integration or outsourcing of units. The disadvantages are higher administrational efforts and a higher demand of managers. (Lippold 2016)

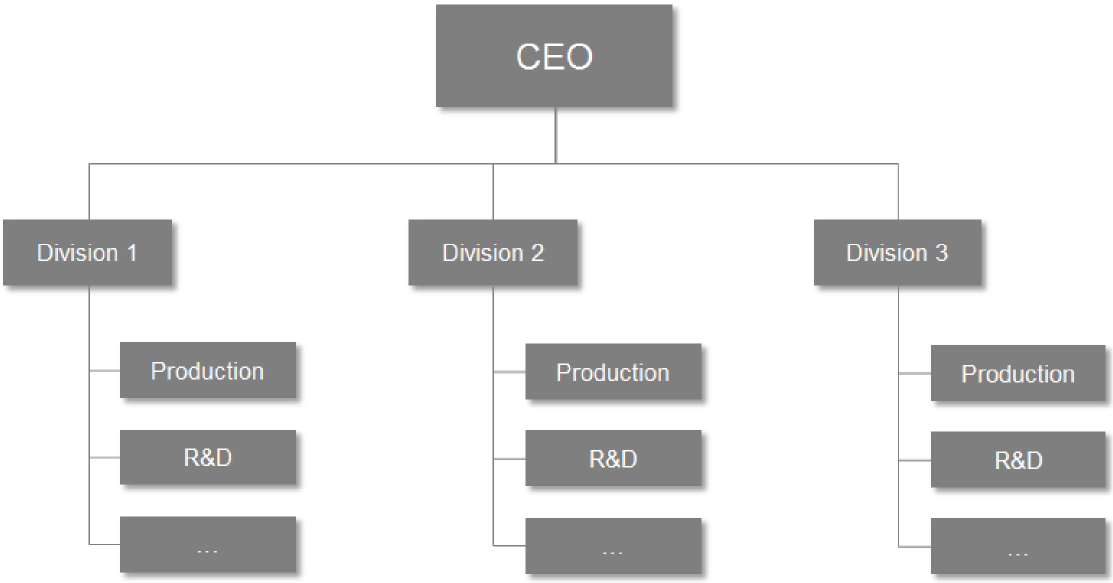


Figure 7: Organigram of a divisional structure

Multi-line system:

In the multi-line system, a unit is supervised by more than one instance. The main idea is the supervision by many experts, where the unit can place its problems at the instance that knows best the type of problem. This leads to high specialization. Furthermore, the workload for the upper instances is decreased. One main problem is the possibility of supervisions that create conflicts due to its contrariness. (Vorbach 2015)

The matrix structure:

The matrix structure is a system in which two guidance-channels are linked. The worker has two superiors. As an example, a worker can be under supervision of a horizontal coordination of a distribution manager and a vertical coordination of a product manager at the same time.

Advantages of this structure (Saaman 2012):

- Short connections (instructions-/information channels)
- Flexible consideration of competition aspects
- Specialization of the supervisors and at the same time discharge of the top management

- The problem solving process takes two views under consideration
- Higher motivation in problem solving

Disadvantages of this structure:

- Conflicts of competences
- Lack of transparency
- High communication effort
- Slow and complicated decision making
- Uncertainty regarding the execution of tasks due to the double-supervision
- Transparency problems when executing several projects at the same time

Figure 8 shows an example of a matrix structure. A worker is placed on each knot of the vertical and horizontal coordination paths.

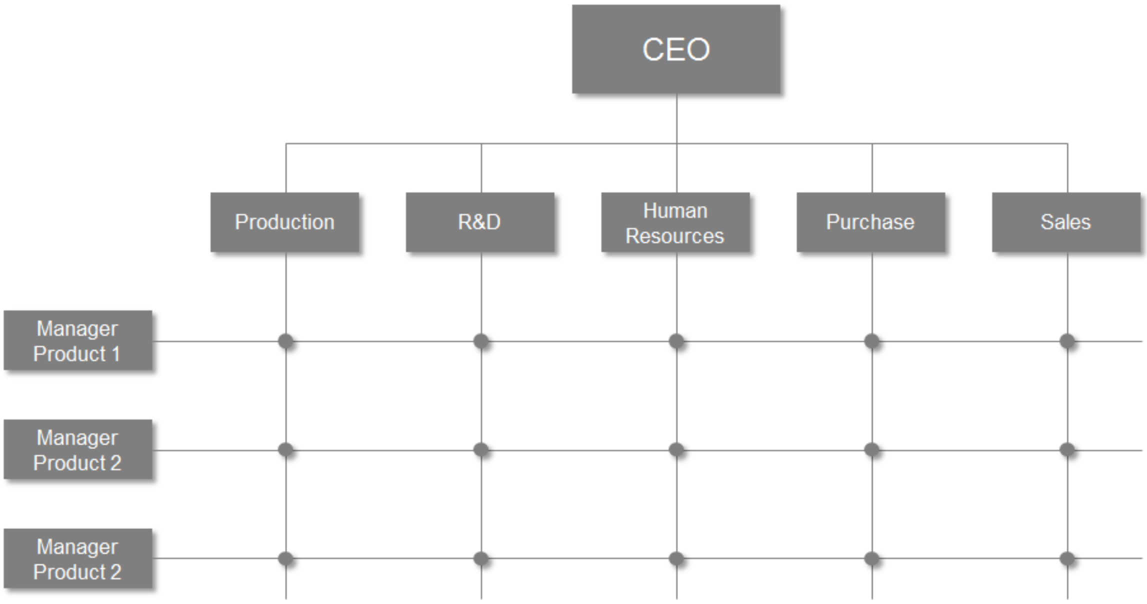


Figure 8: Organigram of a matrix structure

Hybrid structure:

Hybrid structures are combinations of functional and divisional structures which try to combine some of the advantages of both models. On the other hand they of course also combine some disadvantages. The nature of this specific form will not be further discussed in this work.

3.4.3 Operational structure and process organization

The operational structure is concerned with all the processes. Important business processes are for example R&D, purchase, production and sales. (Bauer 2017)

The term process is originated from the Latin word “procedure” which means “to proceed”. It is further explained as a sum of activities that gains valuable outputs upon certain inputs. Furthermore, processes are causal chains which are of high importance for the organization. Characteristics of processes are (Vorbach 2015):

- Activities and logical entailments: Activities which are time- and content-related
- Input and output: It is built upon inputs which get transformed into outputs
- Transformation: The part where the inputs are proceeded into outputs
- Process responsibility: Processes are always related to so called “Process owners” which assure optimized flows

As Lippold (2016) states: the competitiveness and the organization’s capability of surviving strongly depend on fast, flexible and efficient business processes. Therefore, the operational structure and its process organization are highly important. In comparison to the organizational structure the focus is not on the organizational units and their procedures, but on processes and business chains which are customer-oriented.

Marc Sander (2006) puts it as the operational structure focuses on processes related to space, time, work unit and materials.

Purpose of the operational structure (Bauer 2017):

- Staying within the boundaries of time: Coordination of production and customer delivery
- Time optimization: Harmonizing and downsizing throughput times to a minimum so that there are low waiting times during the production process
- Well planned capacities: High utilization to all units to gain high efficiency
- Avoiding failures in the production process

3.5 Decision Support Systems DSS

As the previous chapters show, organizations are highly complex systems that include many different aspects (social and technical) and dimensions (organizational, operational). Due to this complexity, the nature of management decisions that take all facts into account also get more and more complex. In order to manage these huge challenges and still make valuable decision for the organization, managers need support. One supportive tool, that sheds light upon specific sections of the complex problem are Decision Support Systems (DSS).

Decision Support Systems are supportive computer models that aim to help making decisions in problem situations that exhibit a higher complexity than a single or even collective mind can handle. Marek J. Druzdzel and Roger R. Flynn (2009, p. 1) state DSSs as *"…interactive computer-based systems that aid users in judgment and choice activities."* In order to get an overview of the nature of DSSs, first the character of decisions, decision making and a brief definition of a system in context of DSS is given.

3.5.1 Decision

As mentioned in chapter 3.5 the fundamental part of working with DSSs is the awareness of how decisions are structured and made. In general, a decision is *"a choice made between alternative courses of action in a situation of uncertainty"* (BusinessDictionary). Since decisions in the context of DSSs are still entirely made by humans, the fact of no total rationality must be taken into consideration. So it is important to point out that the reason of not making the best choice can be related to human patterns or due to the fact that – especially in complex situations – there is no "best solution". A deeper insight into human nature with personality types, experiences and other psychological insights will not be further discussed in this work.

Decision can be separated using different principles. Decisions can be of a tactical or strategic nature, or they can be related to business units such as marketing versus investment decisions. A very common distinction when it comes to decisions in the context of DSSs is the degree of structuredness. This differentiation evolved in 1960 where the two terms of programmed and non-programmed decisions were linked to this topic for the first time. Later on, a third type of so called semi-structured decision completed the nowadays accepted and used model. The terms structured, unstructured and semi-structured are related to a three-phase process:

- Phase one: Intelligence – searching for conditions that call for decisions
- Phase two: Design – inventing, developing and analyzing possible courses of action
- Phase three: Choice – selecting a course of action from those available

Depending on how many of these three phases are structured or unstructured the proper problem/decision type is defined. The structured decisions arise out of structural problems. Structural problems are typically repetitive routine problems which require standard solution methods. In structured problems, the way of how to find the best or a good enough solution is known. Good examples are cost minimization or profit maximization. The unstructured problems are complex problems for which no standardized solutions exist. This includes, as an example, the planning of a new service or the task of choosing a new R&D project. There is no predefined solution process; therefore the human intuition is often the one key factor.

The third decision, which is related to the third problem, is the semi-structured decision. In this case, the three phases are a mixture of structured and unstructured phases. For solving these types of problems, a combination of standardized solution procedures and human judgment is needed. Capital acquisition analysis is an example for a semi structured problem. (Burstein, Holsapple 2008; Kock 2005; Efraim et al. 2001)

To fully explain the nature of a decision, it is important to remember that a decision is a choice between different possible actions initiated by a specific uncertainty. It is of a different nature according to the perspective from which it is seen. When it comes to DSSs the degree of structuredness, linked to the three-phase process, is of importance in order to know if a DSS is even necessary or if a common solution procedure is sufficient.

3.5.2 Decision making

When it comes to decisions, it is important to understand the decision making process which precedes the decision itself. Usually, the decision making is a time lapse while the decision is just a point in time which finalizes the decision making process.

Frada Burstein and Clyde W. Holsapple (2008) state that decision making is a knowledge-intensive activity that changes the state of knowledge in an organization. It constitutes a learning process because after a decision is being made the decision maker has more knowledge due to his decision and its effect on the one hand. On the other hand, the time it takes to make a decision and realize its affection will also lead to a mature knowledge. They also describe decision making as a movement inside the “problem space” towards a decision and solution. In order to know if the decision is really going into the direction of the solution, different techniques are introduced in the literature. For example, decision trees or multiple-criteria decision making. In the context of time, decision making is a process which is related to the future, however a person’s mind will be affected by the past.

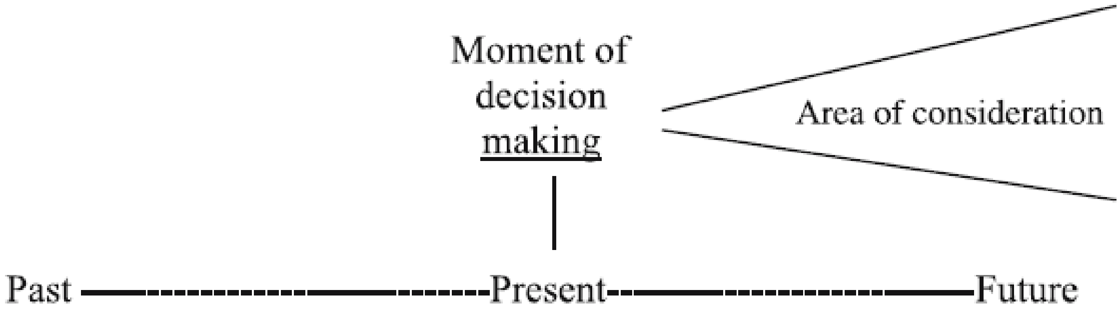


Figure 9 Decision making and time (Burstein, Holsapple, p. 57)

The decision making process

Efraim Turban, Jay E. Aronson and Ting Peng Lian (2001) describe the decision making process mor closely: They build up a model out of three main phases (intelligence phase, design phase and choice phase). These main phases are supplemented by two further phases: the implementation- and monitoring phase (which is more or less the controlling and therefore not shown in Figure 10).

In the “Handbook on Decision Support Systems 1” Frada Burstein and Clyde W. Holsapple (2008) work on the same model in a more general way by not implementing the model process to the concept yet. Hence, they are taking the perspective of decision making rather than the later on coming conceptual modelling view.

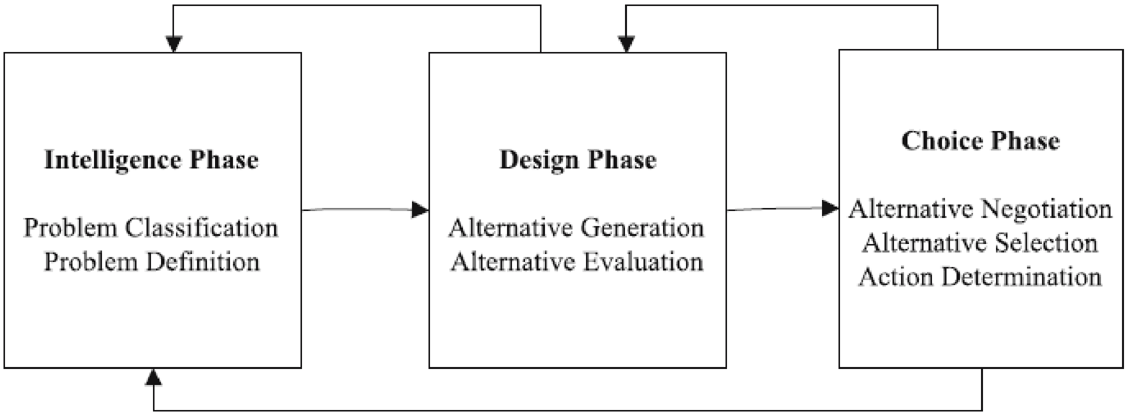


Figure 10: Intelligence-design-choice model (Burstein, Holsapple 2008, p. 85)

In this very general illustration the constant flow of activities is shown combined with the backflow to previous phases in the form of feedback.

In the first phase, the intelligence phase, the opening step is the problem classification, which mainly categorizes if it is a unique, similar to other known or routine problem. The next step within this phase is the problem definition. It evolves out of the problem classification and identifies the problem as stated as well as important characteristics. The second phase, the design phase, aims to define a desired state and how to get there. The alternative generation sets the different possibilities of how to reach the desired state and the subsequent alternative evaluation clarifies if this solution is within the established specifications. In the third phase, the choice phase, the generated solutions are analyzed, compared and contrasted. The three steps, alternative negotiation, alternative selection and action determination, help finalizing the third phase before starting the implementation. (Burstein, Holsapple 2008)

De Kock (2005) illustrated the decision making process as follows:

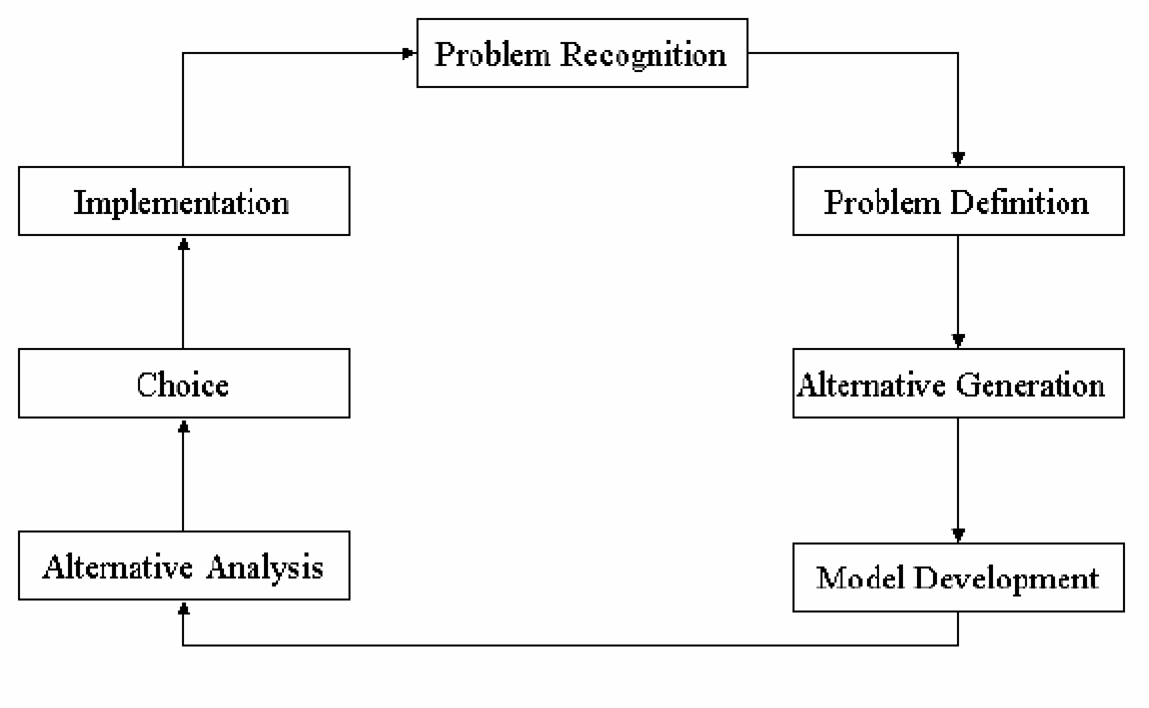


Figure 11: The DSS decision making process (Kock 2005, p. 14)

In this concept the same main steps are currently in place:

- Realizing that there is something that might be changed
- Analyzing and defining what the problem is at the current state
- Generating alternatives
- Abstracting the real situation by developing a model
- Evaluating the alternative solution by analyzing them
- Making a choice
- Implementing the new solution
- Closing the circle by verifying if the initial problem is solved

Decision makers

The decision makers are in the center of the decision making process. They are the last instance which has the power and responsibility to make a final decision. From the point of view of a DSS, they are the receivers who are being helped by the DSS's outcome. Decision makers can be managers, but also any other person who is in the position of making decisions such as team leaders, investors, committees and so forth. (Burstein, Holsapple 2008)

3.5.3 A system

Talking about Decision Support Systems, it is important to clarify the structure of a system. According to the Business Dictionary a system is *"An organized, purposeful* *structure that consists of interrelated and interdepended elements (…). These elements continually influence one another (directly or indirectly) to maintain their activity and the existence of the system, in order to achieve the goal of the system.”* (BusinessDictionary)

Averill M. Law and W. David Kelton (1991) describe a system as interacting entities (for example machines or people) that work toward a common goal. They further state that a system can be separated into two different types: discrete and continuous. Discrete systems change if, in certain points of time, a system variable is changing. Compared to that, continuous systems change their variables with respect to time. This maxim will also be of importance for the different simulation approaches.

The structure of a system is built by three main parts:

- The input
- The processes
- The output

It further has system boundaries that define which parts are being considered outside and inside the system. Figure 12 illustrates an example of how a system can be visualized.

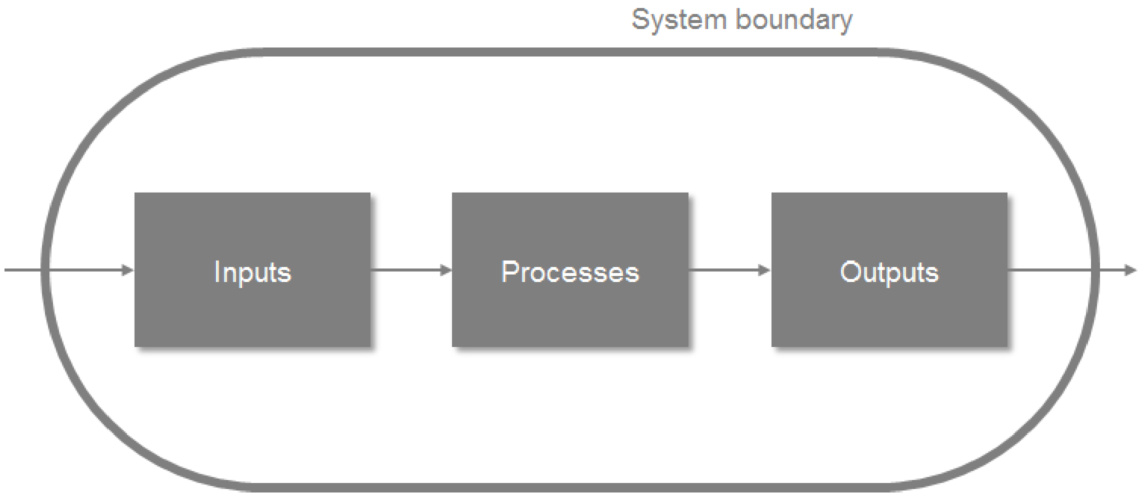


Figure 12: The system and its environment (Efraim et al. 2001, p. 43)

The inputs are those parts of the system which enter the system. The processes transform the inputs into outputs and the outputs are the finished products, information or other objects which are asked from the system. (Efraim Turban p.66)

The nature of a system will be further discussed in chapter 4.2.

3.5.4 Definitions of DSSs

Efraim Turban, Jay E. Aronson and Ting Peng Lian (2001, p. 103) define a DSS in their book “Decision Support Systems and Intelligent Systems” as a *“model-based set of procedures for processing data and judgments to assist a manager in his decision-making.”*

“a DSS is a computerized system which improves the activity of decision-makers situated on different levels in the chain of command (from supervision of different processes to leading positions in politics). At the same time, DSS stimulates the decision-maker to improve the decisional process and make the right decisions in order to obtain high and quickly visible performances (…).” (Cioca, Cioca 2010, p. 21)

“Decision Support Systems exist to help people make decisions. DSS do not make decisions by themselves (…) but attempt to automate several tasks of the decision-making process of which modelling is the core (…).” (Kock 2005, p. 7)

Marek J. Druzdzel (2009, p. 1), author of the paper “Decision Support Systems” briefly defines them as *“(…) interactive computer-based systems that aid users in judgment and choice activities.”*

Combining all these different definitions it can be said that a DSS has certain cornerstones:

- It is model-based
- It is computer-based
- It assists the decision maker
- It does not make decisions by itself

3.5.5 The architecture of a DSS

In this work two different theories will be introduced:

The three components theory:

Marek J. Druzdzel and Roger R. Flynn (2009) divide DSSs in their paper “Decision Support Systems” into three main components:

- The Database management system (DBMS)
- The Model-base management system (MBMS)
- The Dialog generation and management system (DGMS)

The database management system:

The DBMS serves as data base to the DSS, in which huge amounts of relevant data are being stored. It furthermore contains the logical data structure, which enables the interaction with the user.

The model-base management system:

The MBMS is the component which provides independence between the used models in the DSS. It translates data into the understandable information, which then supports the decision of the user.

As the name says, model-based systems rely on models. The nature of models and how they are evolved is further described in chapter 4.

The dialog generation and management system:

The DGMS is an easy to operate interface which helps the user, who often is a manager who cannot spend a great amount of time with handling the system. Its main responsibility is an userfriendly surface from which the user can benefit. (Druzdzel, Flynn 2009)

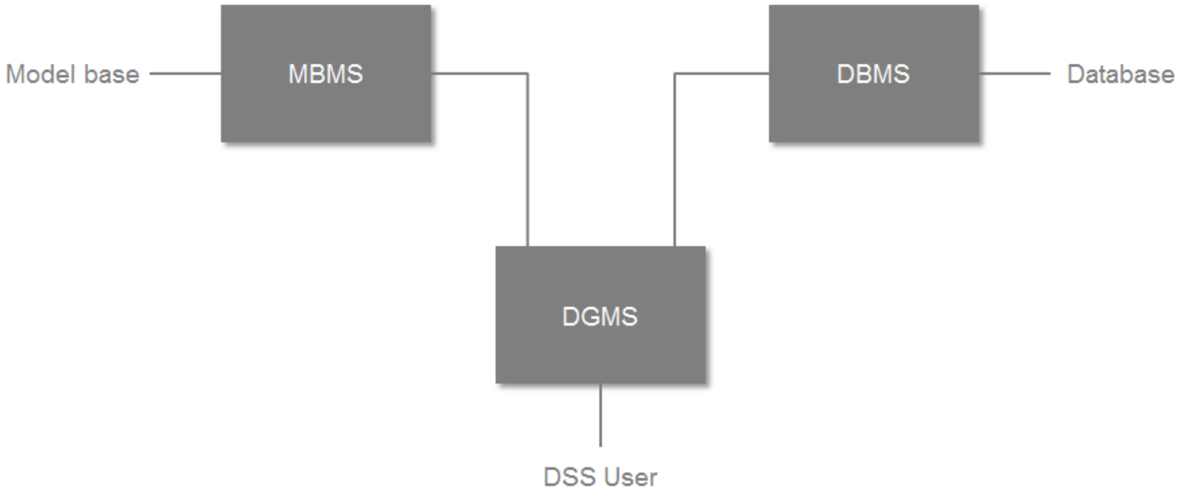


Figure 13: The architecture of a DSS (adapted from Druzdzel, Flynn 2009, p. 4)

Figure 13 shows the interaction of the three components. The user just interacts with the DGMS which then communicates with the other systems as necessary.

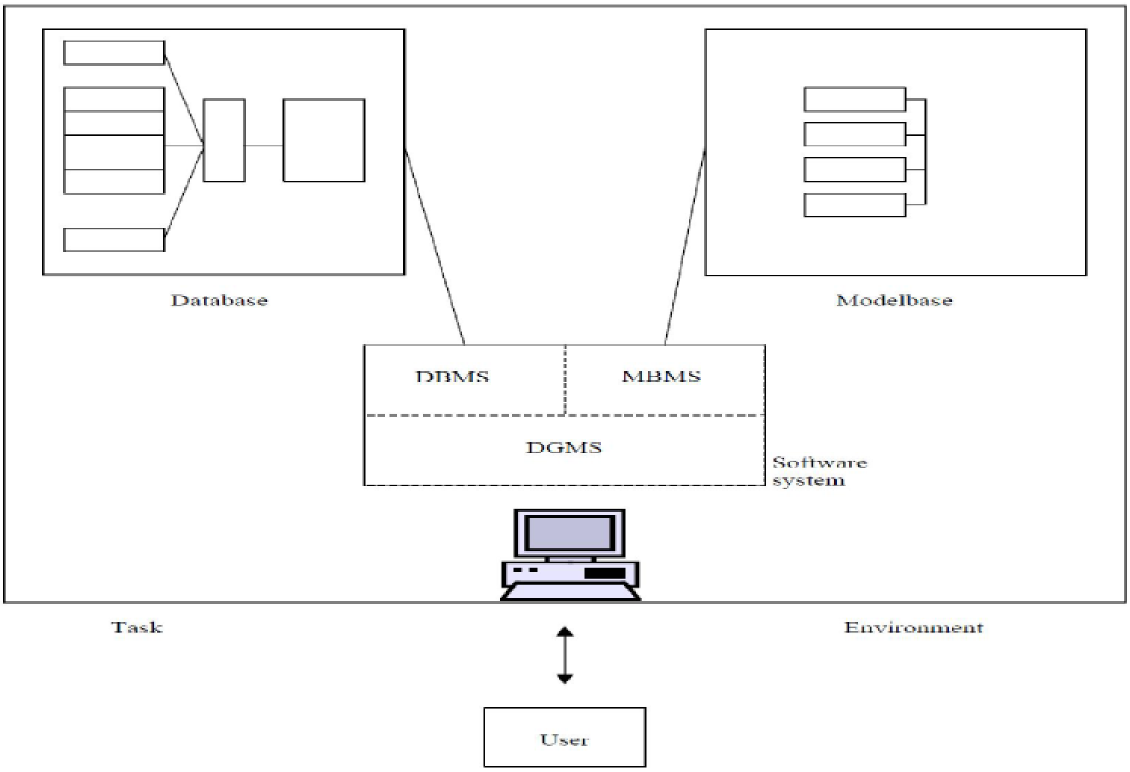


Figure 14: DSS components (Hameed 2012, p. 106)

Figure 14 shows the three components in a wider context. It points out that behind the DBMS there is the whole data base with its specific architecture. Behind the MBMS there is the modelbase which defines how the DSS works and processes the data according to the user's request for useful information. Figure 14 also shows, that the MBMS is the heart of the DSS in which all the data is processed, therefore the next main chapter will shed light upon the modeling process and its importance for high performing DSSs.

The four components theory:

According to the Handbook on Decision Support Systems, the generic architecture of a DSS is built out of four parts and therefore slightly differently explained than the model of Marek J. Druzdzel and Roger R. Flynn.

The four parts are:

- a language system (LS)
- a presentation system (PS)
- a knowledge system (KS)
- a problem-processing system (PPS)

The first three are the systems of representation where the LSs process all the input with which the DSS can work. The PS emits all the messages from the DSS and the knowledge system (KS) represents all the data the DSS has stored. These three components are essential for a DSS but without the problem-processing system (PPS) which, as the name says, processes all the data and inputs to information that the PS can further devote ((Handbook on DSS ch9 p.3) Figure 9Figure 15 shows how the four components interact in the DSS. (Burstein, Holsapple 2008)

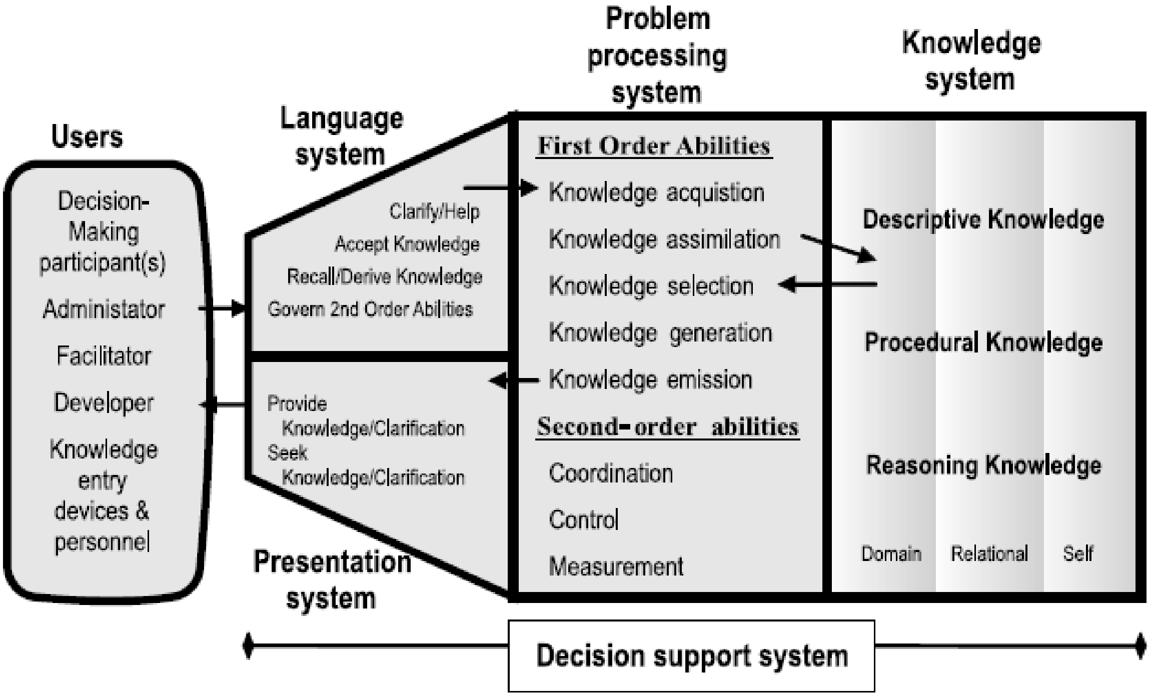


Figure 15: Basic architecture for decision support systems (Burstein, Holsapple 2008, p. 166)

4 Modeling and Simulation

There are many reasons why modeling and simulation are important tools. Examples are decisions and alternative evaluations, forecasting, different kinds of analysis and the like. (Birta, Arbez 2013)

Most of the DSSs include at least one decision model. Also modeling builds the bridge between a sociotechnical system and an organizational structure. Therefore, the definition and structure of models and the modeling process shall be explained here. (Burstein, Holsapple 2008)

4.1 Fundamentals of models and modeling

The process of modeling and models are abstractions of problems and situations of the real world. They can be used for different approaches.

4.1.1 Definition of a model

"A model is an abstraction of a specific problem or a class of problems in the real world." (Burstein, Holsapple 2008, p. 231)

A model abstracts a system of the real world in a simpler way by omitting details which are not important to the thought process. The reason of building models is the very often too high complexity of the real system. (Iglesias et al. 2010, p. 49)

"(…) a model is conceived as any physical, mathematical, or logical representation of a system, entity, phenomenon, or process." (Zeigler et al. 2000, p. 30)

4.1.2 Types of models

Models can be classified into three main types according to their degree of abstraction:

- Iconic models or physical model
- Analog (scale) models or schematic model
- Mathematical (quantitative) models

Iconic or scale models are mostly physical copies of the original system. Very often they are of a different scale so the level of abstraction is very low. A very good example is a photograph, which is an iconic model in 2d. An analog model is an abstraction of a system that behaves the same way, but looks differently. They can be charts and diagrams as well as physical models. The third type of model, the mathematical or quantitative model, is the one with the highest degree of abstraction. It is used when the relationships between the items inside the system become too complex, cumbersome and time consuming in calculation. In DSSs the problems are most likely being solved numerically by quantitative or mathematical models. (Efraim et al. 2001)

Since DSSs usually work with numerical or mathematical models, this type of model will be further analyzed in chapter 4.3.4.

The mathematical model:

"Most models used in (…) DSSs are mathematical models (…)" (Burstein, Holsapple 2008, p. 233).

The structure of mathematical models:

Mathematical models abstract the real problem with variables. These variables are the elements of the problem that influence the consequences of the decision.

The structure of such a model looks as follows:

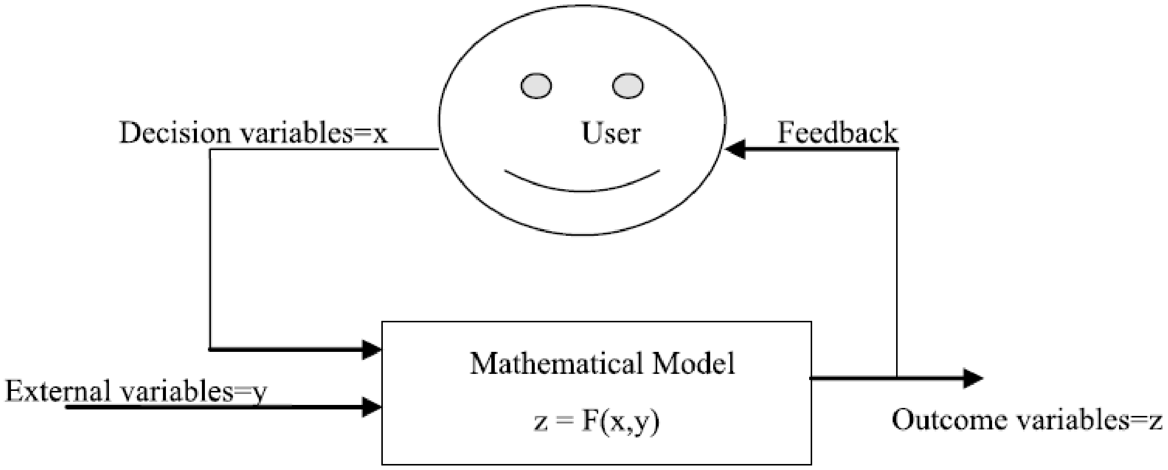


Figure 16: Structure of a mathematical model for decision support (Burstein, Holsapple 2008, p. 233)

In this figure the decision variables represent the input of the user. The external variables are those that are based on the environment and therefore cannot be controlled by the user. The outcome draws the final picture to this specific set of variables. In between the inputs and outputs the mathematical model, or how Turban, Aronson and Liang call it the mathematical relationship, is placed. It includes the rules and formulas of how the inputs are being processed into outputs. (Burstein, Holsapple 2008)

The three classes of mathematical models:

There are three main classes of mathematical models that each has certain benefits for the decision makers. Given to the specific problem situation, one of these types can be chosen (Burstein, Holsapple 2008):

1. Prescriptive models
2. Predictive models
3. Descriptive models (for simulations)

4.1.3 The benefits of models

Turban, Aronson and Liang (2001) state several points of the benefits of using models instead of working on the real system:

- Model manipulation: It is way easier to change variables within the model to try out different scenarios. Meanwhile, the daily business in real life is not being influenced and can keep going.
- Time: Within a model, time can be adjusted as wanted. Therefore years can be simulated inside the model within short amounts of time.
- Costs: Mostly the costs of building a model and changing variables within it are significantly lower than starting to adapt the real world situation.
- Costs of failure: If an idea of how to change a certain situation turns out to be bad, the costs within the modeled scenario stay low with the exception of some additional costs. If a decision was made in real life and it turns out to be a bad one, the costs of fixing it and the costs of the meanwhile lost business activity can explode.
- The amount of solutions: As an example, mathematical models can generate dozens of possible solutions. This provides the decision maker with a great choice of options that would not have been available in real life.
- Models foster learning and training

4.1.4 The modeling process

Modeling is the process in which the decision model is being evolved. In the book “Handbook on Decision Support Systems” Liang, Lee and Turban (2008) describe several steps that are typically included in a modeling process:

- Problem definition: The scope of the model and the key parameters which are related to the problem must be determined.
- Identification of the nature of the variables and parameters.
- The relationships of the variables need to be structured.

- Implementation of the model into a software.
- Validation of the computer model.
- Iteration of these steps until the model fits the requirements.

Nowadays several different frameworks are available to help facilitating the modeling process.

One that will receive a thorough examination will be conceptual modeling, a framework which will also be used in the practical part of this work.

4.2 Conceptual modeling and the conceptual model

As mentioned in 4.1.1, a model is an abstraction of a problem. Modeling, however, is the process of building the model. The question is how this abstraction process is structured and done. There are many different frameworks that help making these abstractions step by step. A specific one, that will be introduced in this chapter, is the conceptual modeling framework of Robinson. Robinson (2008a) states in his paper "Conceptual modelling for simulation part 1: definition and requirements" that this usually is the most important part of a simulation project. He further calls it an art rather than a science, which further highlights the complicated nature of this process. So the very first question that will be answered is: "What is conceptual modeling?"

4.2.1 Conceptual modeling (CM) an Introduction and definition

"*Conceptual modelling is about abstracting a model from a real or proposed system."* (Robinson 2008a, p. 8). As the word abstractions implies, it is not a one to one copy, but a simplification of the reality. Out of several different definitions from literature, Robinson summarized that:

- Conceptual modeling is a journey, starting from a brief problem definition, going over model requirements to a definition of how the problem should be modeled.
- Iterations and repetitions are essential and always change and revise the model throughout a study.
- The conceptual model is always a simplification of the real situation.
- The conceptual model does not include the software code.

Combining all these bullet points, the following definition is formed:

"*The conceptual model is a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model" (Furian et al. 2015, p. 82)*.

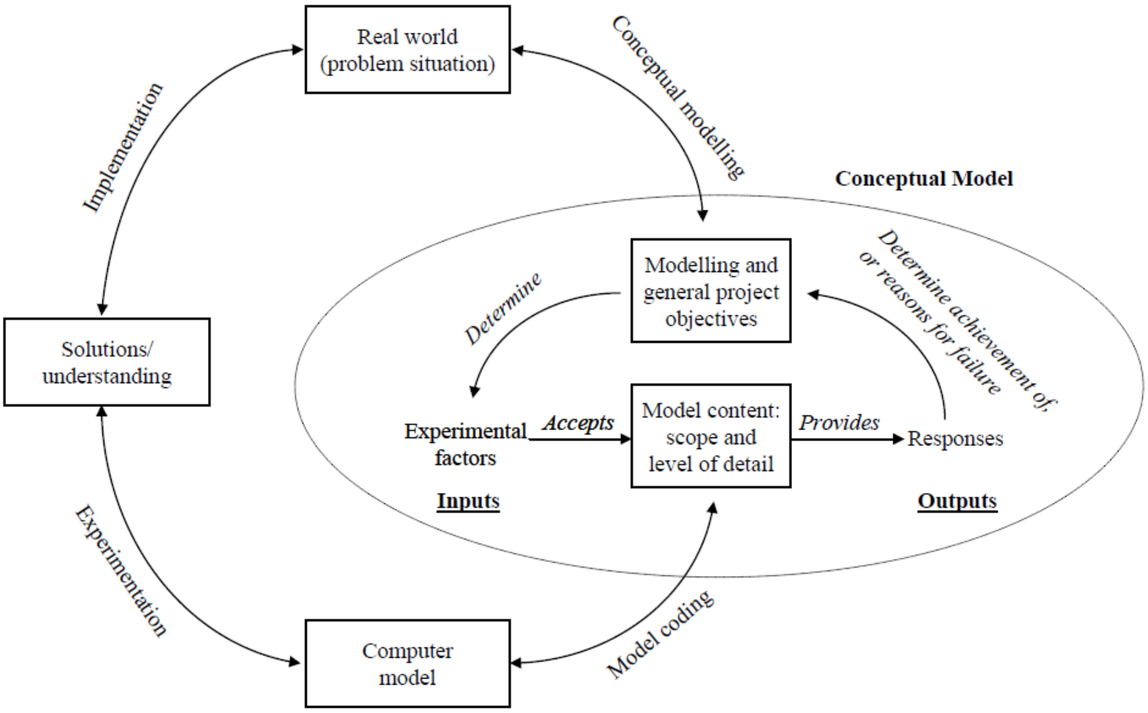


Figure 17: The Conceptual model in the simulation Project Life-Cycle (…) (Robinson 2008a, p. 12)

As the title of Figure 17 points out, this concept describes a whole simulation project life-cycle and the place of the conceptual model in it.

In the following chapters each step of the whole simulation project life-cycle will be described in order to get a better understanding of conceptual modeling and the conceptual model itself. Three important roles that will be mentioned are (Robinson 2008a):

- The client: The person or persons that gave the order to the project and are interested in the result
- The modeler: The person or team that develops the model
- Domain experts: All the persons that can help building the model with their high degree of knowledge and experience

4.2.2 Problem definition

The motivation for evolving a conceptual model is, of course, always a problem that shall be improved. The definition of the problem is not part of the conceptual model, but still an important part of the project life-cycle. The model, as described before, is only a reflection of parts of the real life that addresses the problem situation. The double arrow shows that both, the problem situation and the conceptual model, affect each other in an iterative manner which leads to a deeper understanding of the system. In the end, a deeper understanding is one of the main goals, because only a fundamental comprehension will bring up new and target-oriented solutions. Robinson describes three possible scenarios when it comes to understanding the problem situation:

- Both, the expression and understanding of the problem situation, are good
- Although the problem seems well understood and expressed, it is not the case
- The worst case, the problem situation is insufficiently understood as well as poorly expressed

It is obvious that, depending on which situation resembles the own situation, it becomes more easy or difficult to evaluate the model. In the worst case of the third scenario, helping techniques such as soft system methodology, cognitive mapping or others are proposed. As soon as the problem becomes clearer to the user, the conceptual model can become more and more useful to the whole process. (Robinson 2008a, 2008b)

4.2.3 The conceptual model

As mentioned and shown in 4.2.1 the conceptual model itself is an own system, that is embedded in the simulation project life-cycle. It consists of (Robinson 2008a):

- Objectives
- Inputs (experimental factors)
- Outputs (responses)
- The model content

Objectives:

When talking about objectives, it is important to differentiate between the modeling objectives and the general objectives. The modeling objectives describe the model and modeling project’s purpose. The general objectives determine other factors such as the nature of the model and its use. (Robinson 2008a, 2008b)

Modeling objectives:

When it comes to the process of modeling, it is always important to bear in mind that the main goal of the project is never the evolvement of a model. Although it helps to gain a lot of important insights, this is not the end of the project. This is just a step further and once the model is set, the simulation will start and different scenarios will be developed. In this iterative process, potential for improvements will be identified and this is what the real purpose is. Robinson (2008b, p. 294) says that *“The objectives should always be expressed in terms of what can be achieved from the* *development and use of the model."* They can be expressed in three different components:

- Achievement: What does the client want to achieve?
- Performance: Quantitative measures such as decrease of labor costs by 10%
- Constraints: The space in which the modeler can move. For example, available budget or other fixed boundaries that have to be observed

To conclude, the modeling objectives are a closer description of the conceptual model that help keeping an eye on the final goal as well as defining in which corridor the modeler can move.

The general project objectives:

The general project objectives are, as mentioned, more related to the model itself than its content. The main points which have to be considered are:

- Flexibility: If, for example, a model is changed very often to get the final result the flexibility will be a very important factor.
- Run-speed: Depends on how many experiments will be performed using the model.
- Visual display: If the visual output is important, it can even be in 3d. For other projects it might just be about the numbers and the visualization is not important at all.
- Ease of use: Depending on who will be working with the model, the interface might be easy to control.
- Model/component reuse: Parts of models, or even whole models, can be reused. This has to be considered in advance.

Once the modeling and general objectives are clear, the next step, the Inputs, can be defined.

Inputs (experimental factors):

The inputs, or experimental factors, are the quantitative and qualitative data that can be changed to achieve the modeling objectives. They are, therefore, the set-screws which influence the outcome. (Robinson 2008b)

Outputs:

The outputs are also called responses. They are the responses of the model after one run. Within this response the user can see if the model objectives were achieved or not. If not, they show why the model failed. (Robinson 2008a)

Model content:

As Figure 17 shows it is the part where the inputs are transformed into outputs. The model content consists of two main parts: the scope and the level of detail. While the scope tends to determine the boundaries of the model, the level of detail sets the depth. (Robinson 2008b)

The scope:

Simulation models are conceived of four types of components:

- Entities
- Activities
- Queues
- Resources

Robinson introduced three steps to define the scope of a model:

- Step 1: Identification of the boundaries of the model
- Step 2: Identification of the entities, activities, queues and resources
- Step 3: Defining which components will be included and which ones will be excluded from the model. In order to find out it is important to ask if each component is important to one requirement at least. The four main requirements of a conceptual model are validity, credibility, utility and feasibility.

The level of detail

“That is, determining the level of detail for each entity, activity, queue and resource to be included in the model.” (Robinson 2008b, p. 298) When talking about the model content it is important to introduce assumptions and simplifications which have to be made repeatedly.

Assumptions and simplifications:

Assumptions have to be made when the world being modeled exposes uncertainties. Not everything can be modelled one by one or can be abstracted perfectly. Simplifications are being used to save time and costs during the modeling process. Furthermore, they can reduce complexity and improve transparency. (Robinson 2008a)

Requirements of a conceptual model:

As mentioned before, validity, credibility, utility and feasibility are the four main requirements for conceptual models. In the context of conceptual modeling Robinson defines them as follows: (Robinson 2008a, p. 21 until p. 23)

Validity: *“A perception, on behalf of the modeller, that the conceptual model can be developed into a computer model that is sufficiently accurate for the purpose at hand.”*

Credibility: “*A perception, on behalf of the clients, that the conceptual model can be developed into a computer model that is sufficiently accurate for the purpose at hand.”*

Utility: “*A perception, on behalf of the modeller and the clients, that the conceptual model can be developed into a computer model that is useful as an aid to decision-making within the specified context.”*

Feasibility: “*A perception, on behalf of the modeller and the clients, that the conceptual model can be developed into a computer model with the time, resource and data available.”*

Beside these four main requirements, one additional main requirement is mentioned in every literature: to keep the model simple. Or as Robinson expressed it: *“(…) keep the model as simple as possible to meet the objectives of the simulation study*”. The reason to do so may seem obvious, but is often forgotten:

- Faster development of the model
- More flexibility
- Less data-requirement
- Faster processing
- Better understanding of the model and therefore easier interpretation of the results

4.3 Simulation

In chapter 4.1 and chapter 4.2 the process of modeling and the structure and nature of models was explained. In this chapter, an simulation approach which is built upon these models, will be introduced.

Simulation is an assumption of characteristics of the reality. *“(…) simulation is a technique for conducting experiments (e.g., what-if analyses) with a computer on a model of a management system.”* (Efraim et al. 2001, p. 185)

Since simulations are descriptive methods, a “best solution” is never the output. Instead, certain systems will be examined under different conditions. They are used in complex situations, when numerical techniques for optimization become too sophisticated.

4.3.1 Advantages of simulation

Despite simulations mostly not having a specific “best solution”, other great advantages may arise that make this tool so valuable for managers and other decision makers. (Efraim et al. 2001)

- Time compression: They can depict long time-spans of systems to give the decision maker a feeling for the long term effects.
- The descriptive nature: Decision makers can ask what-if questions and glance at different scenarios of a defined problem.
- Experimentation: While experimenting with the system variables the user gets a feeling of the importance of different inputs.
- Knowledge of the problem situation: Both, the modeler and the decision maker, need a good understanding of the problem situation. In order to get that they need to interact a lot what leads to a gain of knowledge about the problem situation.
- No generalized understanding necessary: Typically, a simulation and its model are built for particular single problems. Therefore the manager does not need a generalized wide view, which in a lot of cases, is rather difficult to achieve.
- Wide range of use: Simulations can handle a great variety of different problem types.
- Real complexities: Usually they can deal with real complexities. Simplifications are very often not necessary as for example in real probability distributions.
- Only option: For some unstructured problems, simulations are the only method for dealing with the problem.

4.3.2 Disadvantages of simulation

There are disadvantages which make it unuseable for certain situations. (Efraim et al. 2001)

- No optimum: Simulations do not guarantee optimal solutions.
- Slow and expensive: It can be a slow and costly process to work with simulation models.
- No multiple usage: Usually, solutions and inferences are not transferable.
- Complex software: Using simulation software very often requires specific know-how.

4.3.3 The process of simulation

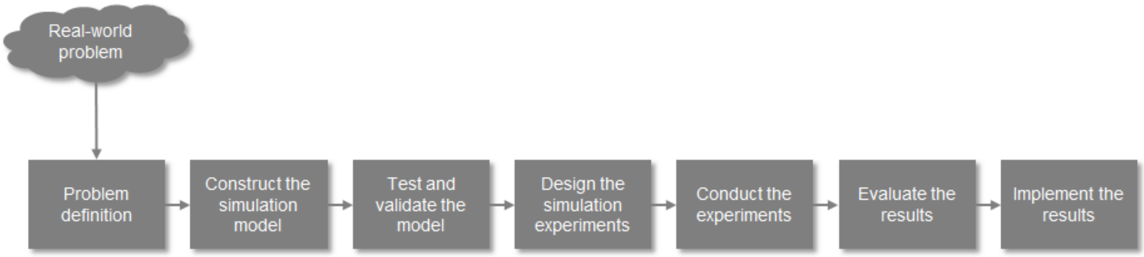


Figure 18: The process of simulation (adapted from Efraim et al. 2001, p. 187)

Figure 18 shows the process from the real-world problem to the result implementation.

- Problem definition: Specification why a simulation makes sense. Some important aspects such as the system's boundaries are defined here.
- Construct of the simulation model: The variables and their relationships are defined in this step. Data gathering is also an important part of this phase.
- Testing and validating the model: During this step it is evaluated if the model represents the system under study.
- Designing of the experiment: The simulation run-time is fixed during this step. Accuracy and costs are also factors which have to be defined during this phase.
- Conducting the experiment: During this step the actual simulation is operated.
- Evaluating the results: In this very important step the results must be discussed and interpreted.
- Implementation of the changes: If the results prove to be reasonable, the implementation starts.

As shown in this chapter, simulation is a very important tool that needs clear and stepwise proceeding. It also revealed the importance of an elaborated model after which the simulation can execute. Chapter 4.2 will introduce a framework which, step by step, shows how to build up such a model. (Efraim et al. 2001)

4.3.4 Simulation approaches

A simulation approach is built out of three main components:

- A time advanced mechanism: Defines how the simulation timely proceeds. The two main types are:
    - The next-event approach: Simulations, which are using this mechanism, always directly jump to the most important future event and change the variables according to this event.

  - The fixed increment approach: As the name says, it has a fixed time step value. According to this value it moves forward, changes the variables and afterwards moves forward in time again.
- The variable's representation scheme: it defines on which items the approach focuses. These can be objects, variables that are tracked or other items.
- The updating mechanism: Is a set of rules which defines how the variables are changed at each time step.

According to the set of these three components the type of simulation can be defined. The four possible types are the discrete event simulation, the system dynamics simulation, the agent-based modeling and the hybrid simulation. (Hettinger et al. 2015)

Discrete event simulation:

The discrete event simulation (DES) is a commonly used approach for simulations which processes stepwise similar to following a flow chart. It is built by so called entities which represent objects like persons, organizations and others. Attributes are sets of characteristics which are assigned to the entities. Examples for attributes, among others, are certain time events such as arrival times or also probability distributed functions. They are next-event approaches. (Hettinger et al. 2015)

System dynamics simulation:

The system dynamics simulation is a fixed-increment simulation approach. It is an approach that processes in a diagrammatic form linked to flows, arrows, stocks and auxiliary variables which's interactions are based on differential equations. They work in an iterative manner, so called loops that lead to subsequent variable changes. The interaction of these changes, which can be either balancing or reinforcing, represents the behavior of the complexity of the modeled system. (Hettinger et al. 2015)

Agent-based modeling:

This newer approach is also based on entities, but they are called agents. Contrary to entities, agents can be set upon rules that enable higher flexibility. The agent-based modeling approach can work with either fixed-increment or next-event time-advance mechanisms. (Hettinger et al. 2015)

As shown in this chapter, simulation approaches depend on models which define their boundary conditions, interactions and targets. In chapter 3 the general characteristics and the process of building a model were explained. In the following chapter a rather new modeling framework for modeling for simulations will be introduced.

5 Maintenance organizational simulation approach

In this chapter the methodology/framework of how to model the concept of a STS for a simulation approach in order to gain the possibility to evaluate organizational maintenance structures to obtain a valuable decision support shall be introduced. The focus lies on the maintenance structures of producing companies. This puzzle will be built out of four main steps: the describing part, the conceptual modeling framework, the simulation and the results interpretation and the implementation part. Figure 19 illustrates the stepwise approach. The issues outside the green box, which mainly include the final decision and its implementation, will not be part of this work.

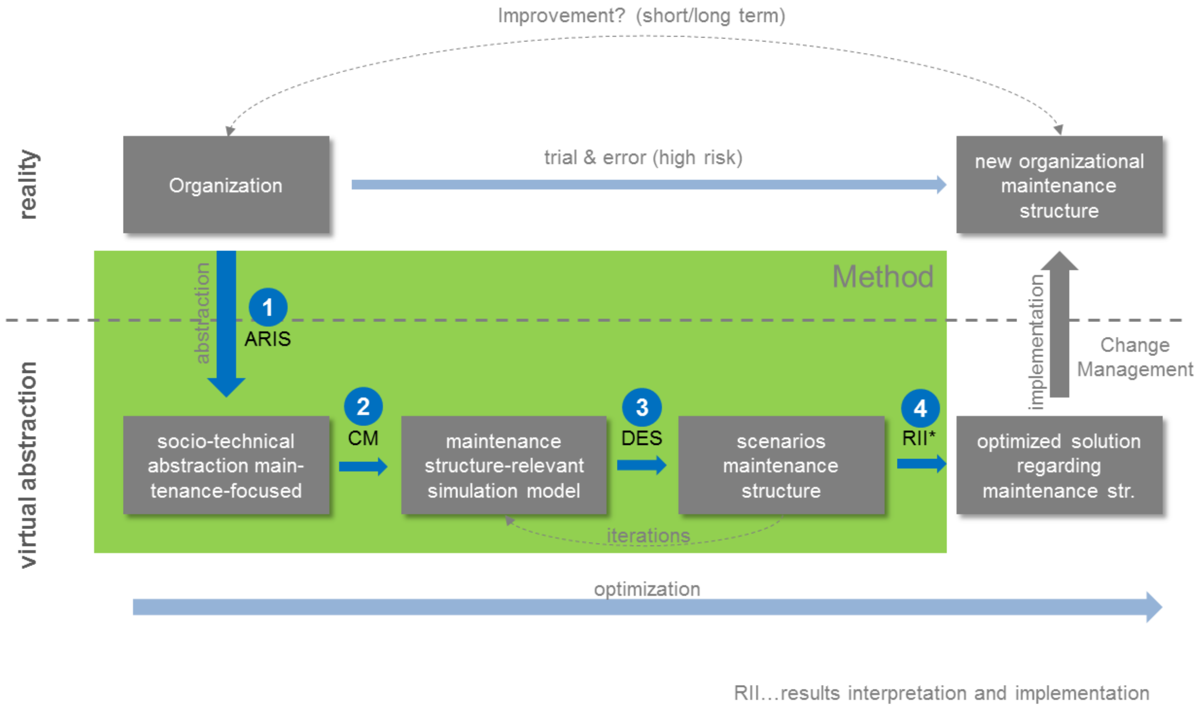


Figure 19: The four step methodology of this work

The first step, the problem & system formulation (abstraction part) will deal with a method of how to transform an existing organizational system into valid formulations on paper. The second part will mold the maintenance relevant parts of these formulations into a model framework that can be used by a DES. The third element, which will only be described briefly, the DES, will transform the modeled inputs into supportive information. The fourth step's aim is the interpretation of the results to provide an understandable decision support for the decision maker.

5.1 Problem and System Formulation

This chapter deals with the process from the first time of looking at an organization until this organization is brought to paper in useful depictions. The most famous framework to do so is the Unified Modeling Language (UML) standard, which is defined in the ISO/IEC 19505. The concept that will be introduced and followed here is the ARIS (Architecture for integrated information systems), a framework for business process modeling. ARIS represents sociotechnical systems in systems of models.

The main goal of ARIS is the development of an overarching view on the core processes of an organization and their continuous optimization. It is a process management tool that can be seen as a bridge from business to IT. Or as Becker, Niehaves and Janiesch (2007, p. 135) put it that way: *“The Architecture of Integrated Information Systems (ARIS) is an example of a framework that offers researchers and practitioners the possibility to model in an integrated socio-technical perspective.”*

The ARIS is always illustrated as a house, the so called house of ARIS which reflects the five main views on the organization: (Sutcliffe 2000; Kronz 2005; Kruppke et al. 2006; Matthes 2011)

- Organization view: Builds the roof of the house and includes all organizational units (all kind of resources) and their interrelations.
- Control view: Integrates the different views into a logical timeframe
- Data view: Describes all the information objects (production data, documents,…).
- Function view: represents all processes and their interrelations.
- Product/Service view: Defines the output of the organization.
- Resource view: Includes the resources of the IT (hard and software).

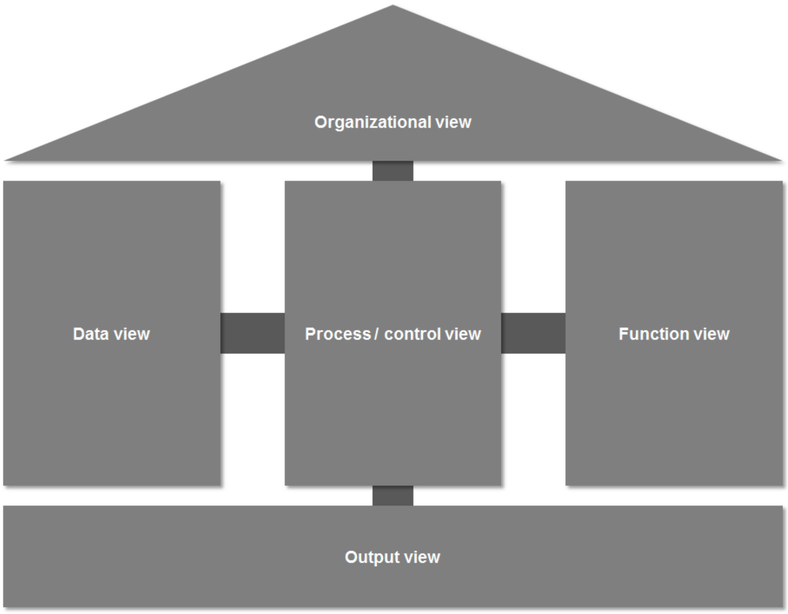


Figure 20: The house of ARIS

5.1.1 The function view:

"Business process strategy creates functions that enterprises must carry out efficiently." (Scheer 1999, p. 21) The main goal of the function view is the illustration of these mainly static function structures. For this purpose the functions have to be described from beginning to end. The tool that shall be used to develop the functional view is the *function tree*. This tool describes the interdependences of the functions of a system. A problem is divided into sub-problems. (Scheer 1999)

The function tree of the OEE is measure related function. Though, other function-trees are of importance as well. Figure 21, for example, illustrates the function view of the production.

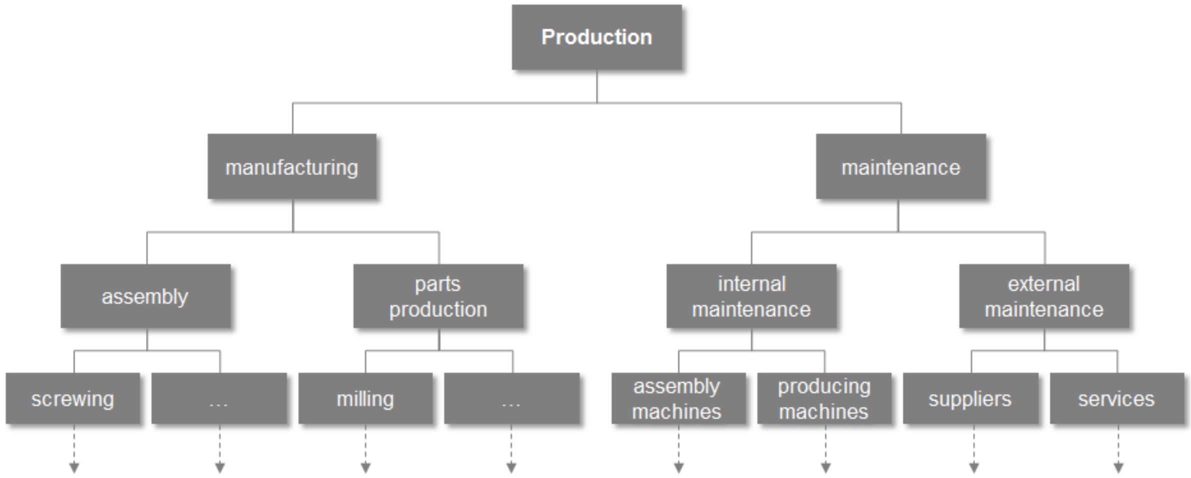


Figure 21: Example of the function tree of a production unit

Once all the functions and their interrelations are defined the definition of the next view, the organization view, can be developed.

5.1.2 The organization view

Its aim is the hierarchical description of the organization. It outlines the organizational units and their reporting and communication relationships. The most common tool, that will be used in this work as well, is the *organigram*. The book "Prozessmodelierung mit ARIS" describes an organigram as a graphical depiction that illustrates the organizational units, workplaces, workers and their hierarchical relations. (Scheer 1999; Seidlmeier 2002)

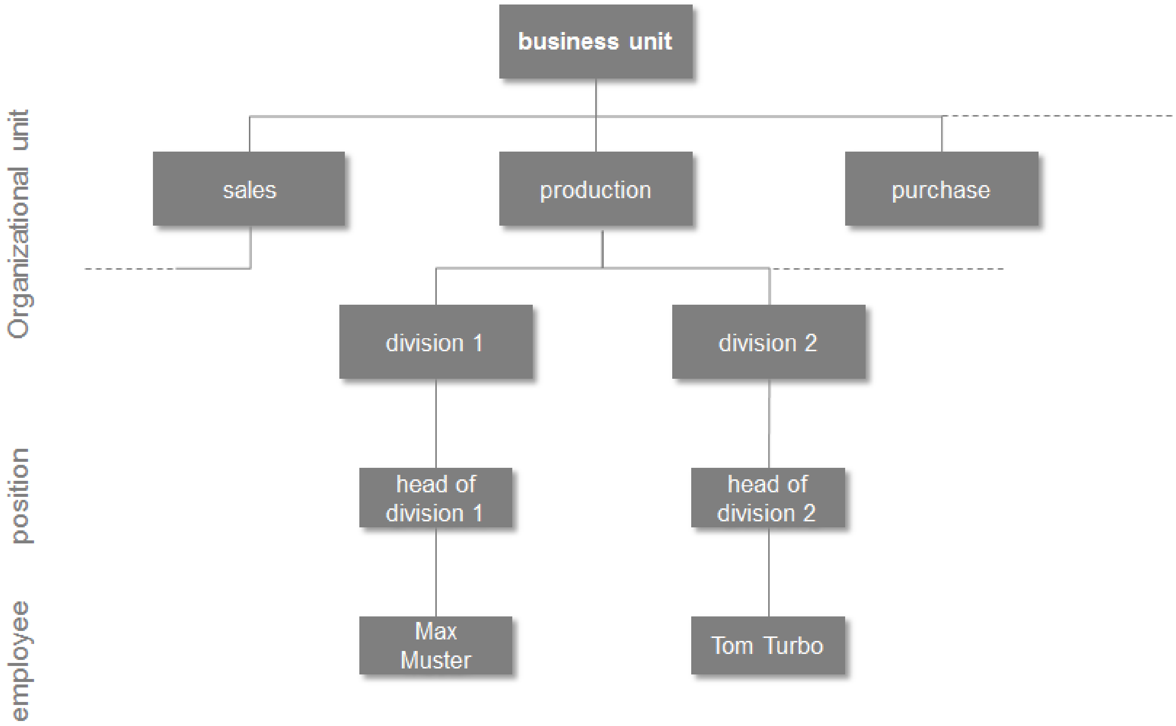


Figure 22: Section of an *organigram*

5.1.3 The data view

The data view describes all the relevant information about objects such as production data, documents and the like. It answers the question *"What information is produced or needed?"* (Scheer et al. 2002, p. 53) The tool that is used mostly for this step is the entity-relationship model (ERM). This approach will also be used in this work. Entity-relationship modeling is of high importance in the process of system design. Figure 23 shows an transparent example that describes the purpose of the entity-relationship model. As can be seen, it takes the relevant objects and the entities and defines how they are related to each other. In this example the entities are *"husband"* and *"wife"*, their relationship is *"married to".* (Matthes 2011; Chen 2002)

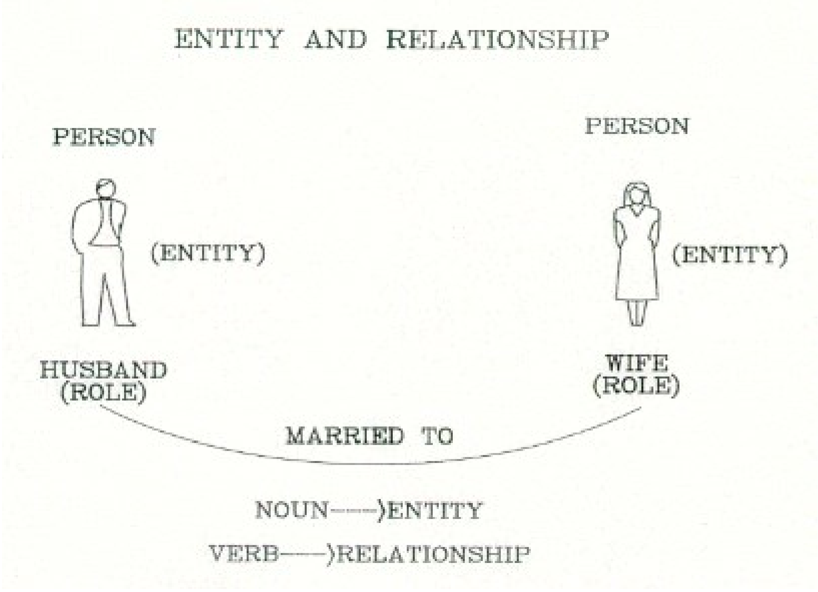


Figure 23: The concept of Entity and Relationship (Chen Pioneers p.3)

A final ERM is build out of entities (depicted as rectangular box), attributes (depicted as oval) and relations (depicted as diamond). If attributes are underlined it means they are unique. The example of a final ERM is shown in Figure 24:

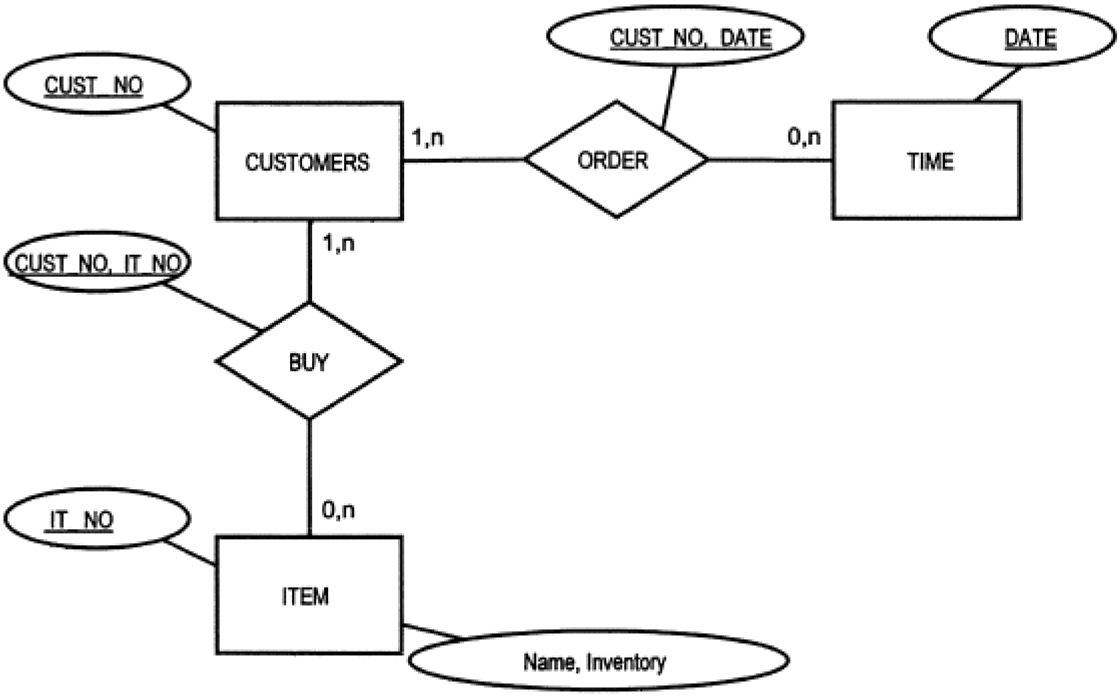


Figure 24: ERM excerpt of a sales data structure (BPM[Prof… p.84)

5.1.4 The output view

The output description, which is often done as the first step, is one of the main parts of defining a business process. Output is a collective term of all the products or services an organization offers. Prof. Scheer (1999) sub divides output as follows:

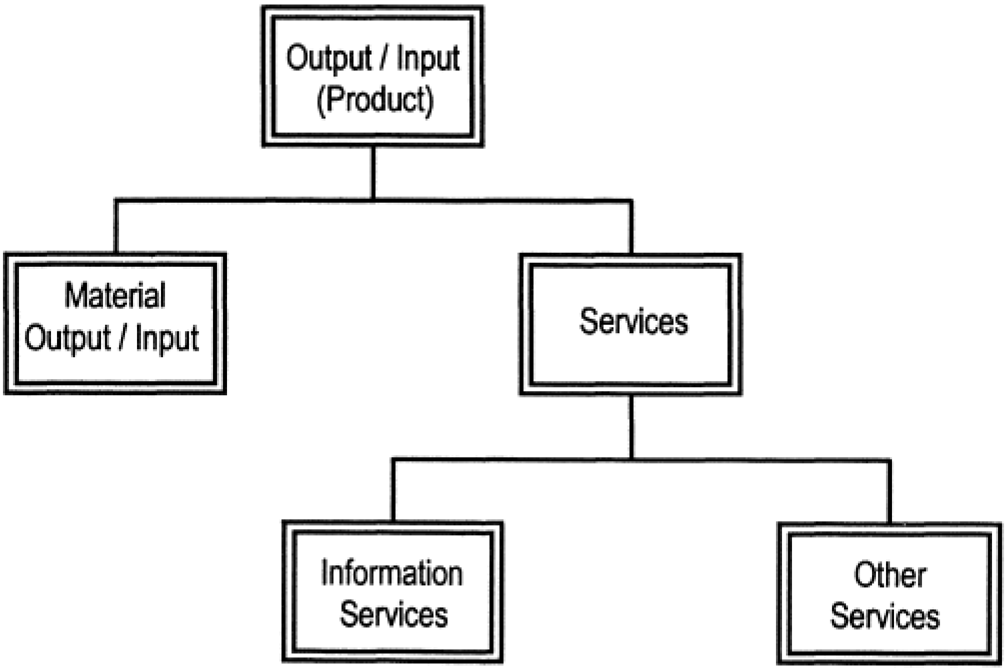


Figure 25: Types of output and products (Scheer 1999, p. 95)

The term *"Other Services"* in Figure 25 could be for example financial services.

The main aim of the output view is a good overview of the entire product and service portfolio. In this step the principle of a product/service tree will be followed, which gives a hierarchical overview of the output.

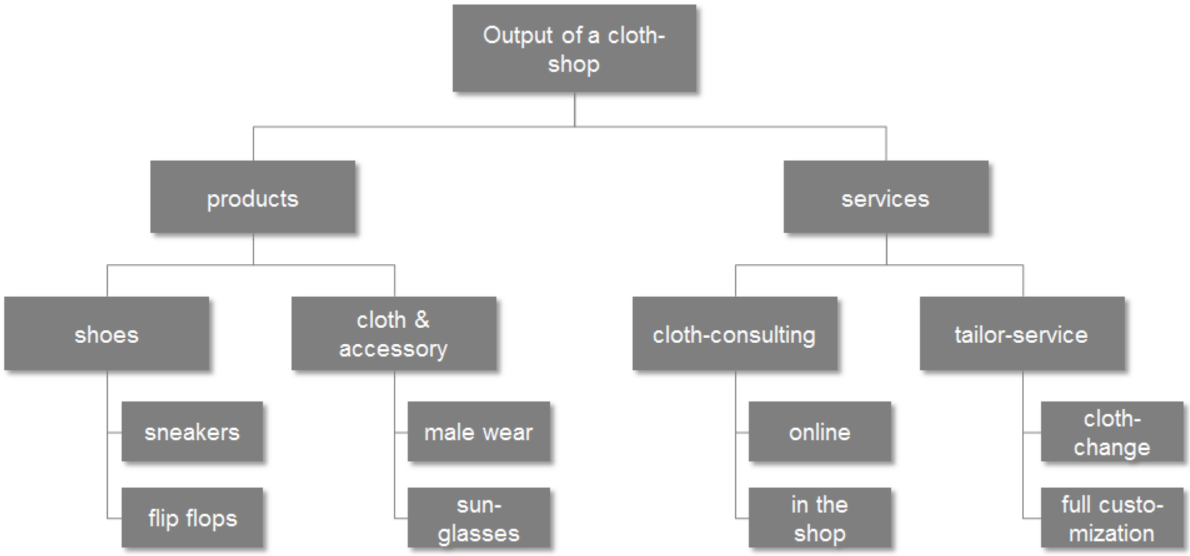


Figure 26: Example of a product tree

5.1.5 The process / control view

In this final step of the ARIS methodology all the previously covered views are connected. Its aim is to describe the dynamic behavior of the organization. The method that will be used is a process flow chart (swim lane) which will be extended later in chapter 5.2 by the Hierarchical Control Conceptual Model (HCCM).

A process is a logical sequence of functions. A function is a task of an object. A function is always started by a start event, the so called trigger and they are finished as soon as a defined target, a new event (end event), is reached. (Seidlmeier 2002)

Swim lane:

"(…) the swimlane diagram has become the primary modeling tool for planning business process reengineering (…)" (Jeyaraj, Sauter 2014, p. 28). It shows a sequence chain of internal activities that are executed to gain output. It visualizes this process to obtain analysis and optimization. The main characteristic of this process flowchart type is the separated illustration of all included actors in individual swim lanes. All the activities that belong to an actor are placed in its swim lane. The development of a swim lane diagram follows the Business Process Modeling Notation (BPMN) *"(…) a standard, graphical modeling representation for business processes."* (White 2008, p. 0; Jeyaraj, Sauter 2014)

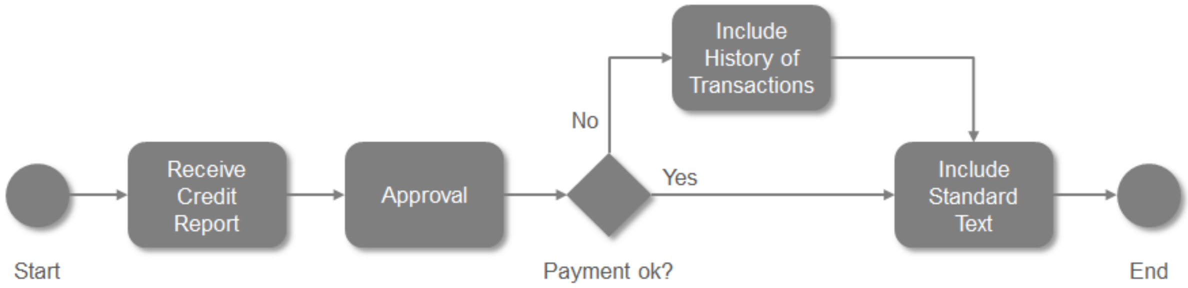


Figure 27: A sample BPMN Process (adapted from [Derek_Miers…p.2)

Figure 27 shows a very general example of a process that is visualized by the BPMN. The BPMN separates the process steps into activities, events, gateways, artefacts and connectors.

Activities:

Activities are the work that is actually performed in a business process. They are split into atomic and compound activities. An atomic activity cannot be further drilled down to see another process below. The atomic activity is the task. A compound activity includes a sub-process. (White 2008)

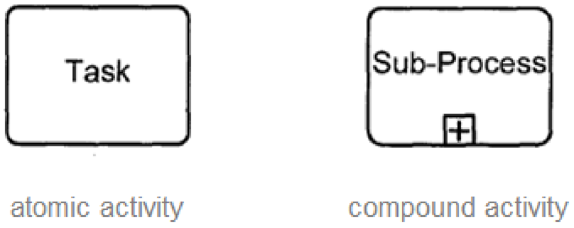


Figure 28: Types of activities (White 2008, p. 62)

Events:

They are happenings that affect the processes such as delay, interrupt and start. Their symbol is a circle and according to the style of boundary it can be a start, intermediate or end event.

Figure 29: Types of events (adapted from White 2008)

Events are mostly classified by symbols which are placed insight the circles. One that will be of interest in this work is the clock symbol which represents a timer that runs out within a defined time span.

Gateways:

Gateways can split as well as merge the process flow according to the controlling of the flow. Whenever there is, for example, a yes-no decision, this diamond symbol is used.

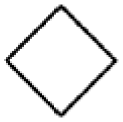


Figure 30: A Gateway symbol (White 2008, p. 133)

Also in the case of gateways, certain symbols can further define what the main role of these gateways is.

Artifacts:

"Artifacts provide a mechanism to capture additional information about a Process, beyond the underlying flow-chart structure. This information does not directly impact the flow chart characteristics of a Process." (White 2008, p. 163) They will not be further described in this work.

Connectors:

As the name says they connect two objects. There are three main types:

- The sequence flow: Defines in which order the processes are proceeded
- The message flow: Represents the information flow
- Associations: They link artifacts and objects

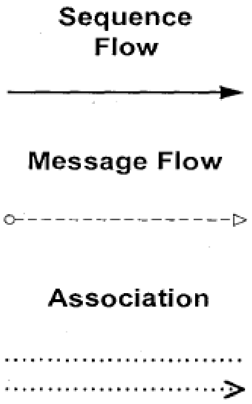


Figure 31: The types of connectors (White 2008, p. 169)

5.1.6 Conclusion

The first step is the step of abstracting an organization via depictions. The introduced method, the ARIS method, takes different views into account and brings them together in the house of ARIS. Figure 32 illustrates the five views and the chosen tools:

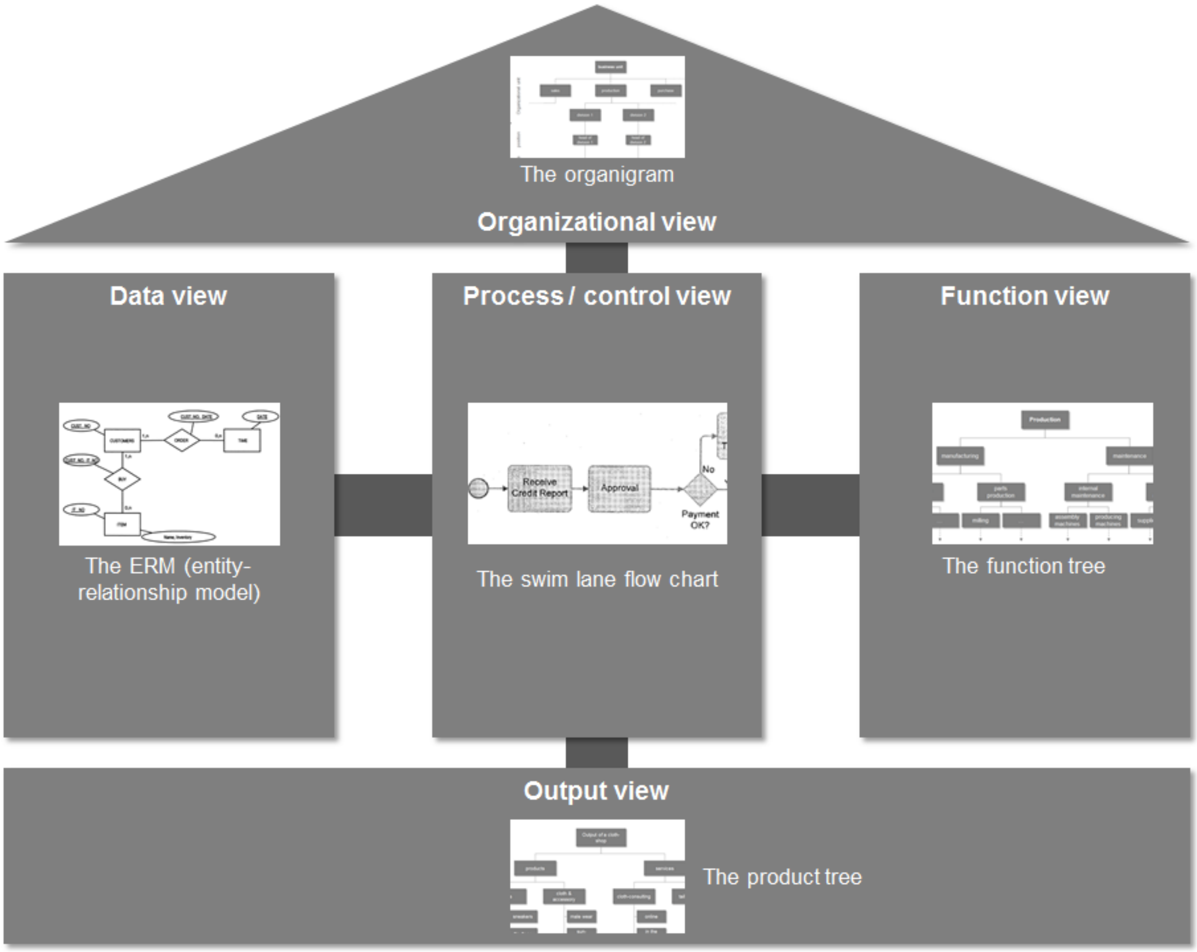


Figure 32: The house of ARIS and the chosen tools

The next step, conceptual modeling, will further abstract the depictions from this chapter into a simulation model that enables a DES.

5.2 Conceptual modeling

The theory of conceptual modeling was explained in chapter 4.2. The steps within this approach have to be proceeded under the context of maintenance organization derived from the formulations in chapter 4.2. One important extension which has to be considered due to its importance for the DES is the Hierarchical Control Conceptual Model (HCCM) or, as it is called by Fritz and Sargent, Hierarchical Control Flow Graph Model (HCFG). In the following description it will be referred to as HCCM.

5.2.1 Hierarchical control Conceptual Model (HCCM)

Fritz and Sargent (1995, p. 1) define it as *"(…) a modeling paradigm for discrete event simulation modeling based upon hierarchical extensions to Control Flow Graph Models."*. They state two main objectives for this extension:

- Easement of maintaining, developing and reusing models and elements of models
- Increase of flexibility and efficiency in the execution of a model

The main elements of a DES are entities, events (actions) and activities. The difference of events and activities is the amount of time they effect the simulation. Events instantly change the model state, while the activities appear over a certain amount of time starting with the start-event and ending with the end-event. Events and activities can be of three main types:

- scheduled
- conditional
- sequential

The HCCM is an extension that handles a special class of conditional events and activities. It sub-divides conditional activities into requested (these were the already existing activities) and controlled (the new added) activities. The main difference is that an entity, as for example a human resource, can also be controlled by a function tree and not just by requested orders of connected entities, events or activities. According to this new possibility, entities can, for example, be sent to places where they will be called to next earlier, due to the order of the function tree and not the order of the finished previous task. This can increase the system performance in addition to other advantages.

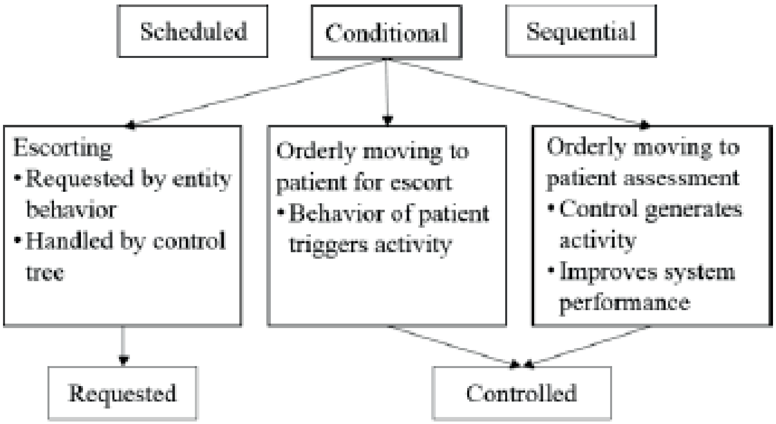


Figure 33: Extended Activity Classification (Furian et al. 2014, p. 3)

This implementation of the function tree, which is build out of hierarchical control units (CUs) (the hierarchical control tree) enables a further major improvement of simplification. Many entities lead to many requests for activities and events. *"These requests are hard to assign to queues as many activities require multiple resources, and resources perform multiple activities."* In the HCCM all these requests that are related to the same organizational area, are combined in lists that are handled by defined control units. This model/sub-model structure is an essential requirement for model reuse.

Now it can be said that "*Control units manage entities, manage requested and controlled activities and handle activity requests."* But how do they decide how to perform? The missing part that answers this question are rules. *"They replace the conditions of activities in a more structured and centralized form (…)"*. According to these rules, the CU processes the requests by using a certain pattern that has to be defined by the modeler. Within the control unit tree certain rules have to be defined which are mostly top to bottom. In this case the rules of the parent CUs are checked and performed before the step by step approach continues to the next deeper level CU until it reaches the CU that is directly related to the request. This connection, of which CU is parented by which other CU, is a defined hierarchy also called delegates. To better understand this hierarchy chapter 5.2.2 describes the structure of a CU tree. (Furian et al. 2014, 4f)

5.2.2 How to model a HCCM

A CU tree is built out of CUs, requested activities and controlled activities. Figure 34 shows the structure of a CU tree:

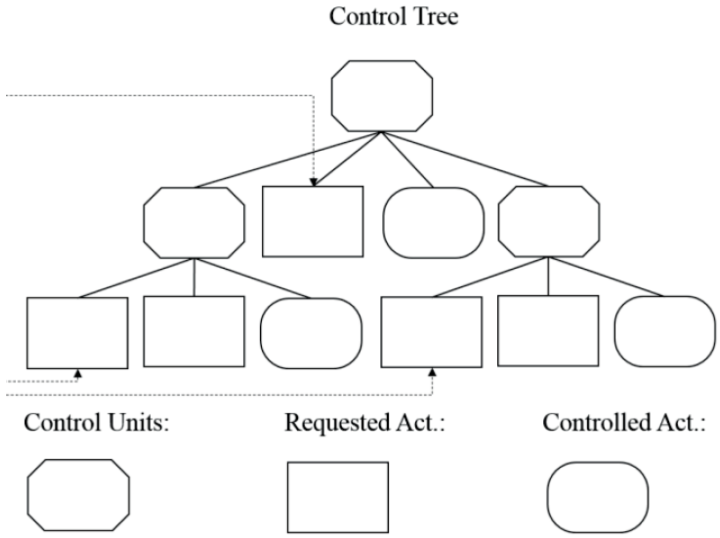


Figure 34: Section of the Concept of Hierarchical Control World View (Furian et al. 2014, p. 5)

The HCCM, that is described in chapter 5.2, is an important addition to the ARIS description from chapter 5.1 that helps building a complete conceptual model which can be used by a DES. In the next chapter, the procedure of the simulation will be explained briefly.

5.3 Simulation

The simulation approach was described in chapter 4.3. In this chapter the step by step method of how the DES shall be embedded in this approach/method is described. The source code and exact software approach of this DES will not be part of this work. Therefore, the simulation will be more or less a black box which will be fed by certain combinations of inputs and return outputs. These are interesting for the last step, the interpretation and implementation.

The first step, in order to be able to find an improved organizational maintenance structure, is a validation of the current state. Therefore the first step is the simulation of the current state. The input factors to do so and the output factors to have measures that can be built on are defined in the previous main step of chapter 5.2. Usually a DES is done in runs. One run represents the time span which is defined as the time period that is checked. Assuming the defined time span is ten years, each run is the processing of one year. Due to the fact that many simulation approaches are built on some random variables, unrealistic solutions are possible. To decrease the risk of such cases, the simulation is run ten times and the output measures are averaged. As a second step, new scenarios, which are mainly defined by the client, are simulated and their measures are stored together with their specific set of inputs to secure the reproducibility. As soon as all scenarios of interest are simulated, the results can be discussed and compared. In Figure 35 the three main steps of the DES approach are visualized.

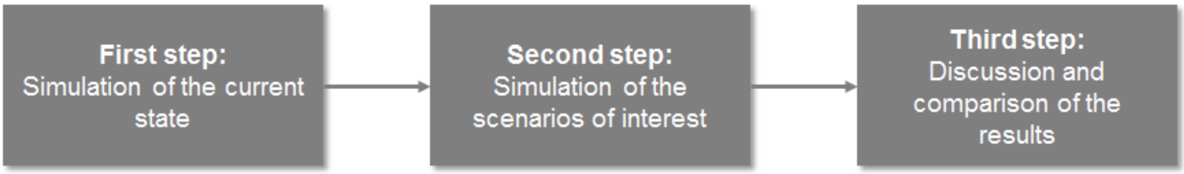


Figure 35: The three steps of the simulation approach

In the third step, an optimized solution can be defined (assuming there is one), but only with a lot of insights. The client, who was not involved in the modeling and simulation process, sees the results without knowing the inputs which have led to these measures. This can result in bad decisions if not all parameters where clear. Therefore, the next chapter, which explains the main fourth step, will introduce a DSS tool that should help the decision maker (which mostly is the client) to make a decision which's consequences are understood completely.

5.4 Results Interpretation and Implementation

Assuming that all the necessary results from the simulation are gained, the client might be confused by the complexity of the situation. The client can, of course, compare the outcomes and see which one is better. However it is hard to see on which inputs, assumptions and simplifications this result is based. Therefore, the results' interpretation and implementation is of high importance. Its purpose is an understandable overview of the situation so that it is clear which one is the best solution and why.

To provide such an overview the first step is the comparison of the outcomes. The tendencies will show which scenario is the better one under the given circumstances. Furthermore, the inputs will be listed next to the outcomes. It is important to understand on which factors, assumptions and simplifications this outcome is based. In a third step these results will be extended by some qualitative factors such as the effort it would take to change the existing situation to the new solution. Sometimes, these factors are crucial and therefore effect the decision to another, from the outcome view even worse solution. In the end the decision maker should exactly know how he came to the chosen decision and what effects this decision might cause.

6 USE CASE: Organization simulation at Audi Hungaria

In chapter 5 the method/approach of how to come from an organization to a DSS was introduced in four main steps. Now this approach shall be applied, similar to a case study, on the example of an optimized organizational structure for the maintenance structure of the Audi Hungaria Zrt. To be more precise the focus will be on the mechanical production of the engine production division and therefore exclude the engine assembly.

First, a brief overview of the company, especially the division of the engine production, will be given. Then, the initial situation of the maintenance management of the engine production will be expounded to give the reader an outline of the current state as well as to enable a better understanding of the ARIS approach. With the problem definition the following process of conceptual modeling will be started as well. Afterwards, the simulation will be described briefly by the inputs and outputs of the simulated scenarios and as a last step the discussion of the results will be shown.

6.1 The Audi Hungaria Zrt. (AH)

The Audi Hungaria Zrt., further called AH, was founded in 1993 in Györ, Hungary with 89 employees as an engine production site for the Volkswagen-group. At the end of 2015 it had grown to the biggest engine production site in the world, employing 11.411 people on an area of 5.200.000m^2. During these 22 years, three other business areas have emerged: the car production, a tool shop and the technical development. This work, as already mentioned, will just focus on the engine production. In the following chapters the engine production, especially the maintenance system, will be introduced and abstracted corresponding to the individual phases of the first main step: the ARIS approach.

6.2 Problem and System formulation with ARIS

Within this chapter the most important information will be supplied and molted into the tool methods which were introduced in chapter 5.1.

6.2.1 The output view: Engine Production at the AH in Györ

The engine production in Györ, is with 6.000 employees the main business unit of the AH. At full capacity it can produce up to 8.800 engines per day of which there are five different engine types which can be seen in Figure 36. The customers of the engine production are 32 different car manufacturing sites of the VW group from all over the world.

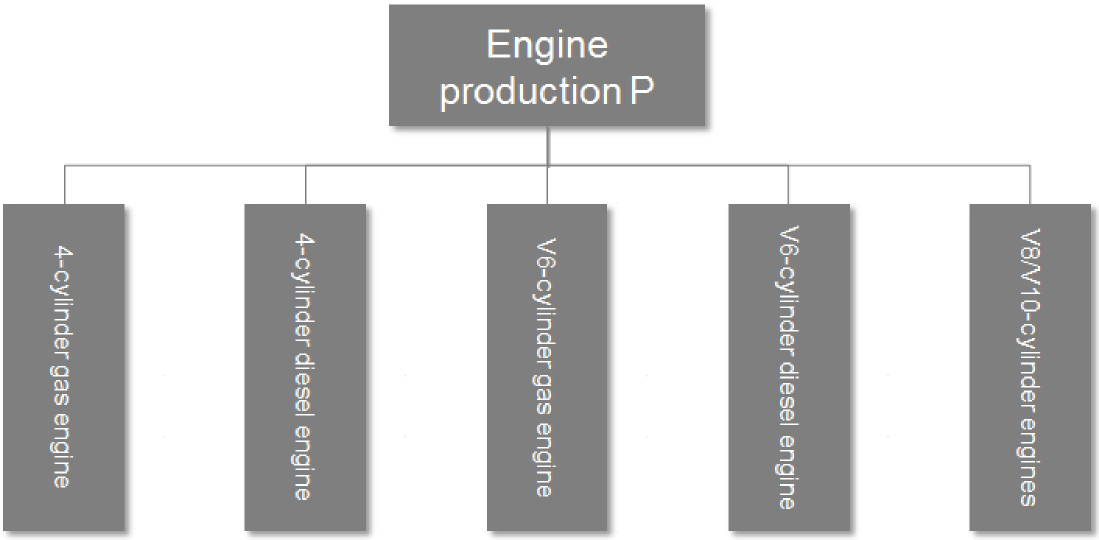


Figure 36: The product tree of the assembled engines

Beside the final assembly of the engines, certain parts are also manufactured in the mechanical production lines. These parts are conrods, crankshafts, cylinder blocks, cylinder heads, cams and camshafts as can be seen in Figure 37. The production lines work in individual shifts which are tailored to the capacity demands of each single production line.

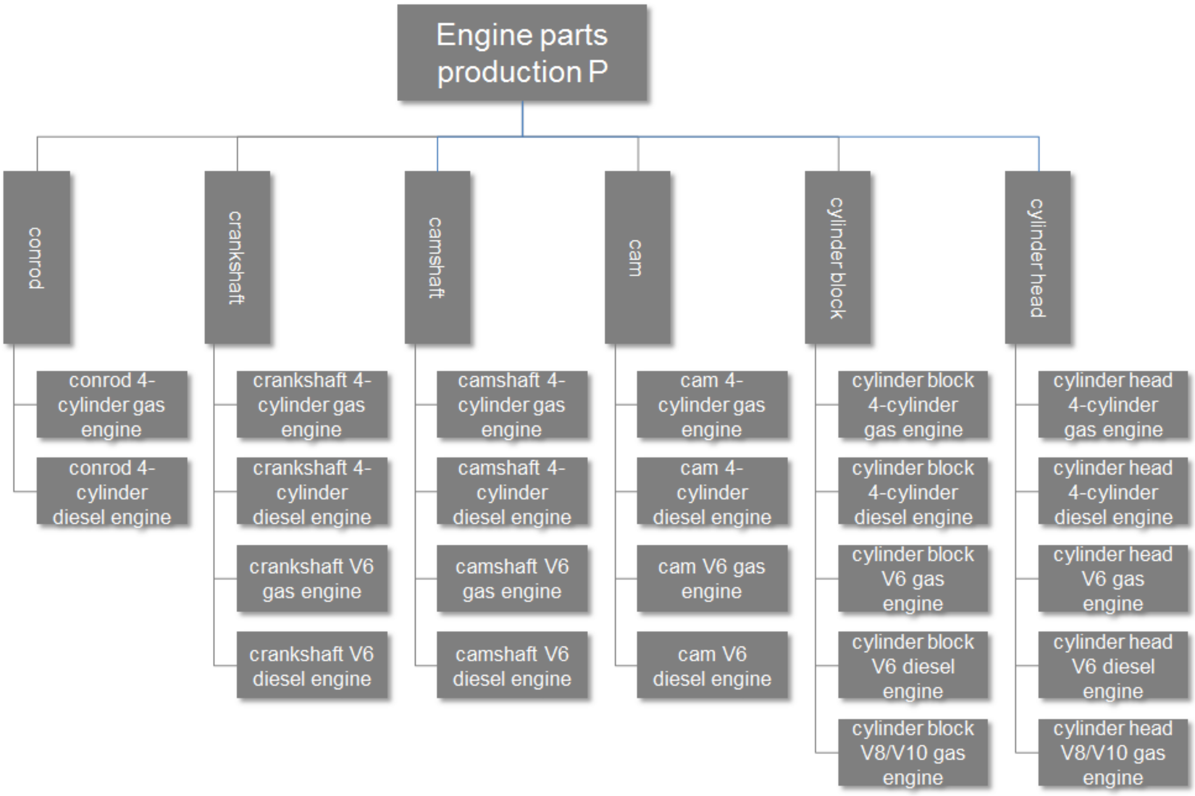


Figure 37: The product tree of the produced engine parts

6.2.2 The organization view 1/2: The organizational structure of the engine production

First, the hierarchical levels of the engine production, which will also be of interest in chapter 6.6.3 for the HCCM, are shown in Figure 38. Upon this illustration the upcoming figures can be better described and understood.

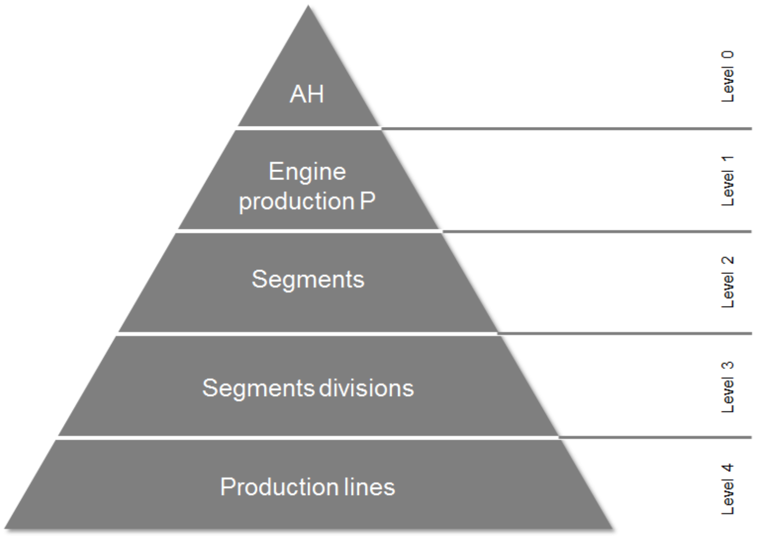


Figure 38: The main hierarchical levels of the AH

The engine production in Györ is a historically developed organization system which is, at level 2, divisionally structured. This means the site is divided into segments which are linked to the engines types they produce. The main separation criteria is the number of cylinders and the type of fuel they use (in the case of four-cylinder gas engines even one further split is made due to the high number of different engine families). As an example, one segment is formed by all the production and assembly lines which work on six-cylinder gas engines. Another segment is the sum of all lines that work with four-cylinder diesel engines and so on. One not-producing segment that will be of interest in this work is the so called Technical Service which includes, among others, a central maintenance service and the spare part depot. The Production System, Engine ramp-up and Logistical planning segments (which will not be further discussed) complete the first layer as Figure 39 shows.

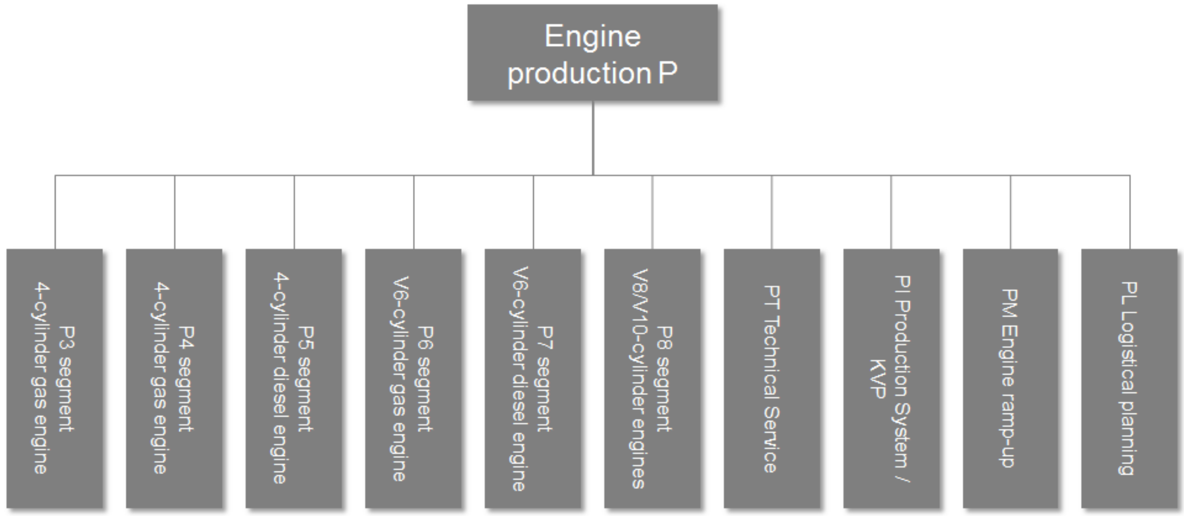


Figure 39: The divisional structure of the segments of the engine production

The next organizational level (level 3), within the producing segments is structured into three areas: the mechanical production, the engine assembly and the “Betriebsmanagement” which mainly focuses on organizational tasks such as troubleshooting and aftersales. This organizational level, therefore, follows a functional structure.

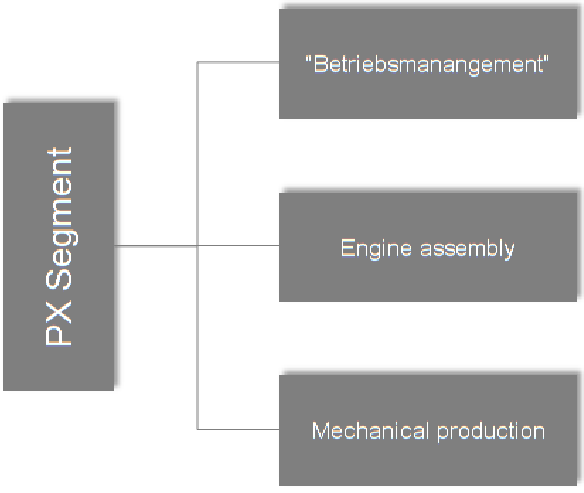


Figure 40: The functional structure on the second structural layer

The level 4, which does not exist in the “Betriebsmanagement”, are either production and assembly lines or departments. They are also the last structural level. This organizational layer does not follow any particular structure principle. The organigram in Figure 41 shows the organizational unit structure which ignores the engine assembly divisions and the three segments PI, PM and PL due to ensure a better overview. This organigram shows the organizational unit structure, the position level is shown in Figure 42 and the employee level is not of importance and therefore left out (for the levels also see Figure 22).

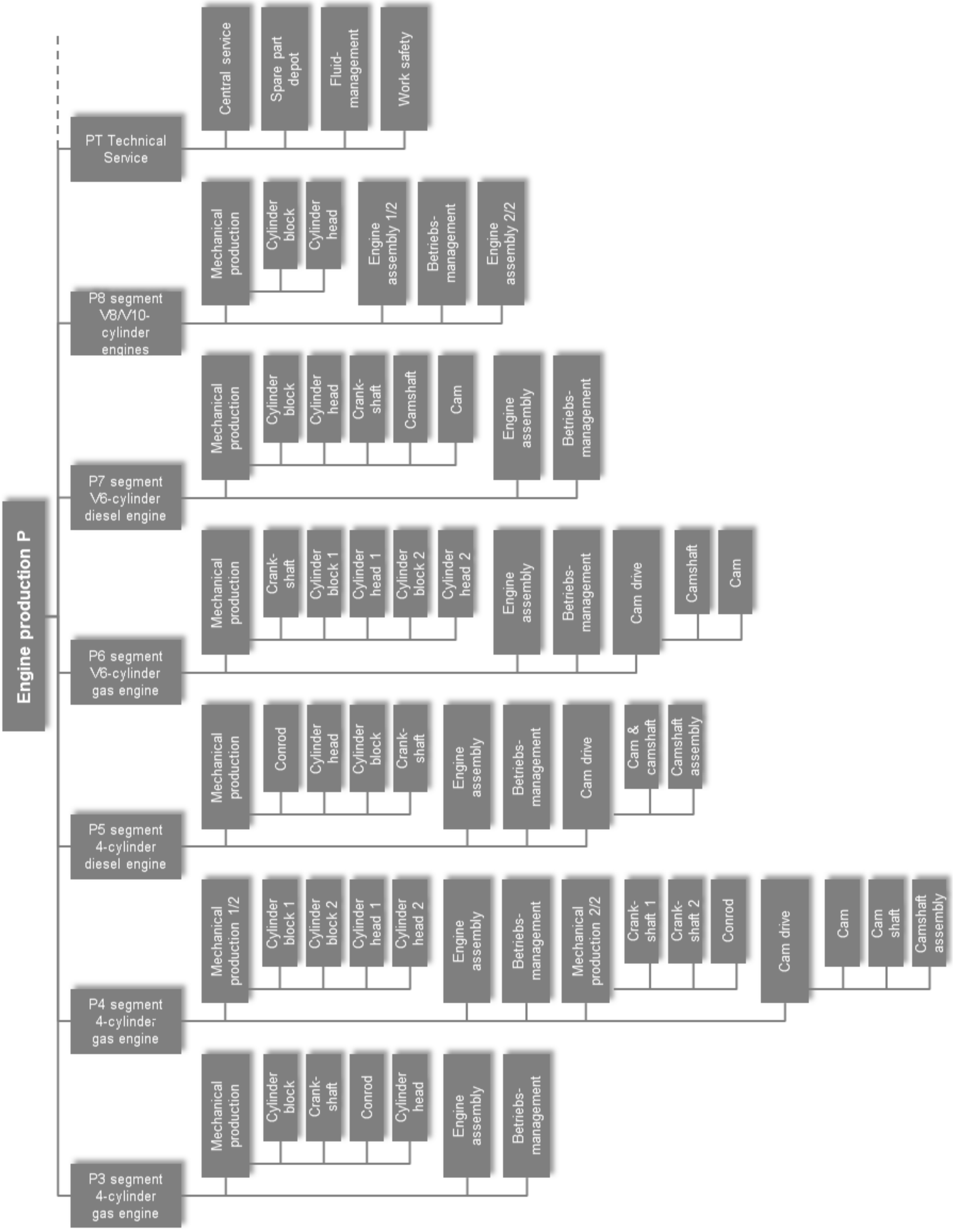


Figure 41: The organigram of the engine production in Györ at organizational unit level

As Figure 41 shows, the engine production in Györ is a huge complex system. Hence, making decisions that affect the whole division is a highly critical issue that asks for first-class management as well as lots of valuable information that supports the decision makers.

6.2.3 The organization view 2/2: The organizational maintenance structure

The organizational maintenance structure is a combination of centralized and decentralized acting units. First, the decentralized maintenance units, which are located at the production lines, will be introduced. Afterwards, the centralized part, the “Werkservice”, will be explained.

The organizational structure of a production line:

Almost every production line seems organized differently by means of number of employees and shift-models. However, the main structure remains the same and is illustrated in a general manner at Figure 42:

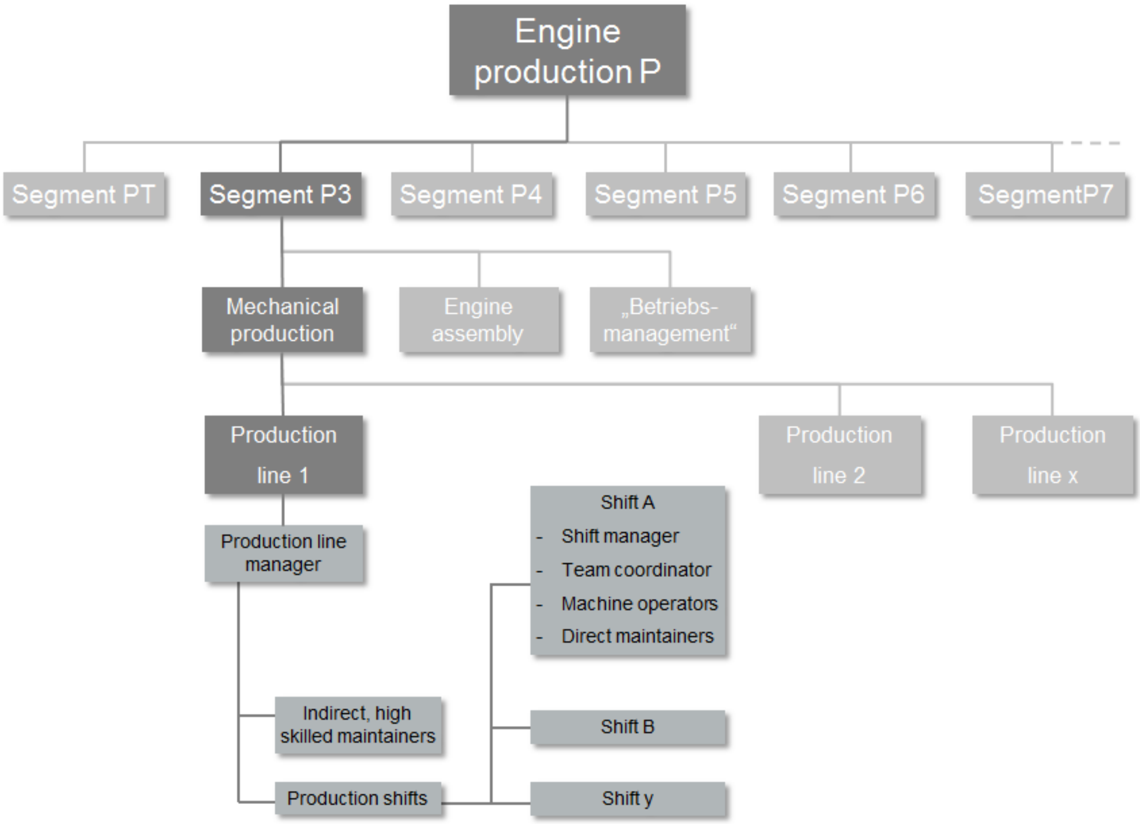


Figure 42: The organigram of a production line at position level (adapted from an Audi-internal document)

As can be seen in Figure 42, a production line is supervised by its production line manager. Usually he/she is placed in an office close to his/her production line together with his/her highly skilled maintainers. The shifts operate, according to the individual shift model of the production line, in eight- or twelve-hour shifts up to 7 days a week.

The other producing segments are structured the same way while the shift models and capacities differ.

The organizational structure of the central acting “Werkservice”:

The “Werkservice” (central maintenance service) is a division of the Technical Service PT. This centralized maintenance unit’s aim is to help all production lines with major problems they cannot handle themselves as, for example, spindle changes.

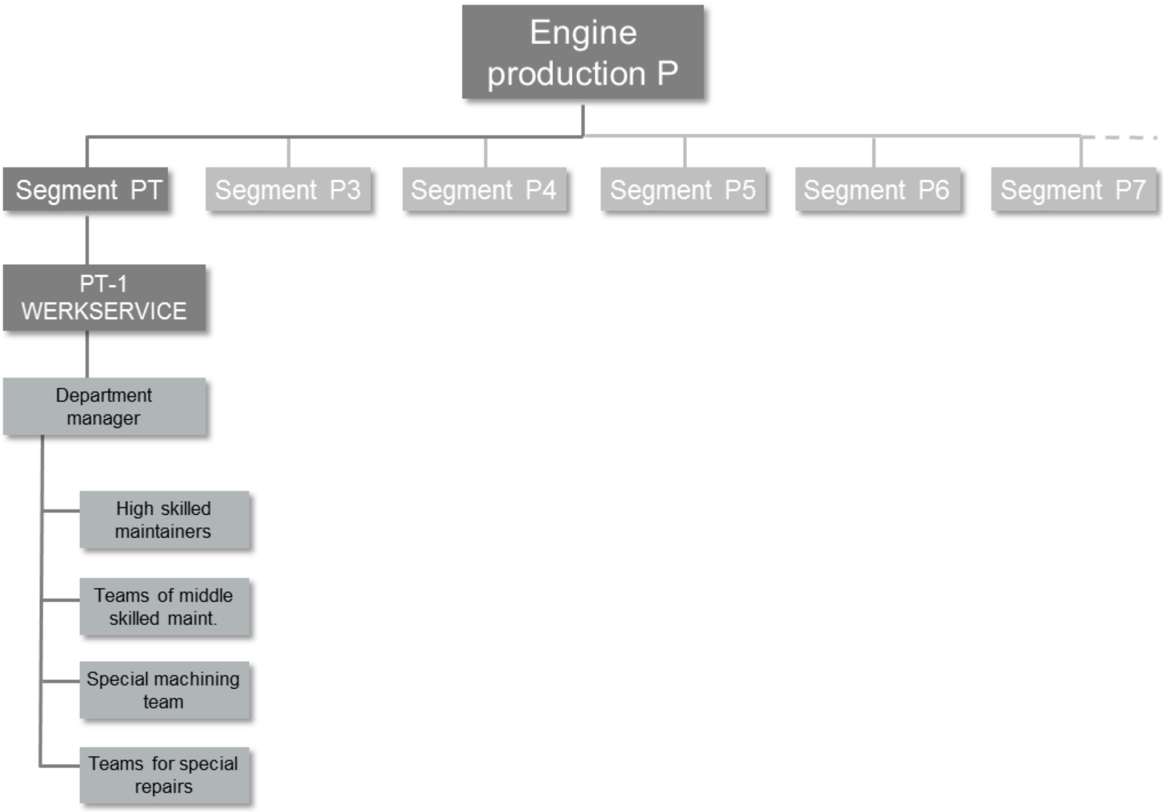


Figure 43: The organigram of the “Werkservice” at position level (adapted from an Audi-internal document)

The organizational hybrid structure:

Combined, the units described above show the hybrid maintenance structure of the engine production in Györ. On the one hand, the centralized maintenance unit at the Technical Service; on the other hand the decentralized organized maintenance units within the production lines.

6.2.4 The function view: The maintainers of the AH

There are many possibilities of how to categorize the different maintainers of the AH. Some methods used at Audi are:

- By skill level
- By affiliation
- By specialization (mechanical, electrical,…)
- By experience
- And many others

However, for this work it is broad enough to illustrate the difference of the maintainers in four dimensions:

- Their Audi-relation (internal vs. external)
- Their acting-boundaries (centralized vs. decentralized)
- Their specialization
- Their skill level/acting boundaries within the production lines

According to these distinctive Figure 44 can be abstracted.

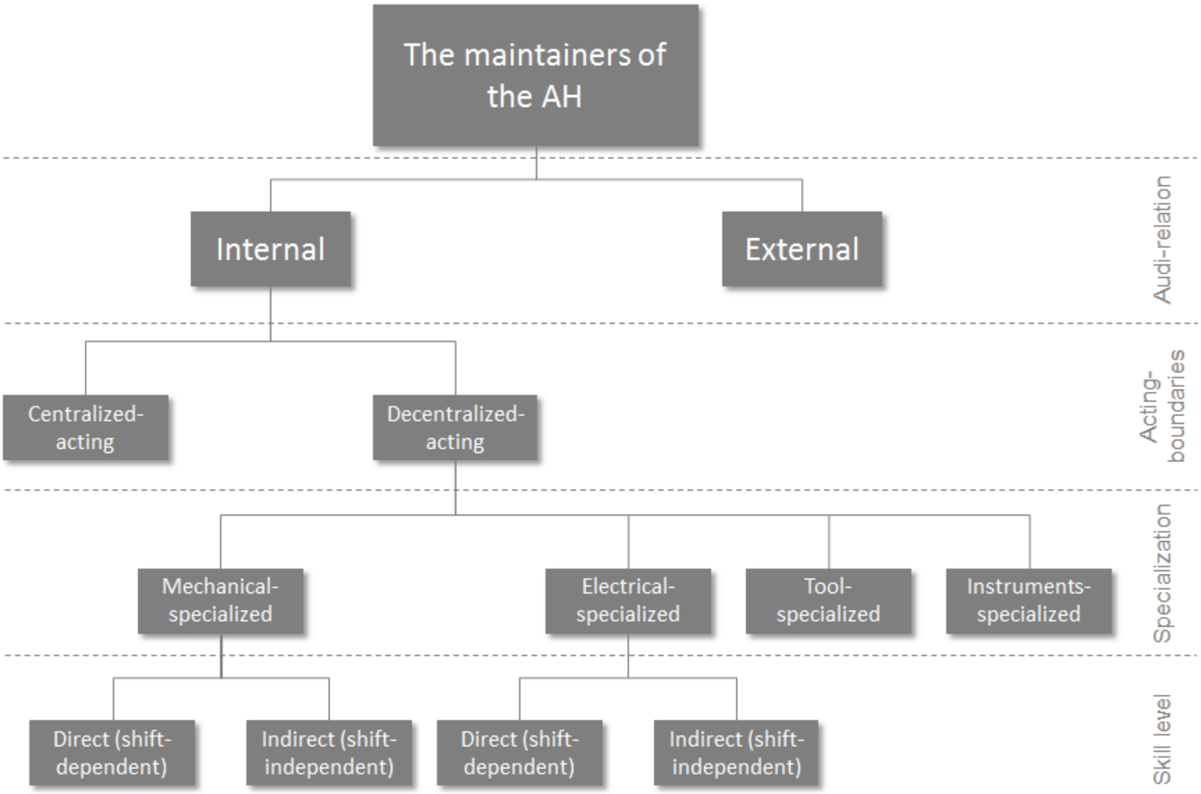


Figure 44: The function tree of the AH engine production

Internal maintainers:

The internal maintainers are all the maintenance units that are employed by AH.

External maintainers:

The external maintainers can either be experts of machine suppliers or external companies which provide maintenance services.

Centralized-acting maintainers:

As shown in chapter 6.2.3 the centralized-acting maintainers are all the maintenance units which belong to the “Werkservice” department of the Technical Service. They are highly skilled in special areas, for example in spindle changes, which usually cannot be handled by the decentralized acting maintainers.

Decentralized-acting maintainers:

These units belong to the production lines and therefore are specialized to its individual machines. Experience is a high valuable feature to these maintainers.

Mechanical-specialized maintainer:

As the name says, these units are well educated on the mechanical side of maintenance.

Electrical-specialized maintainers:

As the industrial evolution of digitalization continues, these maintainers become more and more important. Their tasks include all the electrical issues as well as IT issues such as robot programming. This type of worker is a bottleneck. Also the fast growing complexity of production engines might require a separation of electrical and IT maintainers in the future.

Tool-specialized maintainers:

Whenever there are issues regarding the tools of the production engines, these maintainers are the responsible unit. Even though the machine operators and mechanical-specialized maintainers can also fix some minor problems, mostly, the tool-specialized maintainer is called. They are also shift-independent workers who have to do a lot of administrational tasks too and therefore are more of a mixture of maintainers and production workers.

Instruments-specialized maintainer:

These units are very similar to the tool-specialized maintainers. They are also shift-independent and responsible for administrational tasks. Their main acting field is the production line quality, which for example includes measuring and adjusting units. They are rather supporting production workers than exclusive maintainers.

Direct (shift-depended) and indirect (shift-independent) maintainers:

In chapter 6.2.3 the main difference compared to indirect maintainers regarding their organizational belonging was explained. But there is also a difference in their skill level and responsibility. The direct maintainers have lower skill levels than the indirect maintainers. Their individual jobs are further explained in chapter 6.2.7.

Other production employees:

In chapter 6.2.7 the maintenance strategy, which AH follows, was introduced. At this integrated philosophy all the other production employees are also part of the maintenance team by doing some predetermined maintenance tasks. Vice versa it can be said that the maintenance employees are production employees. Therefore, these workforces complete the team of maintainers at Audi Hungaria and will be closer described in chapter 6.2.7.

6.2.5 The data view: Defining the relationships within the engine production

In this chapter the focus is mainly on the parts production of the engine production, otherwise it would become too complex.

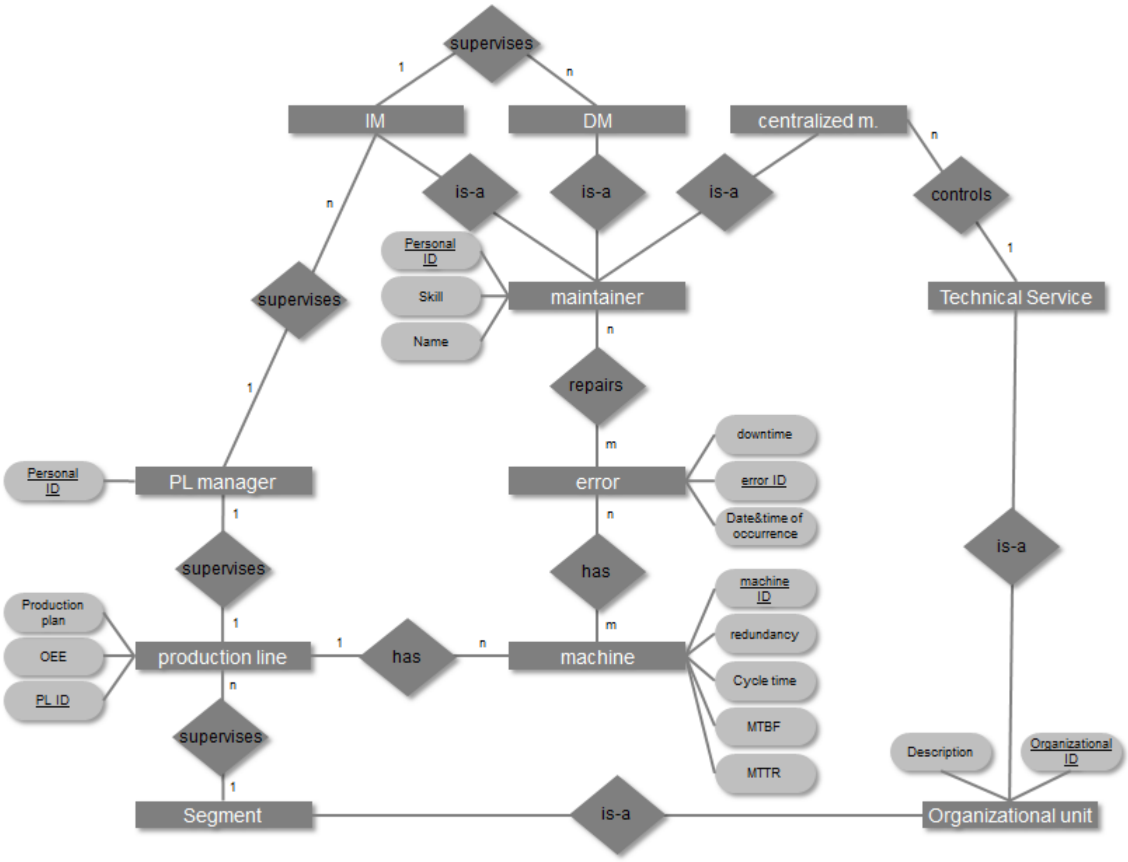


Figure 45: Section of the Entity Relationship Model of the engine parts production maintenance

Figure 45 shows the data structure of the maintenance system on an ERM Entity Relationship Model.

6.2.6 The process/control view: The operational maintenance structure

The operational structure includes the definition of many processing rules and business processes. One that will be of special interest is the escalation process of instant machine repair or as it is further called ad hoc maintenance. This process of “firefighting” requires certain rules in order to keep the downtime of a machine at its minimum. In this chapter the Audi-internal flowchart will be introduced. The term escalation process describes the step by step instruction of whom to call in case of machine failures.

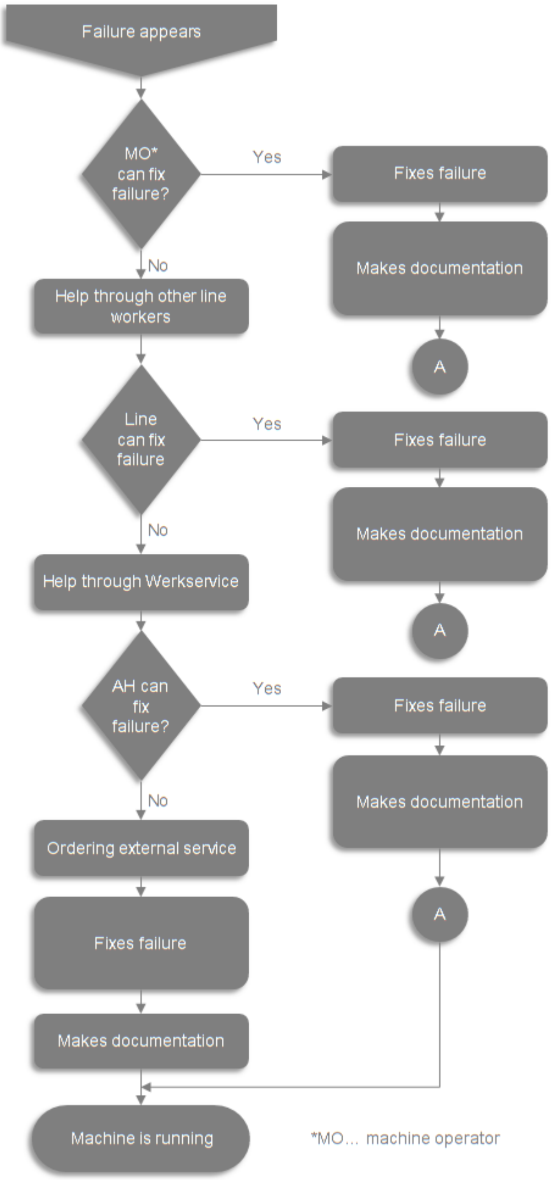


Figure 46: General flowchart of failure fixing (adapted of an Audi-internal document)

This illustrated process from Figure 46 is a general abstracted process which just represents a brief guideline. Within these guidelines a lot of things can be handled differently, like the question of time. How long should one level of maintainer try to solve a problem before escalating to the next level? This and other uncertainties leaf an unspecified room for interpretation which leads to a highly heterogenic operational maintenance structure in the engine production. Later in this work, a simplified, survey-based homogenization of this process will be introduced as an useful abstraction.

In the following to chapters, chapter 6.2.7 and 6.2.8 some more important information will be described.

6.2.7 The TPM philosophy at Audi Hungaria

Audi Hungaria follows the Total Productive Maintenance philosophy. As in chapter 2.4 and in an Audi-internal document described, this is a continuous process that gains the optimal utilization of machines through productive maintenance and the involvement of all employees (Audi-internal document). In the case of AH every in the production involved employee has its defined role within this philosophy.

The role of the TPM manager:

Due to the central role of this worker and his team, they are located at the Technical Service. Some of their main tasks among others are (Audi-internal document):

- Contributing to, and continuously improving the maintenance strategy
- Generating analysis and comparisons of production units to enable improvement
- Supporting the generation of inspection and maintenance specifications
- Monitoring the OEEs
- Arranging trainings that are linked to TPM
- Moderating the TPM-Runde

The role of the production line manager:

The production line manager has to initiate and control the necessary maintenance tasks of his production units. He is responsible for the quality and reliability of the production process of his production line. Therefore is moreover responsible for the proper service and maintenance activities at his area of authority. (Audi-internal document)

The role of the indirect maintainer:

The indirect maintainer's job is the technical supervision of the maintenance tasks. He plans, organizes and controls the maintenance and repair tasks in the production unit (production line) he works for.

Summarized his main tasks are (Audi-internal document):

- Planning, coordination, support, control and sometimes the execution of plant maintenance tasks starting from easy repairs until machine replacement
- Development and implementation of actions
- Efficiency controlling
- Spare part management
- Execution of ad hoc maintenance tasks (after an unplanned breakdown)
- Training of machine operators and direct maintainers
- Inspect executed maintenance tasks

The role of the team coordinator and shift manager:

Their main task is coordinating the machine operators as well as providing the required objects. In case of major problems they can request higher levels of maintainers like the indirect maintainer or the centralized acting maintainers. (Audi-internal document)

The role of the direct maintainer:

This level of maintainers is responsible for minor, repeatedly occurring maintenance tasks. Secondly they have to execute complex, planned tasks. Further they have to optimize the production units and processes. Some more detailed examples are (Audi-internal document):

- Execution of TPM standard tasks
- Execution of planned maintenance tasks
- Correction of sudden machine errors
- Training of machine operators
- Preparation of the planned maintenance tasks
- Assistance at major maintenance tasks

The role of the machine operator:

His job regarding maintenance centers around machine care and service. He also has to take care of small problems, to monitor the machine and make suggestions to increase the efficiency. (Audi-internal document)

The different forums for problem escalation:

Whenever there are major problems that have to be discussed or important decisions to be made which extend the competence of the line staff, different forums are available to bring up these topics. Depending on the importance of the subject, these issues are escalated upwards to the next higher instance. The escalation steps are as follows (Audi-internal document):

1. The shop floor/production meeting or the weekly OEE analysis of the organizational unit (in the case of AH this is the production line)
2. The “TPM-Runde” (TPM round table). This is a weekly meeting which is organized by the TPM manager and attended by the supervisors of level 3 (see Figure 38)
3. Monthly meeting of the TPM manager with each segment manager of level 2 (see Figure 38)
4. The “P-Runde” (round table) takes place once a week and includes the CEO of the engine production together with the TPM manager and all segment mangers of the level 2 (see Figure 38)
5. Every quarter of the year the CEO, the segment managers, the segment division supervisors, the TPM manager and other relevant managers come together for the so called “OEE Quartalsrunde”. These are the managers of levels 1,2,3 (see Figure 38)

6.2.8 The maintenance strategy at Audi Hungaria

The maintenance strategy of the AH is of course strongly linked to the maintenance philosophy TPM. Since Audi in Györ has so far no predictive tools or any diagnostic-related condition based mechanism, the strategy is a combination of a preventive, in terms of planned, time- and condition-based strategy, and a reactive strategy. Figure 47 shows the combination of strategies depending on the complexity of the failure. It also illustrates quantitatively which maintainer according to the complexity of the failure will handle the problem.

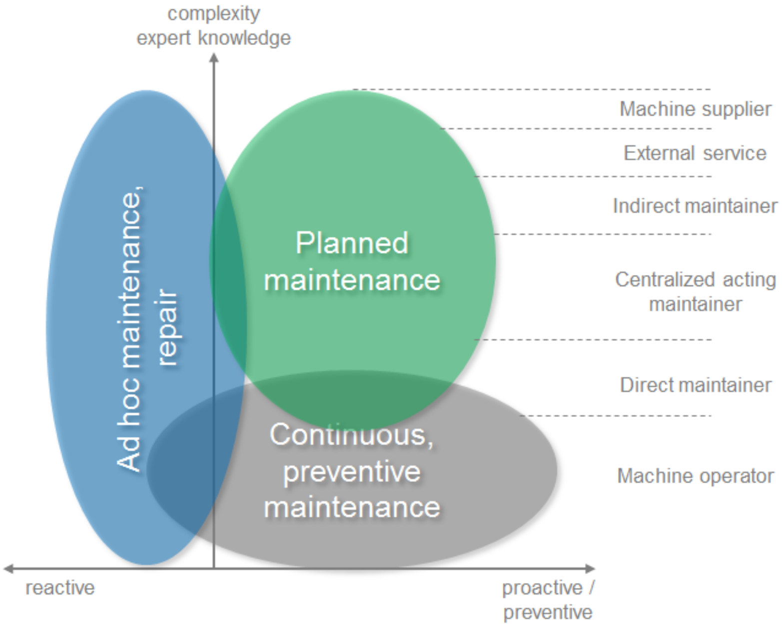


Figure 47: The maintenance strategy of AH (adapted from an Audi-internal document)

This, just in terms of preventive maintenance future-oriented strategy regarding unexpected failures is a great opportunity for the maintenance management at Audi Hungaria and shall be extended to a preventive system. An ongoing project that aims to update this major problem will be introduced in chapter 6.3.

6.3 Additional information: Initial situation

In chapter 6.2.1 the current situation of the engine production especially its maintenance management was explained. As could be seen, the historically grown system is very complex, heterogenic and inflexible for major changes. These among some advantages, like for example the high individual flexibility within the production lines, could or could not be a reason for thinking about profound changes. But one, very urgent issue that came up in chapter 6.2.8 cannot be neglected: This system is not prepared for future challenges; it might not even be up to date regarding predictive strategies, machine diagnostics and supportive intelligence systems.

Hence, in the fall of 2015, the CEO of the engine production in Györ, started the TPM4.0 project. Industry4.0 with the Internet of Things, predictive maintenance, the new corporal strategy with its maxim of digitalization, the fast changing automotive industry: all these factors among many more made this project highly important.

The TPM4.0 project:

TPM4.0 combines the terms of Total Productive maintenance and Industry4.0 and is therefore a project that should provide the basis for an innovative, future-oriented maintenance system. One main partner that accompanies this ongoing project is the Institute of Mechanical Engineering and Business Informatics of the Technical University of Graz. Their experience and scientific input shall assure the innovative nature of the solution.

The project is divided into three sub-projects. These are: the digitalization of processes, a predictive part that combines all the intelligence that enables prediction and the optimization of the organizational structure.

Figure 48: The sub-division of TPM4.0

This thesis exclusively deals with sub-project 3. Nevertheless, the others will be explained to give a better understanding of why this optimization process was triggered.

Sub-project 1:

Sub-project 1 is concerned with the digitalization of processes. Nowadays the gross of the information flow is handled by paper. The instructions, the task confirmations, the documentation, everything is made on paper and stored in physical archives. This fact includes many problems like:

- High administrational effort: Except of Microsoft Excel there is no possibility of supportive IT. Especially the indirect maintainers spend lots of time for planning.
- Dependency on experience: Mostly the planning at the production lines is done by the indirect maintainers by head. If there is an unexpected change of these knowledge carriers, many of the approved planning principles get lost.
- Transparency: One of the major problems is the lack of transparency. It is almost impossible to determine who did what, when and for how long.
- Documentation: Especially for the third sub-project high quality of production data is essential, like the documentation of machine errors. Today the reason

of a failure and the steps for correcting it are mostly not documented or maybe written down somewhere on a paper that cannot be automatically processed by a certain predictive software.

- Analysis: Today it is almost impossible to do any analysis in a proper amount of time. If someone wants to analyze any facts from the past, he needs to find the papers and manually transfer the acquired data into a software.
- Optimization: By looking through the processes, a lot of room for optimization and even elimination emerges.

Sub-project 1 is the first important step that builds the basis for almost all future projects regarding intelligent systems. In comparison to sub-project 3 which focuses on the organizational structure, it focuses on the operational structure.

Sub-project 2:

The predictive maintenance is the vision of forecasting as many severe machine errors as possible to proactively take care of these issues. As a result, the machine downtimes can be decreased and the maintenance operation planned high efficiently with less uncertainties. The prediction is mainly based on machine learn algorithms that learn from machine data and documented events from the past. A second predictive option is machine diagnostics which constantly monitors machine parts with sensors and warns the maintainer in case of inconsistencies. In any case, these methods strongly depend on sub-project 1.

Sub-project 3:

The main thought of sub-project 3 is the following: How can the best performance of the maintenance unit be achieved? Therefore as a first step the current maintenance structure was checked for things that should be improved:

- Raising the productivity: Like every economically based organizational system the mainspring is money. The increase of the OEE can be achieved if the organizational structure gets optimized in a way that a better distribution and utilization of the maintainers leads to shorter machine downtimes.
- Better working conditions: The working condition can be seen from two perspectives: the perspective of the employee and the perspective of the organization (or management). An improvement for the worker is always important and correlated to good change and success factors. But furthermore the conditions for the organization should be improved, as will be explained in chapter 6.5.3.

- No staff reduction: It is not this project’s target to economize workforces. Good skilled maintainers are always hard to find and therefore valuable for the company. The idea of better maintainer utilization in this context leads to more time for proceeding the tasks at best and more time to implement new projects.
- No staff hiring or outsourcing: It is not part of this project to think of scenarios in which new maintainers are hired or any maintenance task get outsourced.

According to these boundary conditions, the process of conceptual modelling will be started with the problem definition.

6.4 Conceptual modeling

By now the structure of the Audi Hungaria Zrt., the maintenance system and the initial project TPM4.0 have been introduced. From this situation the process of conceptual modeling can be started. For the illustration of the process also see Figure 17.

6.5 The problem situation

As mentioned in the literature study, the understanding of the problem situation is no direct part of the conceptual model itself but it is essential as a first step of the conceptual modeling in order to establish a valid and target oriented system.

6.5.1 The OEE as mainspring

The main question *what was the problem that led to this project* already lies within chapter 6.3: the OEE. In 2016, an Audi internal document showed a correlation analysis between the number of maintainers at a production line and the OEE. Furthermore a correlation analysis between the maintainers at a production line and the utilization of the central acting maintainers was published. The result was a positive correlation for the OEE and a negative one for the centralized acting maintainers’ utilization. This means if the number of maintainers decreases, the OEE decreases and the utilization of the centralized acting maintainers increases. If on the other hand the number of maintenance workers at a production line increases, the OEE increases and the utilization of the centralized acting maintainers decreases. (Audi-internal document)

The question now is: How and why is the number of maintainers influencing the OEE and how is the number of maintainers correlated to the organizational structure?

6.5.2 Correlation OEE, number of maintainers, organizational structure

The first thought is pretty trivial: If the OEE is influenced, either the Availability, Performance or Quality have to be influenced as well (see Formula 1).

Availability (A):

Starting with the Availability the loading time and downtime of machines has to be checked further.

$$A = \frac{Loading\ time - downtime}{loading\ time}$$

Formula 2: Calculation of the Availability (Reichel et al. 2009, p. 18)

The loading time is a fixed value, defined by the shift model according to the output demand. It is therefore not further related to the organizational structure.

The down time is the sum of the *waiting for repair* and *repair* time. For checking the down time, a first assumption is being made: *The repair time cannot be influenced.* This theory is based on the idea that a machine repair cannot be quickened by any means of the organizational structure or number of maintainers. It might be influenced by the skill of the maintainer, but this characteristic will not be influenced in the short term view by the organizational structure or number of maintainers either.

Waiting for repair:

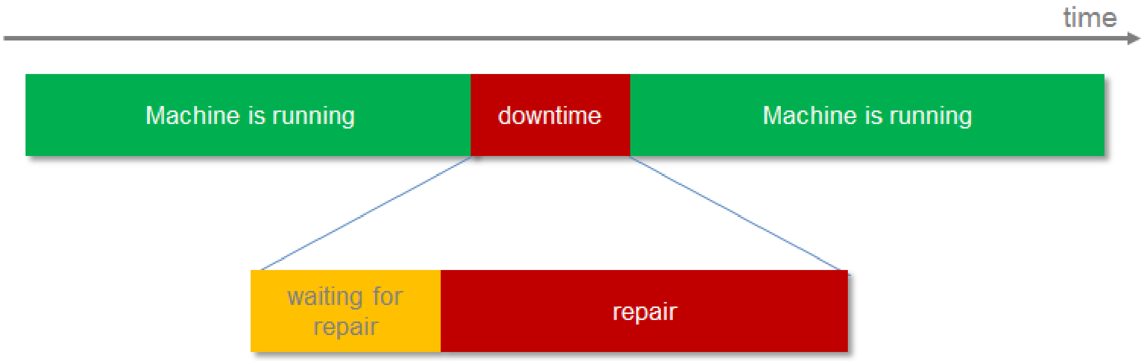


Figure 49: Separation of the downtime

Figure 49 shows the Gantt-chart of a machine which is running – stopping – running. As can be seen, the downtime is split into *waiting for repair* and *repair*. According to the assumption that the repair time cannot be changed, the *waiting for repair* time has to be shortened in order to increase the Availability and therefore the OEE. It is important to bear in mind that Figure 49 shows a processed view. In this view the sum of all *waiting for repair* times and *repairs* is already made. In real life, if a maintainer cannot repair the machine, he escalates the task to the next defined maintenance level. Beginning from that moment the machine is waiting for repair again and as soon as the called maintainer arrives and starts to repair, the waiting for repair time stops and the repair-time counter starts again. As soon as the machine runs again the sum of all *waiting for repair* and *repair* actions is made.

Walking time:

The waiting for repair time can be further split into the *walking time* and the *waiting time for the required skill level*. The *walking time* is the time a maintainer needs to reach the machine (this can either be from a staffroom or from a previous machine he was working on). The *waiting time for the required skill level* is the time it takes until at least one of the maintainers of the required skill level is free from any other more important maintenance tasks.

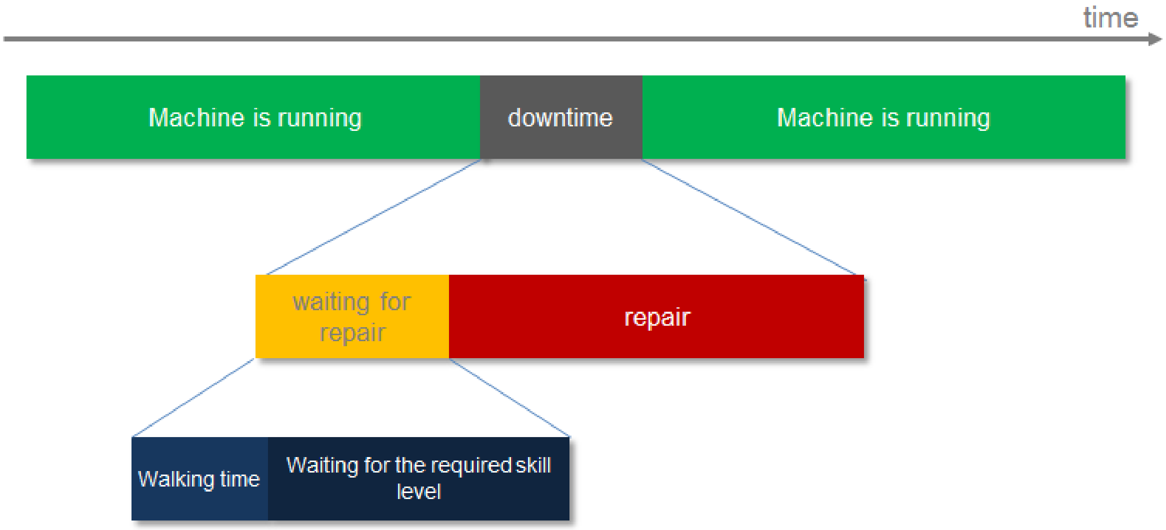


Figure 50: Separation of the *waiting for repair* time

The walking time is depending on where the maintenance units are physically located. This means if the maintainers are located directly at their production line, as they are nowadays, the walking times will be very short. If the maintainers are located at a central unit like for example the “Werkservice”, the walking times will rise depending on how far away the maintenance object is placed. In smaller companies this factor might not be of interest, but as mentioned the engine production in Györ is the biggest in the world, therefore the walking times may exceed 20 minutes.

The difference of hierarchical and physical belonging:

Even though it might seem like the walking time depends on the organizational structure, this is not really the case. The functional structure just defines which hierarchical level (control unit) is in charge of the operational unit (entity) and not where they are physically placed. Hence, a maintenance unit can be centralized, but still be placed directly at a production line or somewhere else. The difference lies within the possibility of shifting maintenance units. A centralized maintenance unit that is placed at a production line can be sent to another production line within the area of competence of its control unit. A decentralized maintenance unit with a control unit at the production line cannot be shifted to other production lines.

Waiting for the required skill level:

The *waiting for the required skill level* time is a representational value for the over- or under capacity of a unit. If the *waiting for the required skill level* times are very high, the organization has under capacity. If it is very low or even zero it has over capacity. The *waiting for the required skill level* time is influenced by two main factors. First, by the number of maintainers. If a company owns an endless pool of all levels of maintainers the *waiting for the required skill level* times will always be zero. In this case the organization had a problem of high over capacity. Since the framework conditions from chapter 6.3 do not allow any changes in employee numbers this influencing factor will not be discussed further. The second influencing quantity is the utilization of the maintainers.

A short example: A company employs two maintainers and owns ten machines; five milling and five welding machines. If now one maintainer is responsible for the welding machines and the other for the milling machines the following can happen: One milling machine reports a failure and the maintainer starts to repair. Suddenly a second milling machine stops due to a problem. Even if the second maintainer has time this milling machine has to wait until the first maintainer has finished working on the first machine because the second maintainer is just responsible for the welding machines. This means the *waiting for the required skill level time* of the second milling machine will rise. Though, if both maintainers were responsible for all ten machines, these utilization problems could be handled better, the workload for both maintainers would harmonize. Of course they would also need a broader field of competence, but in a first step this consideration is not of importance for the organizational structure.

Now that the whole causal chain from the OEE to the organizational structure is explained the following illustration, Figure 51, can be derived and the answer of the correlation between the OEE, number of maintainers and organizational structure is given:

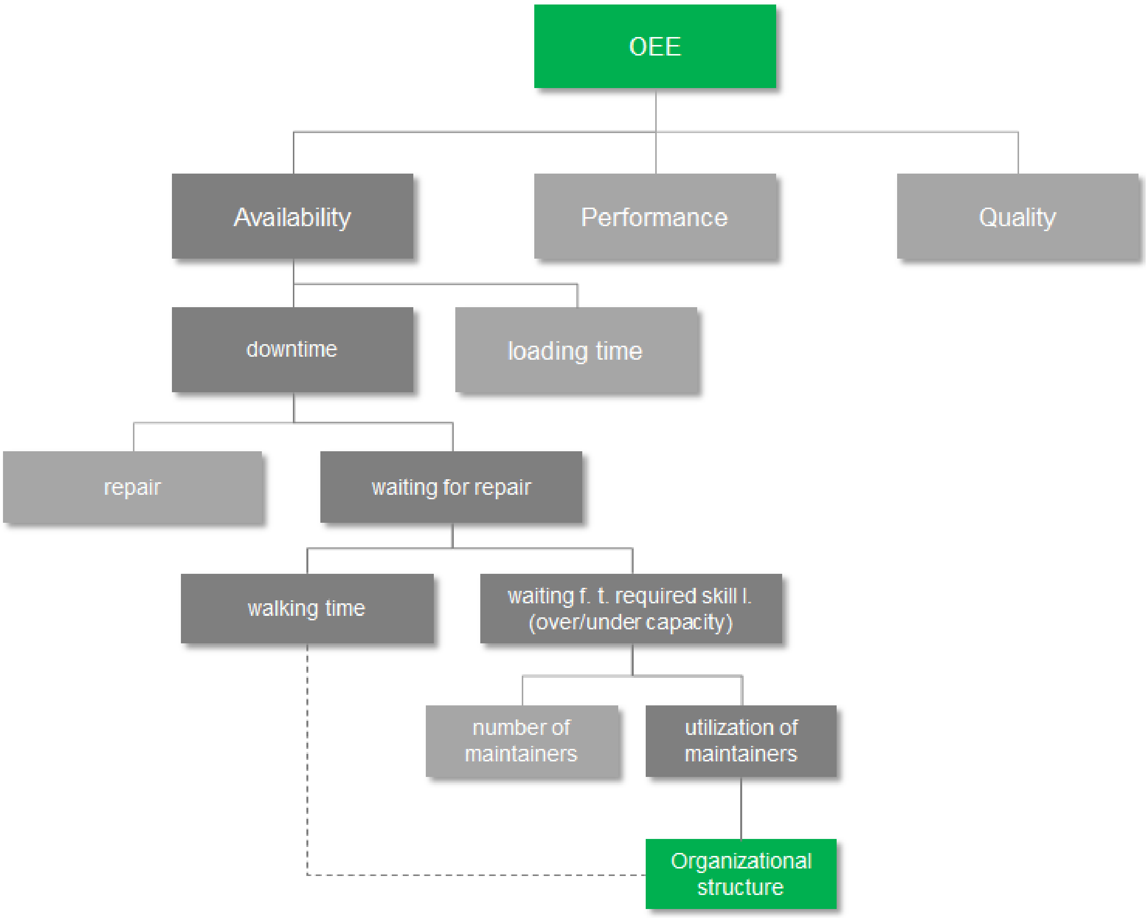


Figure 51: Causal chain from the OEE to the organizational structure

Performance (P) and Quality (Q):

The other two variables for calculating the OEE, the Performance and Quality, are also indirectly related to the organizational structure. The formulas to calculate the Performance and Quality are:

$$P = \frac{Ideal\ cycle\ time * Output}{Operating\ time}$$

Formula 3:The calculation of the Performance (Reichel et al. 2009, p. 18)

$$Q = \frac{Input - Volume\ of\ quality\ defects}{Input}$$

Formula 4: The calculation of the quality (Reichel et al. 2009, p. 18)

As Formula 3 and Formula 4 outline, the *Performance* and *Quality* are indirectly related to the organizational structure. The *ideal cycle time* is usually a question of how well the machine performs. This is a question of how well the machine is being inspected and maintained. The issue of the inspection quality is mostly related to the question of how much time the maintainer or machine operator can spend on inspection tasks, and this in the end is a matter of the utilization: If the utilization of the maintenance units is very high, the time and quality of the inspection will go down. Since this correlation can lead into a dangerous spiral (bad inspection quality – more machine failures – higher utilization of the maintainers – less time for inspection – even worse inspection quality) most companies, including AH, have introduced a fixed inspection-shift. During this shift the production is stopped and all the planned and proactive maintenance tasks are executed. This leads do our second assumption for this essay: *The Performance is not related to the organizational structure*.

For the *Quality*, more or less the same consideration is valid. The *Input* is not of interest and the *Volume of quality defects* is indirect related to the organizational structure. Due to the same situation as in the case of the *Performance*, the third assumption is made: *The Quality is not related to the organizational structure*.

6.5.3 Other influencing factors that were part of the initial problem

In chapter 6.3 the main principles of sub-project 3 (optimization of the organizational structure) were listed. One important point mentioned there is the “better working conditions”. This leads to several issues which have to be distinguished regarding the two perspectives: the perspective of the employee and the perspective of the organization (perspective of the organization is the perspective of the management).

Future-perspective (employee-related topic):

In the existing system the future-perspective for the personal development of a maintainer is bad. Especially within the decentralized units, the production lines, the numbers of maintainers at the different levels are strictly limited. If a motivated direct maintainer wants to extend his expertise he maybe can do some trainings, but it will not be possible to reach a next level as long as this next level is at full capacity. This perspective is a question of personal development (cultural reputation) and money (higher salary).

Knowledge specialization (employee-related topic):

The maintainers at the production lines gain high expertise at their workplaces. This in fact is a great advantage for the production lines and for the maintainers as long as they do not want to change. If a maintainer wants to work at another production line, his/her production line-related knowledge will drop. When thinking of a centralized system, the expertise gets broader (but maybe also less deep).

Knowledge isolation and transfer (organization-related topic):

A big problem at the moment is the knowledge isolation. This problem mainly results from the blocked knowledge transfer through separated areas of responsibility (decentralization).

Some workers who gained a lot of experience have become very important but also irreplaceable. This dependency is always bad for an organization. Today it can also happen that two production lines have the same problem with a machine, but they do not know. So even if one side knows the solution, the other one will still lose a lot of time and energy on this problem (in this case it is also already an employee related problem).

Furthermore, maintainers should learn from each other to reach an as harmonized skill spread as possible.

Transparency and controllability (organization-related topic):

Transparency and controllability are mainly related to sub-project 1 (see chapter 6.3), but also the organizational structure should be easy to grasp and steer. Nowadays every production line follows its own rules and guidelines. According to this manager decisions which are valuable for all production lines are difficult. Not just because of the heterogenic structure but also because of the simple fact that there is no possibility to see what could be improved. As an example: as far now, it is impossible to see if a new, maintainer competence (like an IT maintainer) is helpful or not. In the future this fact should be changed.

6.5.4 Conclusion of the problem situation

In chapter 6.5 the different problems were described step-by-step. In this chapter the essence of these steps will be reduced to the main problems.

- Utilization
- Future-perspective
- Knowledge specialization
- Knowledge isolation and transfer
- Transparency and controllability

The severity of the problems is not equal. The utilization is the main problem that we will focus on in the upcoming simulation model. The other problems are more qualitative than quantitative problems that have to be considered as well but not in the first place.

6.6 Modeling and general project objectives

As described in chapter 4.2.3, objectives are separated into modeling objectives and general project objectives. The three main roles that are of importance during conceptual modeling will be mentioned repeatedly throughout this process and therefore shortly listed again here (Robinson 2008a):

- The client: The person or persons that gave the order to the project and are interested in the result
- The modeler: The person or team that develops the model
- Domain experts: All the persons that can help building the model with their high knowledge and experience

6.6.1 The general project objectives

In this chapter the nature of the model shall be defined regarding flexibility, run-speed, visual display, ease of use and model/component reuse. (Robinson 2008b)

- Flexibility: As explained in the problem definition the utilization shall be improved, therefore different scenarios (different allocations of the maintainers) will be simulated. In order to do that the simulation model will be changed regarding control units and entities. Hence, the flexibility of the model is of high importance.
- Run-speed: Each scenario will be simulated ten times; afterwards the mean values of the output will be calculated. The number of different scenarios can theoretically exceed 80. The period that will be used in the simulation is one year.
- Visual display: The visual display plays a minor role. However, a simplified visualization is important, to make this very complex and complicated topic clear to the client.
- Ease of use: The model will be handled by two experts and the modelers, therefore the interface must not be individualized or simplified.
- Model/component reuse: It is not planned to reuse this model after this project is finished.

6.6.2 The modeling objectives

The modeling objectives are a closer description of the conceptual model that help keeping an eye on the final goal as well as defining in which corridor the modeler can move (Robinson 2008a)

- Achievement: The client wants to reach a better utilization with the same number of maintainers. This means the utilization of the optimized organizational structure shall be lower than the current utilization. The model’s goal in this context is to enable measuring the utilization of the maintainers of the engine production during one year.

- Performance: In quantitative measures this means the utilization (or the related KPIs) has to be better than the current KPIs. The current KPIs will be determined in the first place with the finished simulation model. Afterwards these measures get compared to the measures of the new scenarios.
- Constraints: The main constraints are: no hiring of new maintainers, no outsourcing of any maintenance tasks and no firing of maintainers.

6.6.3 The inputs (experimental factors)

In chapter 4.2.3 the input factors were described as the setscrews which can be changed in order to meet the modeling objectives. Assumptions and simplifications (also see 4.2.3) are important modules which will help defining the inputs.

Maintainers:

A useful classification of the maintainers was made in chapter 6.2.4. But it is not enough to just define which maintainers exist. It has to be further defined how many of each skill level exist. In the following list the skill level and their number is shown:

- Skill level 0 (MO):
  - Machine operator: unlimited
- Skill level 1 (DM):
  - Mechanical direct maintainer (MDM): 21
  - Electrical direct maintainer (EDM): 21
  - Mechanical & electrical direct maintainer (KombiDM): 3 (is a specific skill for some smaller production lines that is not further explained)
- Skill level 2 (IM):
  - Mechanical indirect maintainer (MIM): 29
  - Electrical indirect maintainer (EIM): 29
- Skill level 3 (WS/Ext)
  - Central acting maintainers from the “Werkservice” (WS): 12
  - External maintainers: unlimited

Since the most of the inputs do not distinguish between mechanical and electrical issues, the maintainer levels will be mentioned combined as skill levels. The relevant resources for the simulation will be the skill levels 1 and 2. These maintainers will be shifted in order to see if the performance increases or decreases.

The placement of the maintainers:

The placement of the maintainers is their physically belonging (the place they go to if there is no task to do) and it is not correlated to their control unit. There are five possibilities of where to put the maintainers:

- To a production line: This can be seen as a physical decentralization.
- To a segment: In this case they are placed at an imaginary place that is not existent at the moment but could be in the future. This can also be seen as a physical decentralization, but with less meeting points than the production line placement.
- To the Technical Service: This can be seen as a physical centralization.
- To any other point the client wants: In case the client asks for a specific meeting point for the maintainers, this is possible.
- Combinations: All the upper possibilities can be mixed.

The placement of the maintainers is the main input which really influences the organigram and therefore the organizational structure. It defines if it stays a mixture or if it becomes a just decentralized or centralized structure. It furthermore influences the organizational structure regarding divisional and functional structure.

Walking paths:

This input comes from a plant map. In this map the paths are defined on which the maintainers move to reach the unit they are called to. Theses paths are of importance due to the fact that the walking time effects the utilization as explained in chapter 6.5.2. Assumptions and simplifications made here are:

- The maintainer always moves on the shortest connection between his current state and the machine he has to go to.
- He never leaves the predefined paths.
- The paths do not exactly lead to the machines but to a central point of the production line.
- The simulation always calls the maintainer which is closest to the problematic unit.

The walking speed:

The walking speed is the third variable that influences the walking time. The combination of the physical placement the path network and the walking speed therefore yields the walking (or travel) time. The walking speed is defined as 1,67 m/s in this simulation approach. It can be changed if the client is for example thinking about some kind of vehicle that should carry the maintainers to their targets in the future.

Assumptions and simplifications:

The maintainers always move with the same speed. They never run no matter how severe the problem is.

The sequence of production and repair times

One main input for the simulation is the sequence of production and repairs. Somehow the simulation approach needs to know when a machine is producing and when it is in a state of no production due to an error. The “out of production state” is defined in the production plan which will be explained later in this chapter.

As mentioned, the simulation approach uses one year (the 1st of August 2015 until the 1st of August 2016) of the real production. Due to an Manufacturing Execution System the machine data from this year is available and prepared as follows:

- All machine errors which took longer than 120 seconds are listed. These error times are called “*Time to repair*” (TTR).
- All production times between errors which took longer than 120 seconds are listed. These time spans are called “*Time between failure*” (TBR).
- For all the machine errors which last shorter than 120 seconds the following assumption was made: If the production time before or after the error is longer than 120 seconds, this error is not relevant and therefore seen as production time

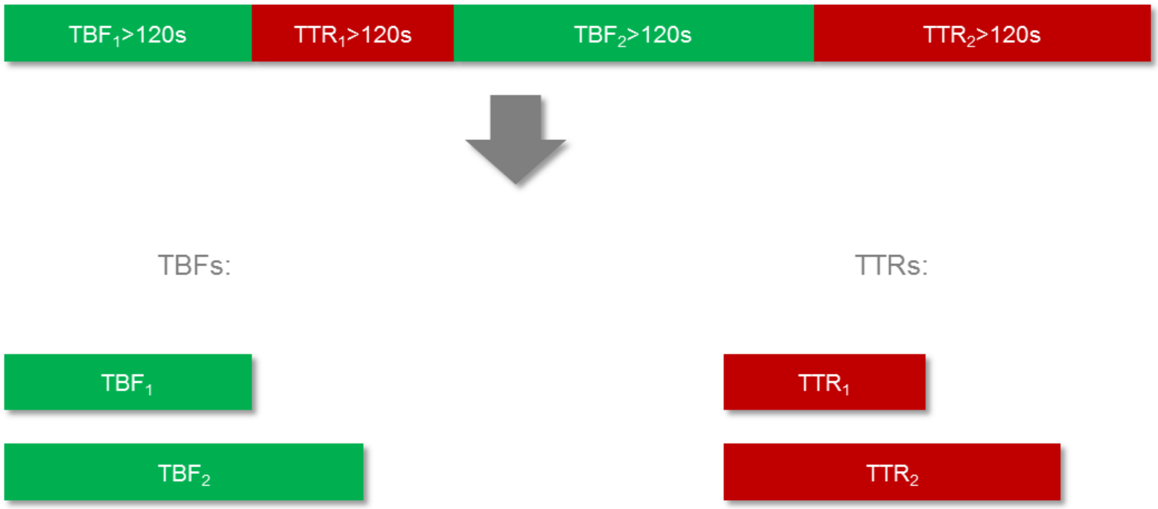


Figure 52: List of the TBFs and TTRs

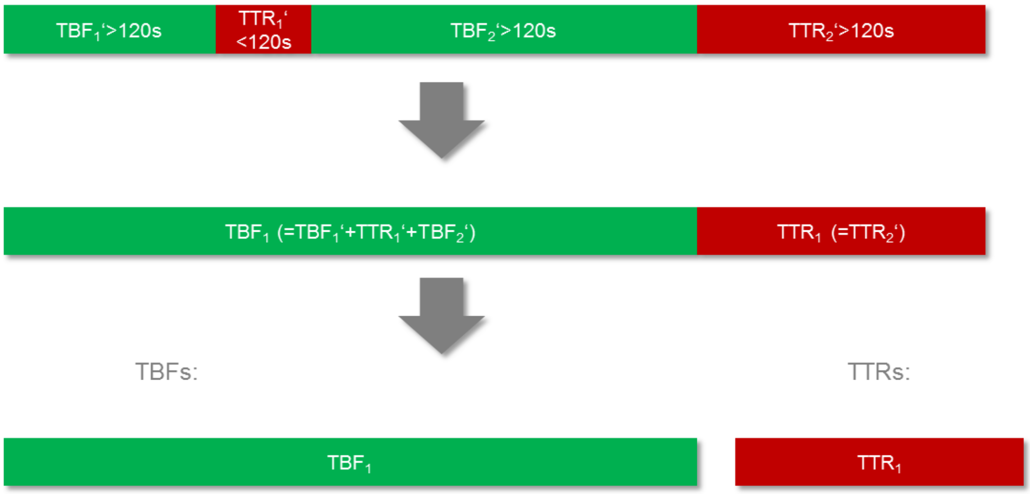


Figure 53: The preparation of TTRs shorter than 120 seconds

- For all production times which are shorter than 120 seconds the following assumption was made: If the error before or after the production time is longer than 120 seconds, this short production time is not relevant and therefore added to the repair time. The principle is the same as in Figure 53 but inverse.
- One last case that is possible is the alternation of errors and production times which are all shorter than 120 seconds. In this case the following assumption was made: the short production time in between the errors are most certainly a test if the preceding errors were fixed successfully. If the machine stops again within 120 seconds, it is obviously not. No matter how many times this error – production sequence goes, in the end it is summed up to one long error (TTR).

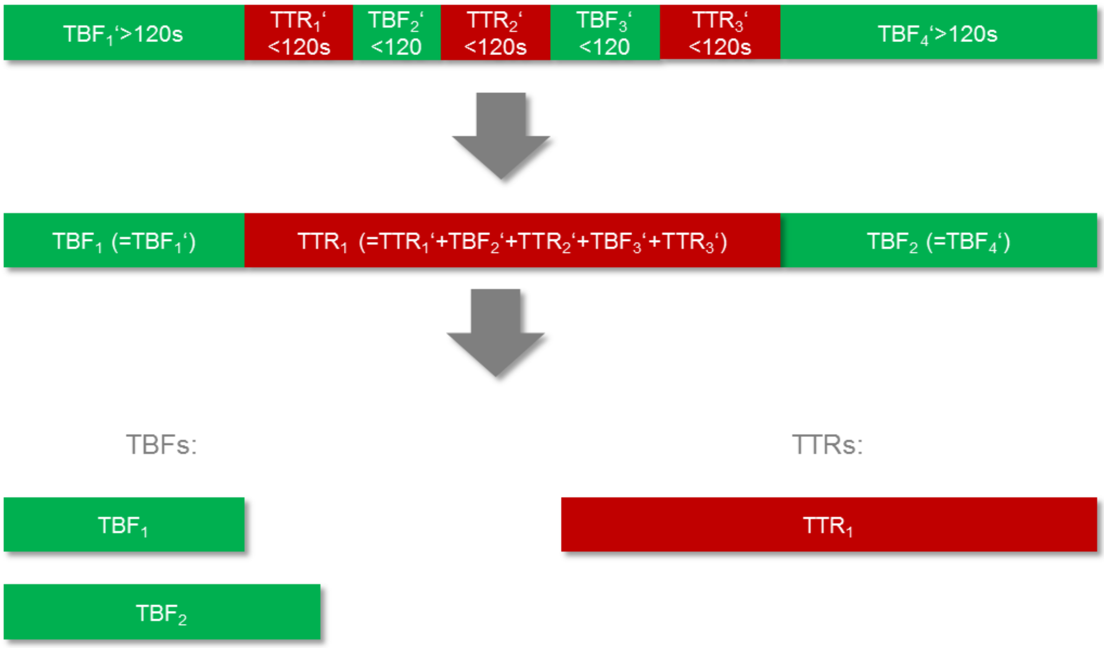


Figure 54: The preparation of error-production-sequences shorter than 120 seconds each

In the end there is a list for each machine with two columns, one with the TTRs and one with the TBFs. The simulation just triggers randomly alternating one TBF and one TTR. Since the TTR runs down to zero from the moment the right maintainer is present, not all the TBFs and TTRs will be used in one simulation run.

The control structure:

The control units are the central part of importance which reflects the organizational structure. It defines: who is the authority that steers the maintainers and who is the entity that they are related to.

There are five main possibilities for control units (CUs):

- The AH: Centralized organizational structure
- The engine production (the Technical Service): Centralized organizational structure from the view of the engine production
- The segments: Decentralized organizational structure
- The functional segments: The functional segments are an organizational layer that does not exist yet. Within this functional structure all the production lines that produce the same engine parts are combined. One segment would be all the crankshaft producing lines, another one all the cylinder block production lines and so forth
- The production lines: Decentralized organizational structure
- Combinations: The upper principles can be mixed (except of the segments and functional segments) as for an example the *level 1* of maintainers is controlled by the production lines and the *level 2* maintainers are controlled by the segments.

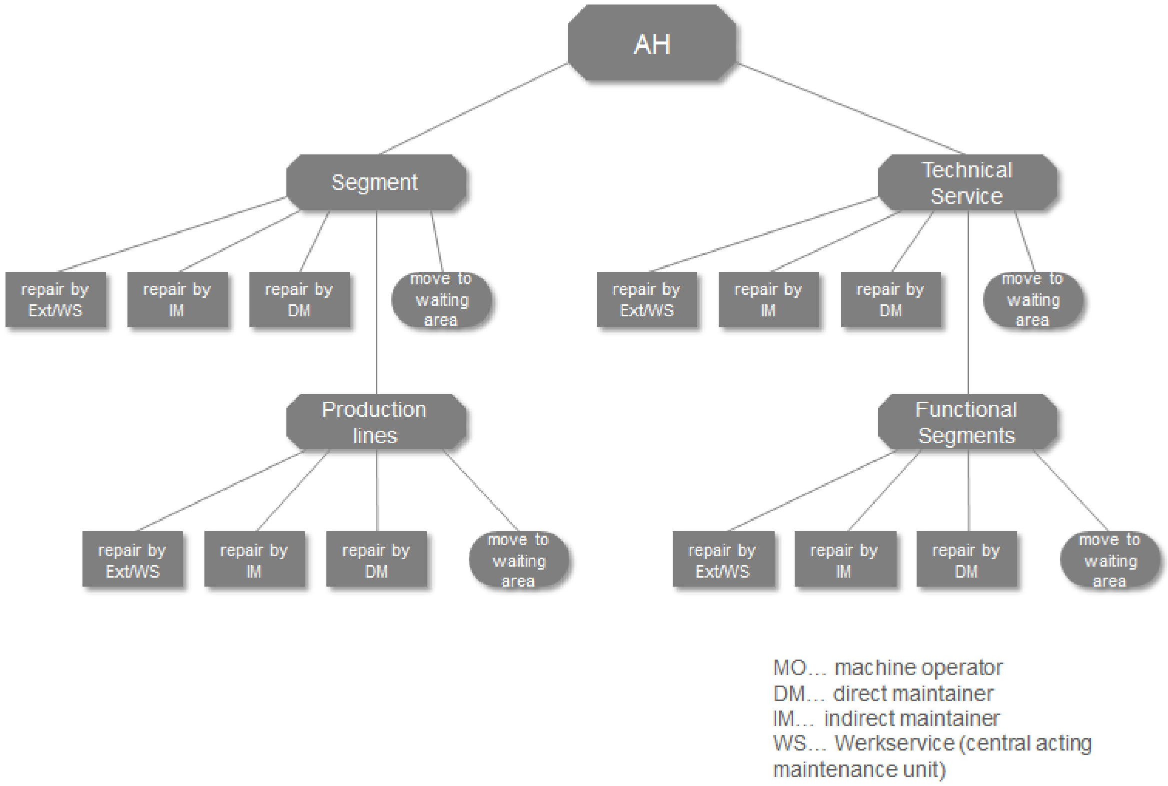


Figure 55: The hierarchical control structure of the AH

Figure 55 shows how the hierarchical structure is built in the simulation model.

The control structure influences the organization regarding its relationships. When changing the control structure the relations can change for example from a single-line system to a matrix structure.

Processes and proceeding probabilities:

In chapter 6.2.6 the official process of failure fixing was illustrated. The main aim of such a process is to keep the machine downtimes at a minimum. The predefined process of Audi is very general. This leads to individual rules how this should be done at each production line and therefore in a highly heterogenic process landscape.

The process of failure fixing is a dynamic, highly complex system. From its occurrence until its correction many human decisions, actions and other influencing factors are happening. Things like learning-effects, the daily condition of the parties involved, even strange coincidences would have to be taken into account. This is on the one hand almost impossible and on the other hand not expedient at all. Therefore a simplification has to be made. The idea of this simplification is to abstract a process that is generally valid, consistent with the general process from chapter 4.2.3 and customizable for each production line. The method of choice, for establishing such a process, were interviews with domain experts, the client and the modelers. The outcome is shown in Figure 56.

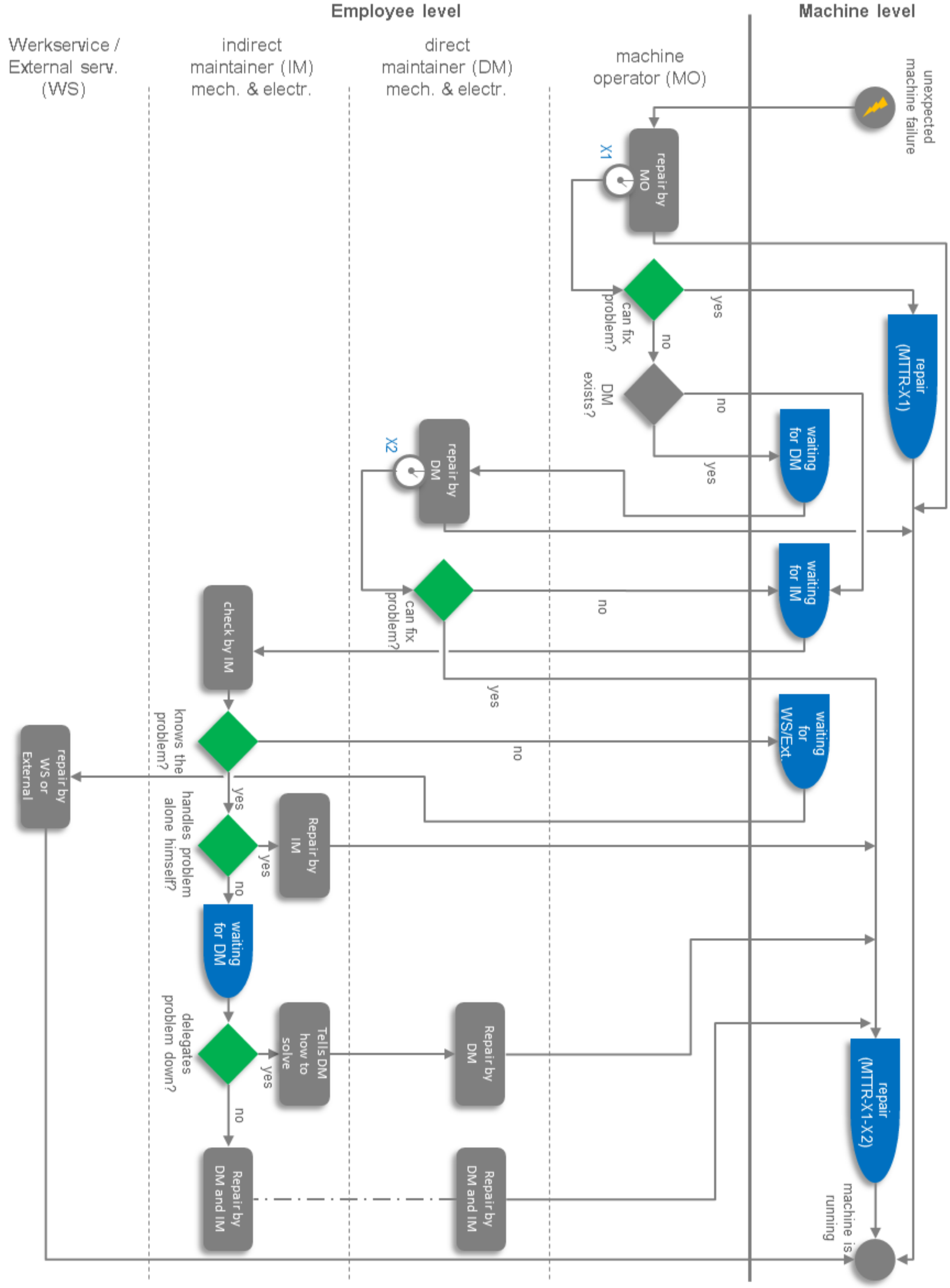


Figure 56: The ad hoc failure fixing process

Due to the complexity of this failure fixing process from Figure 56 a brief explanation is given. The process is triggered by a machine error; this means the machine is not producing anymore. The first person, who checks the machine, is the machine operator. He works on the machine for a defined time (the escalation time). Now there are two possibilities: he can either fix the problem before the escalation time runs out. In this case the process ends and the machine runs again. In the second case after the escalation time has run out, a decision object asks if he can fix the problem or not. If yes, the rest of the MTTR (which is the MTTR minus the escalation time) will run to zero and afterwards the machine will run again. If he cannot fix the problem the process will continue to the next decision object. It is important to know that both, the machine operator and the direct maintainer are assumed to work on the problem before deciding if they can fix the problem or not. Therefore these times have to be subtracted from the MTTR as can be seen in the two bigger, blue waiting objects on the very top of Figure 56.

Whenever there is a green *decision-object* (diamond) that requires a yes or no in Figure 56 the simulation needs to know which way to proceed. Therefore the domain experts were further asked to estimate the probability of which way to go for each production machine of their production line. This means in the end there are as many process sheets combined with proceeding probabilities as there are production machines. As an example the focus was taken on the first production machine of a crankshaft production line. The first green *decision object* that appears after the occurrence of an error asks if the machine operator can fix the problem or not. The domain expert had to estimate now how many of all the occurring errors of this machine are fixed by the machine operator. Assuming he said 25%, the probability that the MO is able to fix any occurring error is 25% and the probability that he cannot solve a problem is automatically 75%. The next green *decision object* asks if the direct maintainer can fix the problem and the domain experts had to estimate the yes and no probabilities for this case and so forth. The question sheet that was given to the domain experts can be seen in Appendix 1 and the result of one machine in Appendix 2. In the end there is a process sheet where every green decision object is probability-based regarding yes or no. This can be seen in Figure 57:

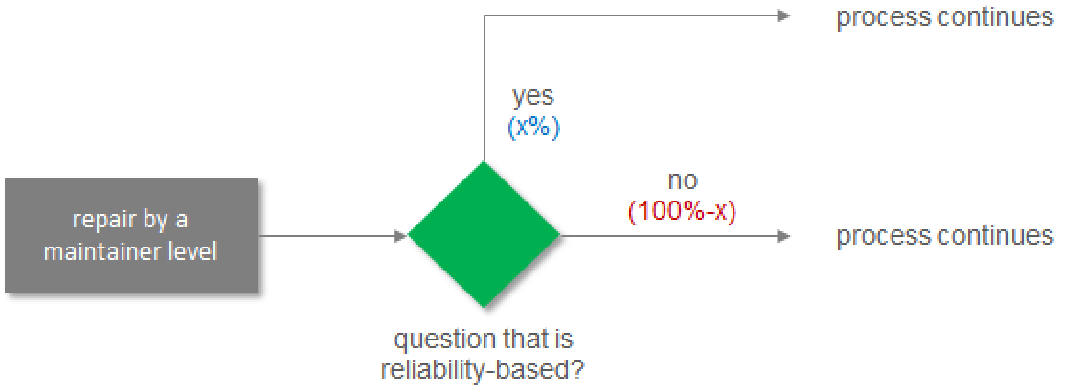


Figure 57: General explanation of a probability-based *decision object*

This process sheet that is illustrated in Figure 56 combined with the probabilities as they are described in Figure 57 was developed for all the production machines of the reference segments, which are the conrod, cylinder block, cylinder head, cam and camshaft production line of the P5 segment (four-cylinder diesel engine) and the crankshaft production line of the P3 segment (four-cylinder gas engine).

As can be seen in this chapter, these processes are a highly complex but represents a very important topic. The simulation proceeds stepwise through these processes and calculates its outputs based on them.

The assumption and simplifications that were made for this input are:

- At each unexpected machine failure there is a machine operator at the machine immediately. This implies the fact there are always enough machine operators no matter how many machines break down.
- The question if a certain maintainer level can fix a problem is based on a probability and not on the specific error.
- There is no learning effect throughout a process. This means the probabilities will not change over the simulated time (which is one year).
- There cannot be any processes which are not shown in the flow chart in Figure 56. Even though in real life it might happen that some maintainer levels are skipped when calling for help, this cannot be the case in this simulation model.
- Within certain time limits, which will be explained afterwards, the maintainer who is currently repairing a machine will never leave this machine until he either fixed the problem or some defined time exceeded

The defined timeframes (the escalation times):

As already mentioned in the description of the processes, some skill levels escalate the process to the next level after a certain amount of time if they cannot solve the problem. This is also illustrated by the clocks that are linked to the process steps in Figure 56.

This is of course a simplification, because in real life in some cases the maintainer will immediately realize that he cannot fix the problem and call for help and in other cases he will try longer to fix the problem. The aim of this fixed value is to represent a mean value of all these cases.

The production line cycle times:

The cycle time is defined as the *“duration for the execution of a defined operating cycle”* (VDI 2516, p. 3). In the case of a production line, the cycle time is determined by the machine with the longest cycle time, the so called bottleneck. The cycle time is important for the estimation of a production output which will be explained at the conceptual modeling step of output definition.

Assumptions and simplifications:

- The cycle time of all production machines is equal to the cycle time of the bottleneck.
- The cycle times never change. There is no data regarding cycle time changes within the simulated year.

Redundancies:

The redundancies are an important input that is needed for the production line output calculation which will be explained in chapter 6.6.5. In the “VDI-Lexikon Energietechnik” redundancy is defined as the installation of more performing systems than actually necessary to fulfill requirements (Schaefer 1994, p. 1037). In the case of a production line this means one process step should have the possibility to be performed by more than one machine. Therefore if a redundant machine breaks down, the production line can still produce, though at lower capacity.

Production plan for the simulated year:

Within this production plan, the production free times of the AH (the so called “Betriebsurlaub” which means plant holiday) are listed. This is also important for the production output which will be explained at the conceptual modeling step of output definition.

Assumptions and simplifications:

- Except of the plant holidays which are in December and August, the rest of the year the production lines produce with full capacity according to their shift plan.
- The plant holidays start and end at the same time for all production lines.

Shift plan:

The shift plan is a very important input. It defines when each of the production lines produces during a week. It also defines when and how long the TPM shift is made and who has to be present. The typical shift model at the AH are two shifts of twelve hours up to seven days a week (i.e. continuous production). The TPM shifts are six to twelve hours mostly once a week. The shift plan furthermore describes which maintainer is present at which time during production. At the current state the *level 1* maintainers (the direct maintainers) are present whenever the line produces. But the indirect maintainers work in normal 40 hour working weeks and therefore do not work at night or weekends.

Assumptions and simplifications:

- The production lines work strictly according to the shift plan.
- The TPM shift is always performed on the defined day, at the defined time.
- The direct maintainers to not exceed 40 hours of work per week.

Conclusion of the inputs:

The inputs can be categorized generally into three main groups: the organizational structure-related, the operational-structure related and the production line-related inputs. All of them are important. The change of one single input can cause huge changes in the output and has to be considered carefully. Figure 58 illustrates which inputs belong to which group.

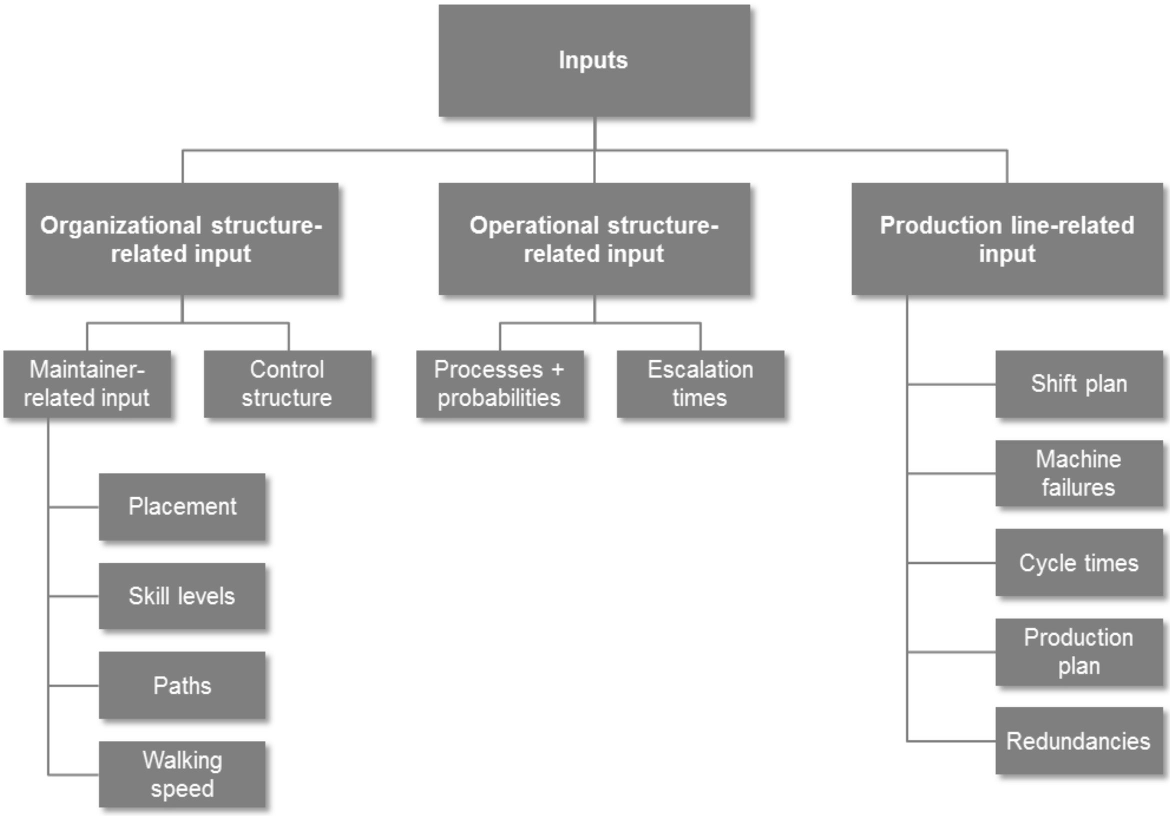


Figure 58: The categorization of the inputs

6.6.4 The scenario (A set of inputs):

A scenario is not a single input like for example the walking speed, but a combined set of some of the above described inputs. So the individual scenarios can be distinguished by the difference of their input values. They are the main criteria that shall be examined in order to find the optimized organizational structure. The inputs on which a scenario is based are:

- The physical placement of the maintainers
- The control structure (which control unit controls the maintainers)

It is important to bear in mind that due to the simplifications and assumptions in the simulation model, absolute values will not be obtained. As an example it is not possible to forecast an exact production output that will be reached in the future by a new organizational structure. Instead tendencies can be shown, so in the case of the production output it can be said if it will increase or decrease under the new circumstances. To be able to show these tendencies, it is as a first step essential to simulate the current state to have a base unit to which all new solutions can be compared. The different scenarios that were simulated are described in chapter 6.7.2.

6.6.5 The outputs

With the aid of the outputs (or responses) it can be determined if the objectives were achieved or not (Robinson 2008a).

The results of one simulation run are the following KPIs:

Mean waiting for repair time:

This measure is a utilization-based value in unit at seconds, minutes or hours. It reflects how long all the machines of one production line had to wait on average until a maintainer started working on them. This mean waiting time is separately listed for each maintainer type. As explained in chapter 6.3, this KPI is a combination of *walking times* and *waiting for the required skill* time. Based on this measure, other interesting measures can be calculated if inquired by the client. The simplification that is of importance is:

This measure is an average, therefore it cannot be distinguished between production lines for which the existing structure works very good and those which perform very badly and therefore worsen this KPI

The production line output:

The production line output is related to the downtime of a machine. Therefore it is related to the *mean waiting for repair time* and to the *repair time* (which cannot be influenced in this project). This measure is based on the simple thought of “if a machine is out of production due to a downtime, the production line cannot produce parts”. This assumption shows, that buffers are not considered in this project. This already leads to the following simplifications and assumptions:

- Buffers are not considered in this project
- Different cycle times are not considered

The connection of the upper two outputs:

As mentioned these two described outputs are related. The production line output in the calculation model is decreased by machine downtimes. The machine downtimes are a sum of the *waiting for repair* time and the *repair time*. The *repair time* is a fixed value based on history data that is not changed by the simulation approach. Hence, the production line output differs due to the different *waiting for repair* times of the different scenarios.

The total waiting for a maintainer type:

This KPI is interesting due to the better comparability of the total workload of the maintainers at the production lines.

Production line availability:

The production line availability is a measure that shows how much could have been produced compared to the current production line output. It is therefore the ratio of the achieved production line output and the theoretical output without any machine errors.

6.6.6 The model content

The model content defines how inputs are transformed into output. According to Robinson two main criteria are of importance: the scope and the level of detail. *"The scope is the boundary of the model in terms of its breadth. The level of detail is the boundary of the model in terms of the depth of detail modelled for each component within the scope."* (Robinson 2008b, p. 292)

Since the development of the simulation with its programming and source code is not part of this work, the model content will be a description of how the simulation works.

The simulation start:

When hitting the *start button* some of the main inputs are checked first. These inputs are for example the scenario, the placement of the production lines, the shift plans and others. The scenario includes information of how many maintainers of which type at which times are available, where are they placed and who is in control of them.

After these general inputs are checked and implemented, the clock starts running (in this approach it was one year). The question of which error occurs at which machine and when is answered by a randomized generator. Every machine gets one of its TBFs sampled and as soon as it has run out, a TTR gets sampled. At the same time an error solving process gets triggered to the TTR, which proceeds as follows:

The failure fixing process and its outcome: the *waiting for repair* time:

Since the simulation approach is a Discrete Event Simulation (DES), it is following the process sheet from Figure 56 stepwise from event to event, until the machine runs again. To make this stepwise approach more clear an example is developed:

- Starting event: An unexpected machine error occurs, the process starts.
- Next event: The machine operator tries to repair the machine. Due to the fact that he/she cannot repair the machine before the defined time has run oin time, the process goes on to the first green decision object. This is always the case when the MTTR is higher than the defined escalation time. During the machine operator tries to fix the problem, the MTTR is counted down.

- Next event: At the first green diamond, the one question being raised is if he/she can or cannot handle the problem. According to the probability-based random generator a choice is made. In this case the probability that he can handle the problem is 25%; chances that he/she cannot handle the problem is 75%. For this example it is assumed that the random generator triggers a no.
- Next event: According to the yes or no, the green decision object proceeds the simulation to the next event. In case of this example this is the direction of no and therefore the direction of the “DM exists?” question.
- Next event: In this example an direct maintainer exists, therefore the direction of “yes” is being followed.
- Next event: This blue marked event is a delay event, which represents the *waiting for the required skill level* and the walking time. This object is counting the seconds until the required skill level arrives at the machine.
- Next event: The direct maintainer fixes the problem in time, therefore the process jumps to the end event.
- Next event, End event: The simulation approach jumps to the End event (see Figure 56) and the repair process for this occurred error is over.

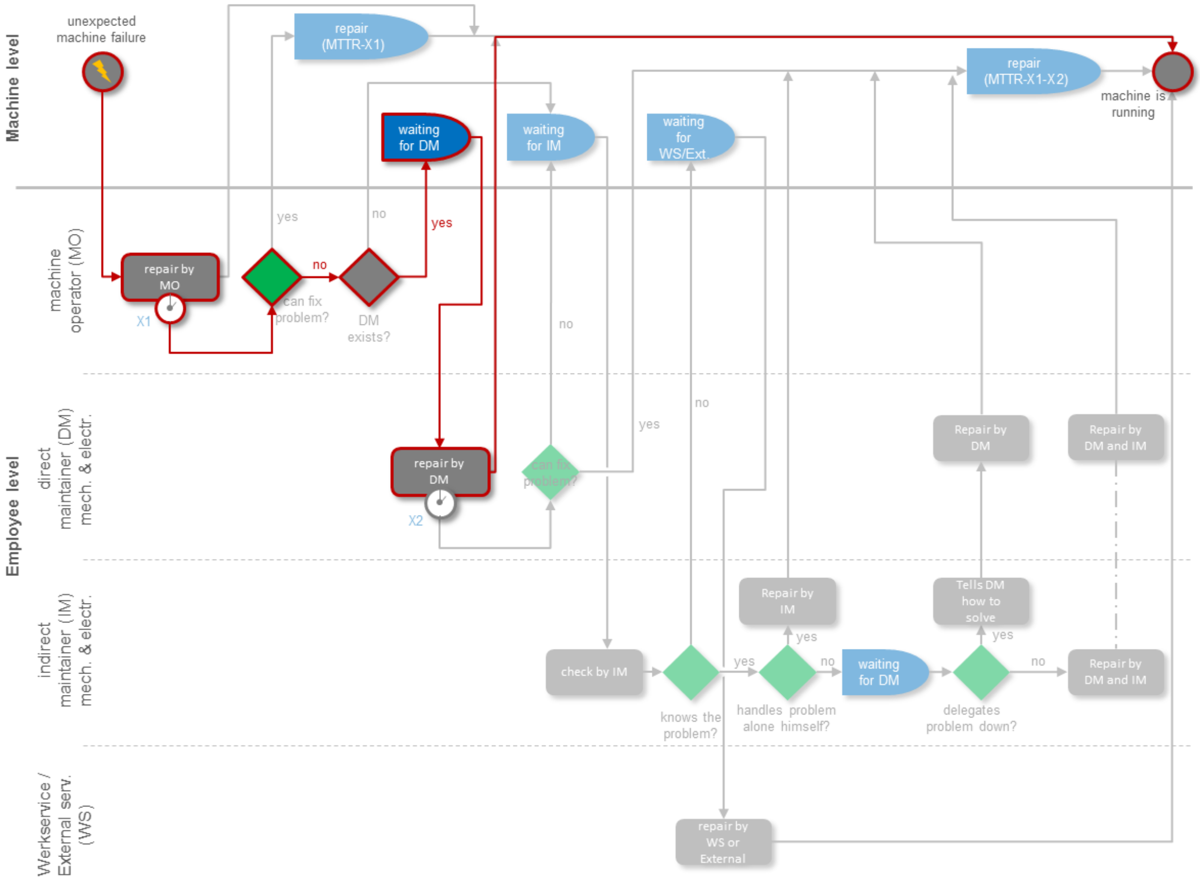


Figure 59: Illustration of the stepwise process example

Out of this failure fixing process the waiting for repair time is determined. The simulation continuous as follows:

The simulation of one year:

Over the time of one year, the previously described processes occur randomly. Each time a failure is triggered, the failure fixing process is being triggered and the waiting for repair time determined. Due to the, in the beginning of this chapter explained inputs, the simulation approach exactly knows when a production line is producing (only during this time errors can occur), when it has to make a TPM shift and when it is out of production due to weekends and/or production holiday.

The end of the simulation:

At the end the *waiting for repair* time for each maintainer type at each production line is stored as the *total waiting time* for a maintainer type. Furthermore this value is divided by the number of occurred errors at this production line. The result of this ratio is the mean waiting time for one maintainer type at one production line. It is calculated for all maintainer types at all production lines. The next KPI is the production line output. It is calculated as a ratio of the achieved production time and the cycle time of the production line. As a last measure the ideal production line output of each production line is calculated. By dividing the achieved production line output by the ideal output an efficiency measure can be obtained.

6.7 Simulation

In this chapter, different scenarios which were simulated are explained. Also some general assumptions and simplifications that have been made are listed. It is not part of this chapter, neither of this Thesis, to explain the details of the software or even the programming code of the simulation.

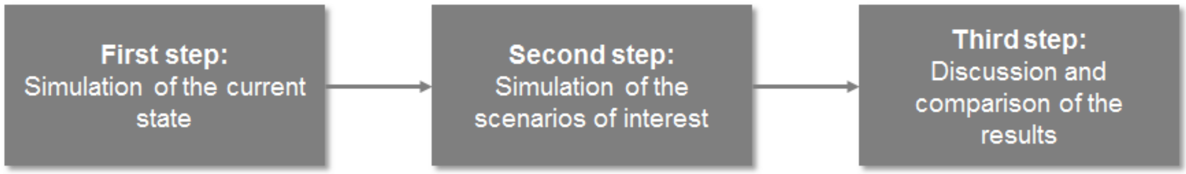


Figure 60: The steps of the simulation approach

6.7.1 Some general assumptions and simplifications

In chapter 6.6 some assumptions and simplifications were already mentioned concerning inputs and outputs. Here some more are listed which the client should bear in mind when working with the upcoming DSS tool.

“Rufbereitschaft” (on-call duty):

Nowadays indirect maintainers work in 40 hour shifts and are therefore not present during nights and weekends. But they have on-call duty, which means they can be called in case something sever happens that requires their help. Mostly they can fix the problem by assisting via phone, but sometimes they even have to drive to the factory.

In this simulation approach, no difference is made between an indirect maintainer who is present and an on-call duty maintainer. This means whenever in real life a maintainer has on-call duty, the simulation uses a virtual indirect maintainer who is present.

Upscaling:

In this simulation approach 25 production lines with each of them consisting of ten machines and more are integrated. This would have meant hundreds of questionnaires and even more implementation work. Therefore five reference production lines, of each part type one, were developed. The other production lines where copied from these reference lines and output fitted by a scale factor. This means the output of these copied production line is very close to the real output of this line.

6.7.2 The simulation approach

First step: Simulation of the current state (the base scenario)

As shown in Figure 42 the organizational structure of the engine production is a combination of a divisional and a functional structure. The divisional structure separates the organizational level 2 and the functional structure the organizational level 3 (see Figure 38). It is furthermore a single line system with the line manager at the top of the production line (level 3), one executive department in which the indirect maintainers are located and the direct maintainers and machine operators at the end of the organigram. Due to the self-organization of the maintenance operations of each production line, this is a decentralized control. Another maintenance unit is the group maintainers which belong to the Technical Service. They are responsible for all production lines and therefore a centralized unit. This leads to the combination of a centralized-, decentralized control of the maintenance operations at the current state.

- The physical placement: Direct and indirect maintainers are placed at the production lines. PT/Ext maintainers are placed at the Technical Service.
- The control structure: The direct and indirect maintainers are controlled by the production lines, PT/Ext are controlled by the Technical Service.

Second step: Simulation of the scenarios of interest

The possible scenarios can be dozens, but it is time consuming and simply not target-aimed. Instead it is better to develop some general scenarios (like for example a completely centralized system) first, to see in which direction the final solution could go. Despite of that, meetings with the client are important to take into account which scenarios are not conceivable for him/her.

Scenario 1 (the centralized system):

For this scenario the maintenance units at the production lines are switched to the Technical Service. This leads to a completely centralized maintenance structure with a centralized control.

- The physical placement: All units are placed at the Technical Service
- The control structure: All units are controlled by the Technical Service

A major change in such a scenario would not just be the new placement and control of the indirect and direct maintainers. Also the role of the indirect maintainers would change. The planning part, which is nowadays a main part of the indirect maintainers' work, would be done somewhere at the Technical Service. This increase of time for the indirect maintainers would open new possibilities like new competences, more projects and more time for the training of direct maintainers.

For scenario 2,3,4 and 5 the same considerations as for this scenario are valid.

Scenario 2 (the centralized scenario with no travel times):

In this scenario it is assumed that all the maintainers can reach the machines immediately. This is of course not realistic, but it shows the unadulterated utilization of the maintainers.

- The physical placement: All units are placed at the Technical Service
- The control structure: All units are controlled by the Technical Service (centralized control)

Scenario 3 (the 125% centralized scenario with no travel times):

In this scenario the optimum with a clear maintainer unit overload shall be simulated.

- The physical placement: All units are placed at the Technical Service
- The control structure: All units are controlled by the Technical Service (centralized control)

Scenario 4 (the 75% centralized scenario with no travel times):

In this scenario the decrease of performance with 25% units less, compared to the centralized scenario 1 shall be visualized. This test shows, if the new scenario with current employees would exhibit an overcut of units.

- The physical placement: All units are placed at the Technical Service
- The control structure: All units are controlled by the Technical Service (centralized control)

Scenario 5 (centralized scenario with five minutes travel time max):

The goal of this scenario is to find out if a centralized control with decentralized physical placement could make sense.

- The physical placement: All units are placed at the Technical Service
- The control structure: All units are controlled by the Technical Service (centralized control)

Scenario 6 (the segment scenario):

In this scenario all the indirect and direct maintainers of all the production lines of one segment shall get bundled at the segment. This means in comparison to the centralized scenarios, not all units can be assigned to all production machines, but only to those of the particular segment. It is consequently a semi-centralized organization.

- The physical placement: The indirect and direct maintainers are located at the segments. The WS/Ext are still located at the Technical Service
- The control structure: The indirect and direct maintainers are controlled by the segments, the WS/Ext are controlled by the Technical Service

Scenario 7 (centralized DM, decentralized IM):

In this scenario the DM and IM get split. Therefore they would sit at different places and be supervised by different places. The organizational structure would be an even more mixed scenario than nowadays.

- The physical placement: The DM are placed at the Technical Service, the IM at the production lines
- The control structure: The DM are controlled centralized by the Technical Service, the IM are controlled decentralized by the production lines

Scenario 8 (decentralized DM, centralized IM):

For scenario the same considerations as for scenario 7 are valid.

- The physical placement: The DM are placed at the production lines, the IM at the Technical Service
- The control structure: The DM are controlled decentralized by the production lines, the IM are controlled centralized by the Technical Service

Scenario 9 (centralized control, decentralized placement) – not simulated yet:

Due to the huge area of the engine production in Györ, walking paths for maintainers can become very long when they are placed centralized. The advantage of centralized control is the more harmonized utilization of maintenance units. Therefore this scenario should combine these two advantages.

- The physical placement: The indirect and direct maintainers are located at the production lines. The WS/Ext are still located at the Technical Service
- The control structure: The indirect and direct maintainers are controlled by the Technical Service as well as the WS/Ext

Another interesting aspect is the possible change of a single-line system to a matrix structure. When controlling the units centralized, the maintainers could get supervised by the Technical Service and the production line they are placed at.

All scenarios in one table:

Scenario		Workplace		Physical Placement and Workplaces			Controlled by		
Number		Skill level		Line (26Lines)	Segment (6 segments)	Technical Service	Line	Segment	Technical Service
scenario 0	base (current) scenario	skill level 1	direct maintainer	21			x		
		skill level 2	indirect maintainer	29			x		
scenario 1	cetralized scenario	skill level 1	direct maintainer			21			x
		skill level 2	indirect maintainer			29			x
scenario 2	centralized scenario, no travel times	skill level 1	direct maintainer			21			
		skill level 2	indirect maintainer			29			
scenario 3	125% centralized scenario, no travel times	skill level 1	direct maintainer			26			x
		skill level 2	indirect maintainer			36			x
scenario 4	75% centralized scenario, no travel times	skill level 1	direct maintainer			16			x
		skill level 2	indirect maintainer			22			x
scenario 5	centralized scenario, travel times <= 5min	skill level 1	direct maintainer			21			
		skill level 2	indirect maintainer			29			
scenario 6	segment scenario	skill level 1	direct maintainer		21			x	
		skill level 2	indirect maintainer		29			x	
scenario 7	mix: centralized DM, decentralized IM, travel times <=5min	skill level 1	direct maintainer			21			x
		skill level 2	indirect maintainer	29			x		
scenario 8	mix: decentralized DM, centralized IM, travel times <=5min	skill level 1	direct maintainer	21			x		
		skill level 2	indirect maintainer			29			x
scenario 9	centralized control, decentralized placement	skill level 1	direct maintainer	21					x
		skill level 2	indirect maintainer	29					x

Table 2: All scenarios in one table

6.8 Result Interpretation and Implementation

As mentioned in chapter 6.6.5 the outputs of the simulation approach are the *"mean waiting for repair time"* (MWRT), the *"production line output"* (PLO), the *"total waiting for repair time"* (TWR) and the *"line availability"* (LA). These measures will be listed in the first part of this chapter. Afterwards these figures will be discussed in the interpretation.

6.8.1 Results

In the first place the results will be just listed in this chapter. One figure always belongs to one scenario, one skill level (see chapter) 6.6.3 and one production line. The first result is the *“accuracy”* which should show how close the simulation comes to the real world in terms of production output.

Accuracy:

Since the actual production numbers of the simulated year are known, the deviation between real life and the simulated base scenario can be calculated.

Accuracy			
Production line / scenario	scenario 0 (base scenario)	Real Output	Deviation
G_P3-11 R4 Otto EA211 ZKG	476452	483524	1,46
G_P3-12 R4 Otto EA211 KW	340419	350000	2,74
G_P3-13 R4 Otto EA211 PL	1298043	1380420	5,97
G_P3-14 R4 Otto Linie 6 ZK	356941	375189	4,86
G_P4-12 ZKG R4 Flex	141278	185000	23,63
G_P4-14 R4 Otto GE ZKG	445730	455000	2,04
G_P4-18 ZK R4 Otto Linie7	410026	433000	5,31
G_P4-19 ZK R4 Otto	136074	142000	4,17
G_P4-51 KW R4 Otto GE Linie 1	325518	350000	6,99
G_P4-52 KW R4 Otto GE Linie 2	244002	253000	3,56
G_P4-61 NW AVS NS GS1	892362	918909	2,89
G_P4-62 R4 NW AVS PN	521583	532285	2,01
G_P5-13 R4 TDI PL	2026613	2300000	11,89
G_P5-14 R4 TDI ZK4	439758	450000	2,28
G_P5-16 R4 TDI ZKG	501132	500000	-0,23
G_P5-17 R4 TDI KW	445865	485000	8,07
G_P5-41 R4 MDB iVM Nocke	7009333	7000000	-0,13
G_P5-41 R4 MDB iVM Rohr	868975	900000	3,45
G_P6-11 KW V6 Otto	104363	109000	4,25
G_P6-12 ZKG V6 Otto	156335	169000	7,49
G_P6-13 ZK V6 Otto	343789	353000	2,61
G_P7-12 ZKG V6_V8	182381	213000	14,37
G_P7-13 ZK V6 TDI	338433	388000	12,78
G_P7-14 KW V6 TDI	267037	292000	8,55
G_P8-1 ZKG V8_V10	15141	18000	15,88
G_P8-12 ZK V8_V10	1433	1500	4,47

Table 3: Accuracy of the simulation

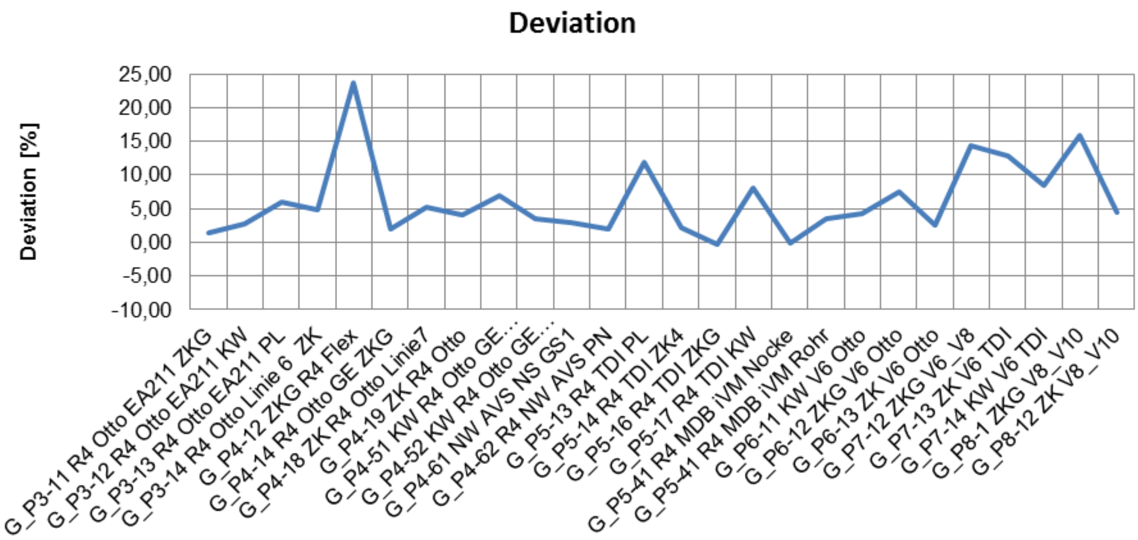


Figure 61: Deviation Chart

As shown in Figure 61, for most production lines the deviation stays within 15%.

Mean waiting for repair time (MWRT) for direct maintainer (skill level 1):

The *"mean waiting for repair time"* is the average time of all the machines of the production line, between the request for one certain skill and this skilled maintainer actually starting to work at the machine. This means, this time is affected by the distance of the machine to the direct maintainer and more importantly by the utilization of direct maintainers. As an example, if a direct maintainer works on a machine and meanwhile at two other machines errors occur, these machines will have to wait longer for this direct maintainer. Even if a second direct maintainer exists, the third machine will still have to wait longer. Therefore the *"mean waiting for repair time"* is a KPI for the utilization and placement of the maintainers.

average/mean waiting time for direct maintainer (skill level 1)

Production line / scenario	scenario 0 (base scenario)	scenario 1 (centralized system)	scenario 2 (centralized, no travel)	scenario 3 (125% centralized, no travel)	scenario 4 (75% centralized, no travel)	scenario 5 (centralized 5min travel)	scenario 6 (segment scenario)	scenario 7 (centralized DM, decentralized IM, 5min travel)	scenario 8 (decentralized DM, centralized IM, 5min travel)
G_P3-11 R4 Otto EA211 ZKG	0,095185711	0,19885199	0,01669794	0,016667013	0,155142213	0,083409316	0,029296594	0,083401441	0,096462014
G_P3-12 R4 Otto EA211 KW	0,14899623	0,205869007	0,016641731	0,016630503	0,147163646	0,083083706	0,029392222	0,083124736	0,158109683
G_P3-13 R4 Otto EA211 PL	0	0	0	0	0	0	0	0	0
G_P3-14 R4 Otto Linie 6 ZK	0,263217846	0,121178178	0,011451514	0,011531323	0,117373815	0,057983249	0,022147106	0,057884314	0,266792795
G_P4-12 ZKG R4 Flex	0,069175839	0,161049024	0,014323092	0,014317092	0,12184221	0,071614908	0,014421442	0,071625943	0,069904537
G_P4-14 R4 Otto GE ZKG	0,09525406	0,169445845	0,014327954	0,014326949	0,123659499	0,07161528	0,014421401	0,071626641	0,101328752
G_P4-18 ZK R4 Otto Linie7	0,336415556	0,193391191	0,016705604	0,016665661	0,168699243	0,083392388	0,017447647	0,083410847	0,337012216
G_P4-19 ZK R4 Otto	0,333849619	0,301871671	0,016706569	0,016666899	0,170351829	0,083384741	0,017512113	0,083404618	0,323845752
G_P4-51 KW R4 Otto GE Linie 1	0,067597622	0,158778898	0,016695795	0,016666236	0,145898415	0,083391768	0,017393871	0,083382617	0,073888042
G_P4-52 KW R4 Otto GE Linie 2	0,121676719	0,172179079	0,016344246	0,016364087	0,135690775	0,081620362	0,016619606	0,081707648	0,130079008
G_P4-61 NW AVS NS GS1	0,049901835	0,270614937	0,016754116	0,016827643	0,52775559	0,074761499	0,019173918	0,200703863	0,047775918
G_P4-62 R4 NW AVS PN	0,030593046	0,302502117	0,015894237	0,015942528	0,486705789	0,071528656	0,017884247	0,195128418	0,027857754
G_P5-13 R4 TDI PL	0	0	0	0	0	0	0	0	0
G_P5-14 R4 TDI ZK4	0,263217846	0,105560179	0,011623977	0,011549817	0,126611696	0,058045457	0,029112587	0,057759869	0,281535294
G_P5-16 R4 TDI ZKG	0,107520007	0,374732231	0,016685773	0,016666519	0,161513046	0,083405649	0,123606944	0,083392397	0,113377014
G_P5-17 R4 TDI KW	0,115987979	0,131111826	0,009553799	0,009552239	0,093712781	0,047765021	0,019296727	0,047743404	0,116673268
G_P5-41 R4 MDB iVM Nocke	0,351158135	0,228742078	0,018114787	0,018253252	0,538127115	0,067284837	0,35023708	0,061232552	0,388747658
G_P5-41 R4 MDB iVM Rohr	0,320429356	0,194253824	0,017025572	0,017903187	0,512643634	0,0672479	0,328170344	0,059799552	0,365164938
G_P6-11 KW V6 Otto	0,14899623	0,275913151	0,016633463	0,01662102	0,165400486	0,083218044	0,081248503	0,08308402	0,147467728
G_P6-12 ZKG V6 Otto	0,050398412	0,114388236	0,009582035	0,009551324	0,089158722	0,047824323	0,016100197	0,047823965	0,051064157
G_P6-13 ZK V6 Otto	0,25736745	0,209647206	0,014328774	0,014318408	0,143985425	0,071616013	0,093341796	0,071571494	0,267289827
G_P7-12 ZKG V6_V8	0,073081073	0,338450307	0,016672445	0,016666667	0,145893067	0,083319706	0,069007565	0,083298945	0,077604667
G_P7-13 ZK V6 TDI	0,265963395	0,196993328	0,014313157	0,014317359	0,138446145	0,071598707	0,10488665	0,07160954	0,264744456
G_P7-14 KW V6 TDI	0,109727128	0,230252381	0,014105159	0,014014925	0,115597559	0,070226669	0,083904962	0,070008061	0,116165237
G_P8-1 ZKG V8_V10	0,181251457	0,249296226	0,013816604	0,013813795	0,111444624	0,069057887	0,092311332	0,069118337	0,133761284
G_P8-12 ZK V8_V10	0,296216693	0,171209211	0,016690468	0,016660788	0,192606213	0,083339535	0,127362439	0,083333177	0,251090581

Table 4: The average waiting time for the direct maintainer

Table 4 shows the results of different scenarios of the "*mean waiting for repair time*" for direct maintainers. For two production lines all the results are zero. This is because of these production lines not having direct maintainers. For better understanding and enabling an easier comparison of the results, the following chart is derived:

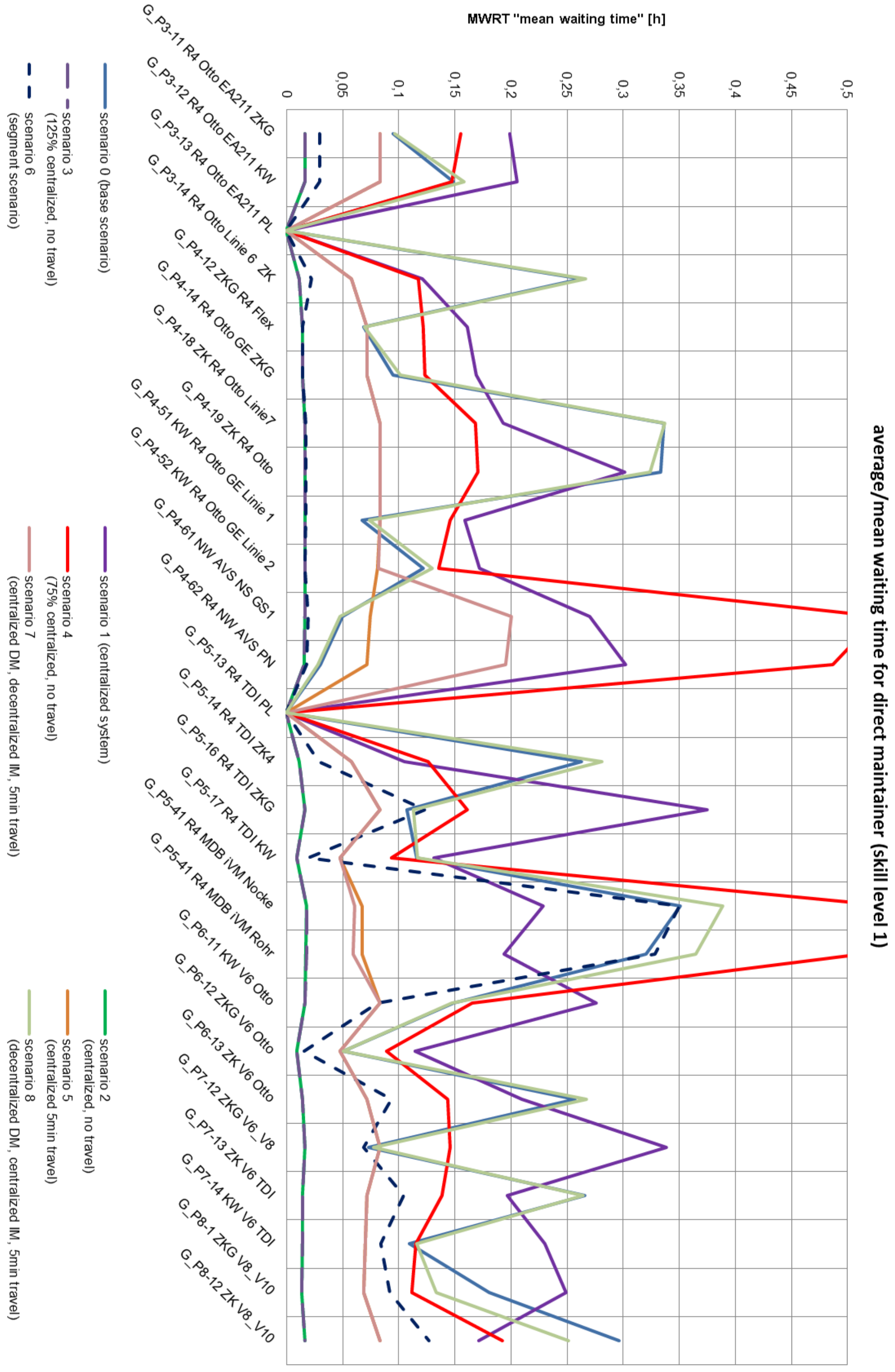


Figure 62: The visualization of the "*mean waiting for repair time*" for direct maintainers

On the ordinate the waiting time is shown in a range between 0 and 0.5 hours. This means all the results (except for one) stayed within half an hour. On the x-coordinate, production lines are listed. The connection of the y-values is unimportant, but helpful for better visualization of the difference of the results, compared to a chart with just single points.

Mean waiting for repair time (MWRT) for indirect maintainers (skill level 2):

It is the same KPI as the previous one, but for the second skill level, the indirect maintainers. The results are the following:

average/mean waiting time for indirect maintainer (skill level 2)

Production line / scenario	scenario 0 (base scenario)	scenario 1 (centralized system)	scenario 2 (centralized, no travel)	scenario 3 (125% centralized, no travel)	scenario 4 (75% centralized, no travel)	scenario 5 (centralized 5min travel)	scenario 6 (segment scenario)	scenario 7 (centralized DM, decentralized IM, 5min travel)	scenario 8 (decentralized DM, centralized IM, 5min travel)
G_P3-11 R4 Otto EA211 ZKG	0,073501083	0,171277501	0,016594341	0,016357485	0,056929508	0,082017112	0,016510836	0,117951795	0,08200676
G_P3-12 R4 Otto EA211 KW	0,026044322	0,094754291	0,008422886	0,00840796	0,028522126	0,042880135	0,008675949	0,058263494	0,042438144
G_P3-13 R4 Otto EA211 PL	0,08978002	0,142338138	0,011993926	0,011825871	0,013266835	0,058594838	0,012088024	0,078963531	0,05935665
G_P3-14 R4 Otto Linie 6 ZK	0,014052689	0,097079385	0,011015205	0,010845771	0,040362865	0,055257543	0,010925288	0,048939561	0,054864431
G_P4-12 ZKG R4 Flex	0,049369847	0,139629525	0,013946496	0,013582066	0,053870547	0,067812009	0,013701422	0,060165219	0,067439586
G_P4-14 R4 Otto GE ZKG	0,036987814	0,151904143	0,014177773	0,013859515	0,057319113	0,069555816	0,013840796	0,043829824	0,069351209
G_P4-18 ZK R4 Otto Linie7	0,082959946	0,152424478	0,015511747	0,015578214	0,019324092	0,077225968	0,016574977	0,103677487	0,078375836
G_P4-19 ZK R4 Otto	0,080237693	0,253356787	0,015636181	0,015576192	0,048754439	0,077685761	0,016153652	0,109458679	0,077661883
G_P4-51 KW R4 Otto GE Linie 1	0,015572465	0,079922937	0,010095613	0,009917045	0,028503662	0,050747769	0,010422653	0,017565162	0,051636604
G_P4-52 KW R4 Otto GE Linie 2	0,001025602	0,07179322	0,007757937	0,007743056	0,031435352	0,039271487	0,007638889	0,004510666	0,038638806
G_P4-61 NW AVS NS GS1	0,016454525	0,102453946	0,00797857	0,008196624	0,089883568	0,039239861	0,008147418	0,031990265	0,035042437
G_P4-62 R4 NW AVS PN	0,004418684	0,107519707	0,006690756	0,006794387	0,074015509	0,032711457	0,006962309	0,033542395	0,02537879
G_P5-13 R4 TDI PL	0,00378165	0,056503978	0,006287064	0,006004975	0,020028771	0,030607264	0,006258706	0,005676744	0,030401947
G_P5-14 R4 TDI ZK4	0,014052689	0,082597752	0,011062788	0,010881303	0,046634615	0,054578557	0,011704051	0,042034774	0,054944764
G_P5-16 R4 TDI ZKG	0,055738815	0,350202676	0,016838803	0,016581133	0,058637799	0,08314392	0,031714428	0,071330705	0,083114631
G_P5-17 R4 TDI KW	0	0,079745471	0,005862132	0,005845771	0,029796197	0,030074794	0,005686567	0,002509913	0,029197666
G_P5-41 R4 MDB iVM Nocke	0,066653062	0,079540506	0,008294946	0,008471812	0,072883522	0,038163939	0,043964776	0,154728473	0,076937146
G_P5-41 R4 MDB iVM Rohr	0,059365355	0,070746547	0,006817629	0,007563533	0,070578561	0,031817543	0,053909797	0,071603136	0,075220154
G_P6-11 KW V6 Otto	0,026044322	0,131426685	0,009175606	0,00839801	0,034334649	0,042642053	0,008864184	0,061392417	0,042779085
G_P6-12 ZKG V6 Otto	0,03337659	0,111573896	0,009849163	0,009357832	0,072736887	0,046620836	0,009473777	0,047724818	0,046627279
G_P6-13 ZK V6 Otto	0,002160308	0,165192361	0,012676553	0,01281592	0,039894896	0,063402411	0,013498813	0,033815278	0,063227905
G_P7-12 ZKG V6_V8	0,030470765	0,301443419	0,015856523	0,015655899	0,056902163	0,078871085	0,025977717	0,040127607	0,079059536
G_P7-13 ZK V6 TDI	0,016307054	0,157312069	0,012675346	0,012522388	0,045696538	0,063024373	0,013751928	0,050518944	0,062956703
G_P7-14 KW V6 TDI	0,000106423	0,107552505	0,006829161	0,006681592	0,027387752	0,033575442	0,007677932	0,002669053	0,034311646
G_P8-1 ZKG V8_V10	0,036832374	0,227985209	0,013340409	0,013062147	0,058280642	0,065541166	0,019382215	0,055285995	0,065560128
G_P8-12 ZK V8_V10	0,011097803	0,119947294	0,015018064	0,014675544	0,043919389	0,074210296	0,019298847	0,049360965	0,059811273

Table 5: Average waiting time for indirect maintainers

Based on these values, the following chart has been made:

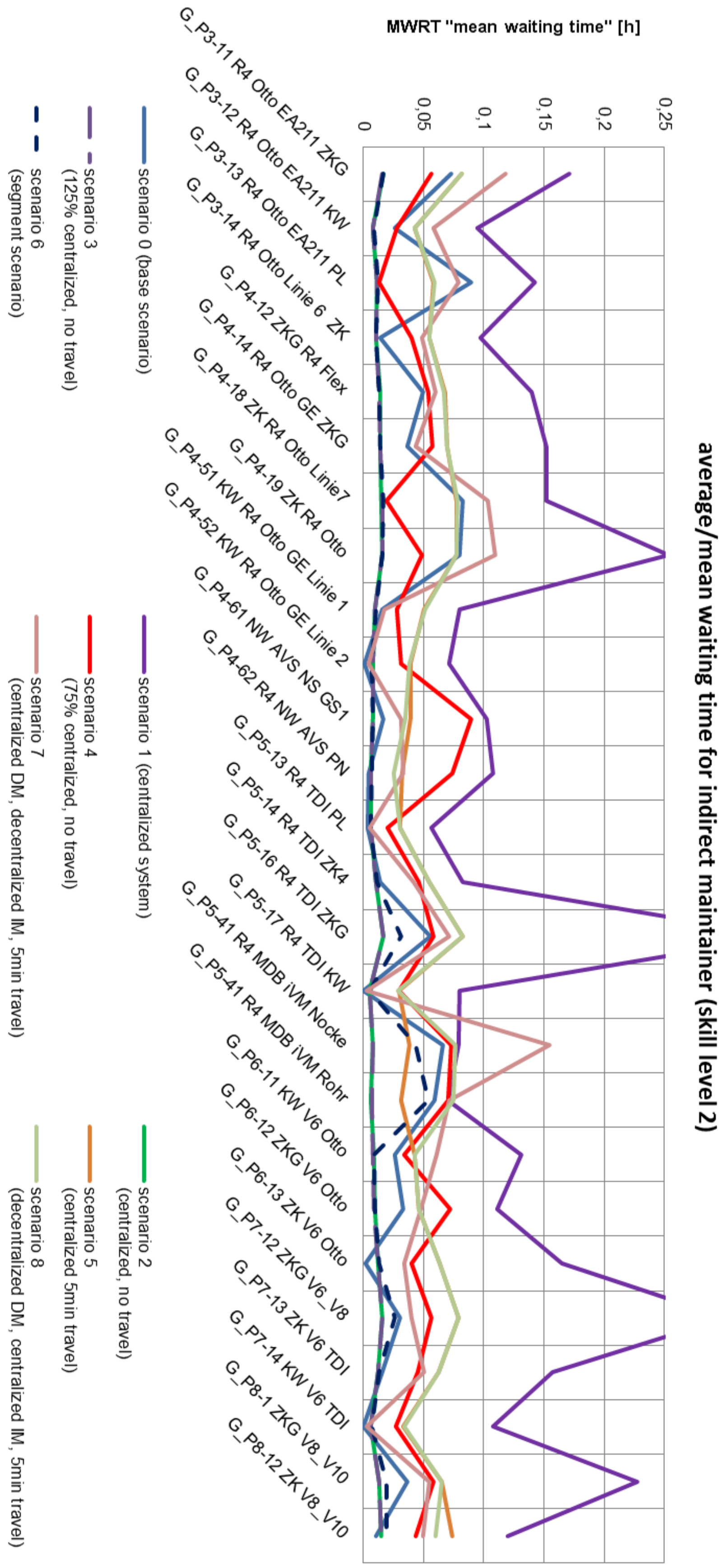


Figure 63: The visualization of the “*mean waiting for repair time*” for indirect maintainers

The x- and y-coordinate are the same as in Figure 62, but the ordinate range has been stated differently. All the results are within zero and 15 minutes, which shows that the average waiting time for indirect maintainers is lower than the average waiting time for direct maintainers. A detailed consideration of this outcome will be interpreted in chapter 6.8.2, the discussion.

Total waiting for repair time (TWR) for direct maintainers (skill level 1):

The TWR time is a determining factor which states which skill level in total is requested more often and therefore the bottleneck. For direct maintainers, results are shown below:

total waiting time for direct maintainer									
Production line / scenario	scenario 0 (base scenario)	scenario 1 (centralized system)	scenario 2 (centralized, no travel)	scenario 3 (125% centralized, no travel)	scenario 4 (75% centralized, no travel)	scenario 5 (centralized 5min travel)	scenario 6 (segment scenario)	scenario 7 (centralized DM, decentralized IM, 5min travel)	scenario 8 (decentralized DM, centralized IM, 5min travel)
G_P3-11 R4 Otto EA211 ZKG	697,8327683	1535,107627	129,045616	129,0915433	1179,292245	637,6565523	228,627923	636,2086382	690,3703068
G_P3-12 R4 Otto EA211 KW	413,3959467	553,0453379	44,134585	44,17786	437,2853047	217,6081591	83,00584122	219,681844	447,7957956
G_P3-13 R4 Otto EA211 PL	0	0	0	0	0	0	0	0	0
G_P3-14 R4 Otto Linie 6 ZK	1771,628077	943,4604493	89,37072444	88,53241667	939,0556973	445,9383681	170,4614428	444,988997	1726,161686
G_P4-12 ZKG R4 Flex	494,4234106	1084,100204	93,39271833	93,74460889	852,9267542	474,7139261	94,25862589	470,3453953	483,1652414
G_P4-14 R4 Otto GE ZKG	831,95419	1418,734482	118,7131911	118,5601989	1085,512153	586,5749722	119,8948294	599,9294283	870,7227314
G_P4-18 ZK R4 Otto Linie7	2530,617683	1441,84401	121,992662	122,6675267	1274,706539	610,0580543	129,3112868	613,5138779	2526,748554
G_P4-19 ZK R4 Otto	2507,822284	2220,417649	121,4144877	121,5622811	1265,642003	611,0590034	128,2533417	610,3848631	2410,862936
G_P4-51 KW R4 Otto GE Linie 1	262,6929689	532,549767	56,46896444	56,37384667	498,7530379	283,2539686	59,25504333	277,7760011	289,3821262
G_P4-52 KW R4 Otto GE Linie 2	357,5015756	404,1028326	39,72333333	39,96333333	331,3151217	199,5418416	39,777992	198,5479844	384,263557
G_P4-61 NW AVS NS GS1	205,24447	990,6250199	60,03410444	61,18923444	1791,481123	260,2781476	67,74134778	728,6528149	193,5141935
G_P4-62 R4 NW AVS PN	65,12271333	519,8339571	29,26542889	29,03395556	716,6609408	128,9796256	32,51600222	353,5805219	61,49071111
G_P5-13 R4 TDI PL	0	0	0	0	0	0	0	0	0
G_P5-14 R4 TDI ZK4	1771,628077	820,5930538	88,60609167	88,90049667	1004,669005	446,1803471	193,5503292	446,4699249	1743,128622
G_P5-16 R4 TDI ZKG	1104,732438	3795,275906	171,6911688	170,6803394	1640,953031	854,0763734	1109,564056	852,3754164	1155,287171
G_P5-17 R4 TDI KW	450,47554	457,2422921	33,41092722	33,28333333	341,6820364	164,4776628	70,55277044	166,2709778	460,2410494
G_P5-41 R4 MDB iVM Nocke	1280,56295	914,794125	76,59825556	77,56707444	1982,69681	278,6993587	1291,890471	248,1514896	1445,67094
G_P5-41 R4 MDB iVM Rohr	549,0557044	372,5376268	35,84895889	37,70486889	842,7963043	135,2013166	549,0428331	119,4635905	626,4242583
G_P6-11 KW V6 Otto	413,3959467	733,8573426	44,38737933	44,71695778	491,1835356	219,2502677	248,5153431	223,194831	434,6693878
G_P6-12 ZKG V6 Otto	351,8019011	792,424908	65,84900944	65,37824167	599,1804298	326,3342912	115,7663623	330,1238386	349,3237611
G_P6-13 ZK V6 Otto	1853,028712	1398,687565	93,76042333	95,38666667	1007,510888	474,5403428	364,7625331	470,6823924	1863,941804
G_P7-12 ZKG V6_V8	530,9132478	2230,225118	111,2697994	112,0466667	922,3254271	562,1411143	494,5696769	555,8671257	563,7416049
G_P7-13 ZK V6 TDI	1822,435282	1274,984698	91,37778833	92,05650444	943,0786769	457,1338011	329,4185793	452,1351694	1813,470215
G_P7-14 KW V6 TDI	320,4934456	562,063958	34,24198444	33,49	314,5070719	168,3653918	110,5292389	170,5236046	335,6290567
G_P8-1 ZKG V8_V10	496,9719111	1720,01612	93,75662	94,12190944	816,0586048	469,5012917	410,9943731	467,4919157	485,6198092
G_P8-12 ZK V8_V10	2165,135775	1108,004631	110,4670643	110,76287	1138,75622	552,5572835	765,5369229	551,3027896	1820,176961

Table 6: The total waiting times of the direct maintainers

The two production lines with zero hour waiting times do not have direct maintainers and therefore exhibit the value zero. The results are visualized below::

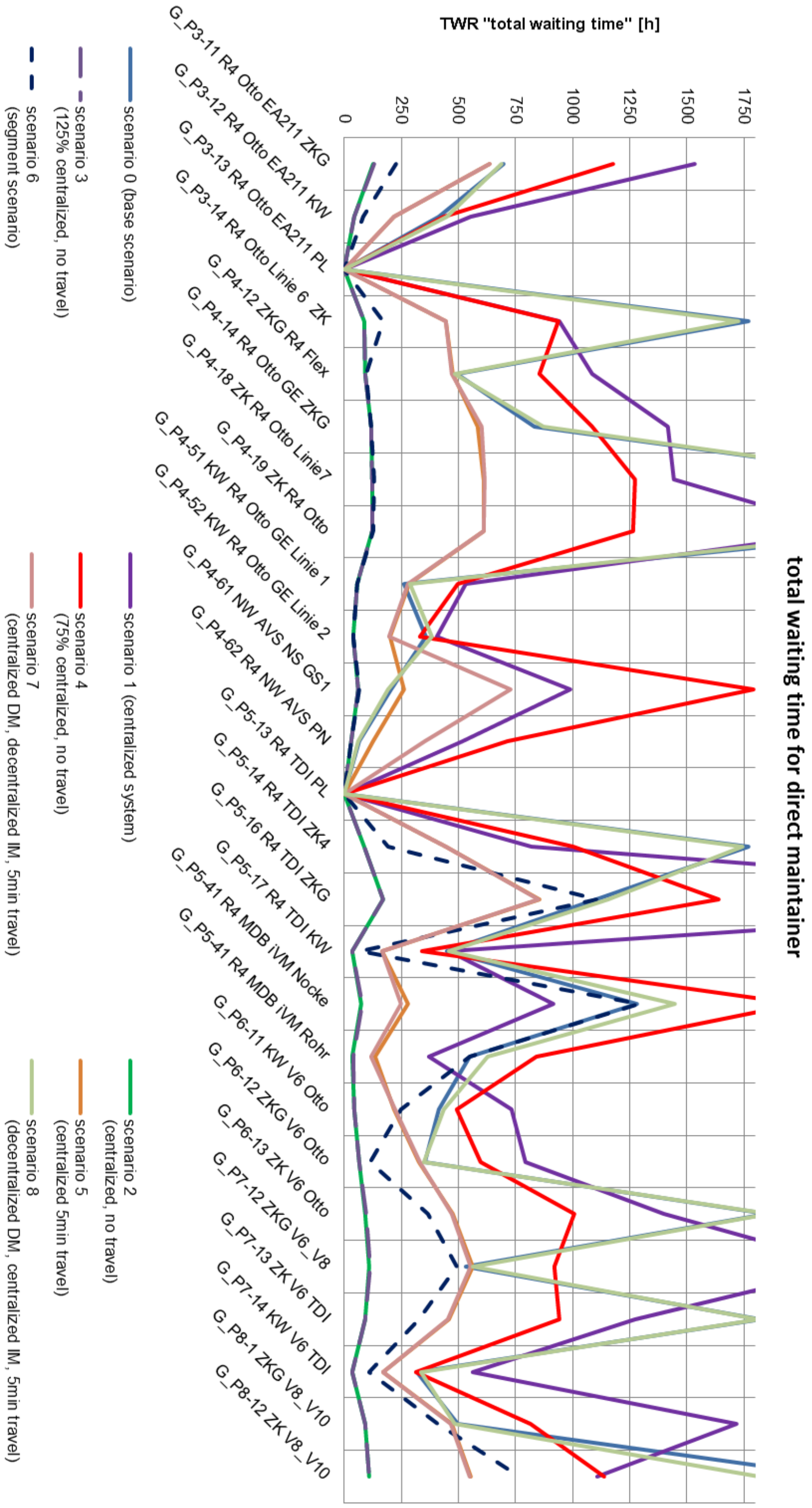


Figure 64: The visualization of the “*total waiting for repair time*” for direct maintainers

The ordinate again is shown in hours; the abscissa shows the different production lines.

Total waiting for repair time (TWR) for indirect maintainers (skill level 2):

For indirect maintainers results are listed in the following table:

total waiting time for indirect maintainer									
Production line / scenario	scenario 0 (base scenario)	scenario 1 (centralized system)	scenario 2 (centralized, no travel)	scenario 3 (125% centralized, no travel)	scenario 4 (75% centralized, no travel)	scenario 5 (centralized 5min travel)	scenario 6 (segment scenario)	scenario 7 (centralized DM, decentralized IM, 5min travel)	scenario 8 (decentralized DM, centralized IM, 5min travel)
G_P3-11 R4 Otto EA211 ZKG	108,2459822	285,9522207	28,078721	27,159515	97,94789111	136,3246866	27,90132789	162,5463962	136,1007516
G_P3-12 R4 Otto EA211 KW	11,84495222	46,65374125	3,981666667	4,131666667	13,07865256	20,46277556	4,176219444	23,90696333	19,84664667
G_P3-13 R4 Otto EA211 PL	44,76160556	85,53297308	7,224386111	7,185	8,157151333	35,816875	7,431380556	47,44682778	36,13865278
G_P3-14 R4 Otto Linie 6 ZK	6,644845556	104,2502318	12,05643056	11,84666667	45,20530322	59,03765108	11,94262578	54,41694681	56,98766944
G_P4-12 ZKG R4 Flex	83,498155	210,5197767	20,59168811	19,87705778	89,929809	100,4891354	19,86154833	95,03959647	99,65955739
G_P4-14 R4 Otto GE ZKG	81,54782	277,6639814	26,32187144	24,88381222	122,5648401	125,4401678	25,20333333	102,4961839	127,7525397
G_P4-18 ZK R4 Otto Linie7	58,25605333	159,8138187	16,28763956	16,42370178	19,28809389	80,99078644	17,63370156	95,1409265	81,38555089
G_P4-19 ZK R4 Otto	55,30117756	265,0662404	16,25433744	16,11043067	53,72748111	82,66856444	17,11011722	102,624389	79,40818733
G_P4-51 KW R4 Otto GE Linie 1	10,71673111	42,51584261	5,182049889	5,091435556	15,70113678	25,98484167	5,421588667	12,093565	26,57466778
G_P4-52 KW R4 Otto GE Linie 2	0,674542222	34,30586822	3,611666667	3,703333333	14,16743911	18,77377261	3,578333333	4,049795556	18,13087744
G_P4-61 NW AVS NS GS1	24,2247	87,58583342	5,743422222	6,020711111	96,97791878	28,49421142	5,956048889	33,02094397	25,81945158
G_P4-62 R4 NW AVS PN	4,461623333	81,59681361	5,070797778	5,082826667	62,26127711	24,86465928	5,391643333	30,15898067	19,91390667
G_P5-13 R4 TDI PL	3,483833333	31,64046225	3,354896	3,373333333	10,23117189	17,44818333	3,576666667	4,951555556	16,869356
G_P5-14 R4 TDI ZK4	6,644845556	88,56055219	12,077413	11,97998789	52,91939911	60,47775511	12,086366	45,72715981	58,13272633
G_P5-16 R4 TDI ZKG	126,1597167	749,7748554	36,99145722	36,12548556	127,1974049	182,4823114	75,72851122	162,6171225	181,5882655
G_P5-17 R4 TDI KW	0	41,06771042	3,144535111	3,085	15,65084944	15,57055647	2,986666667	2,061488333	15,62767278
G_P5-41 R4 MDB iVM Nocke	70,17703667	70,84394881	6,276746667	6,597681111	78,32045178	28,89962839	39,39278011	97,10353386	62,26601233
G_P5-41 R4 MDB iVM Rohr	53,55486	56,91052758	5,235719444	6,453132222	57,56108789	23,79330328	42,90878822	59,21857844	57,44266325
G_P6-11 KW V6 Otto	11,84495222	63,58010292	4,293383111	4,008333333	16,54471967	20,15115611	4,299868778	25,752849	20,20599333
G_P6-12 ZKG V6 Otto	51,77623333	162,2047528	14,45503944	13,73244833	78,73734533	69,62448447	14,39909956	70,51173094	69,89777
G_P6-13 ZK V6 Otto	2,850912	165,1269081	12,796383	12,62666667	43,67632944	63,01668783	13,31324811	46,41648867	61,85779944
G_P7-12 ZKG V6_V8	59,96345556	458,4842885	24,42887789	23,72843722	97,81408033	119,9671058	42,14640256	76,54579156	118,212
G_P7-13 ZK V6 TDI	15,76349378	150,2104984	12,22990344	12,16	44,93502933	60,42450572	12,91572767	61,54941733	60,51341967
G_P7-14 KW V6 TDI	0,085138889	51,16736394	3,234747778	3,123333333	11,75378989	15,68199611	3,644348333	2,052886667	16,27443389
G_P8-1 ZKG V8_V10	52,70778889	353,7453383	20,58331744	20,20906878	99,38744011	100,1367856	27,20381044	75,54254389	100,3012021
G_P8-12 ZK V8_V10	12,55097889	121,6282481	14,91005133	14,47863244	46,78218256	73,17888256	20,05563644	65,990323	58,85954911

Table 7: The total waiting times of the indirect maintainers

The chart derives from these numbers:

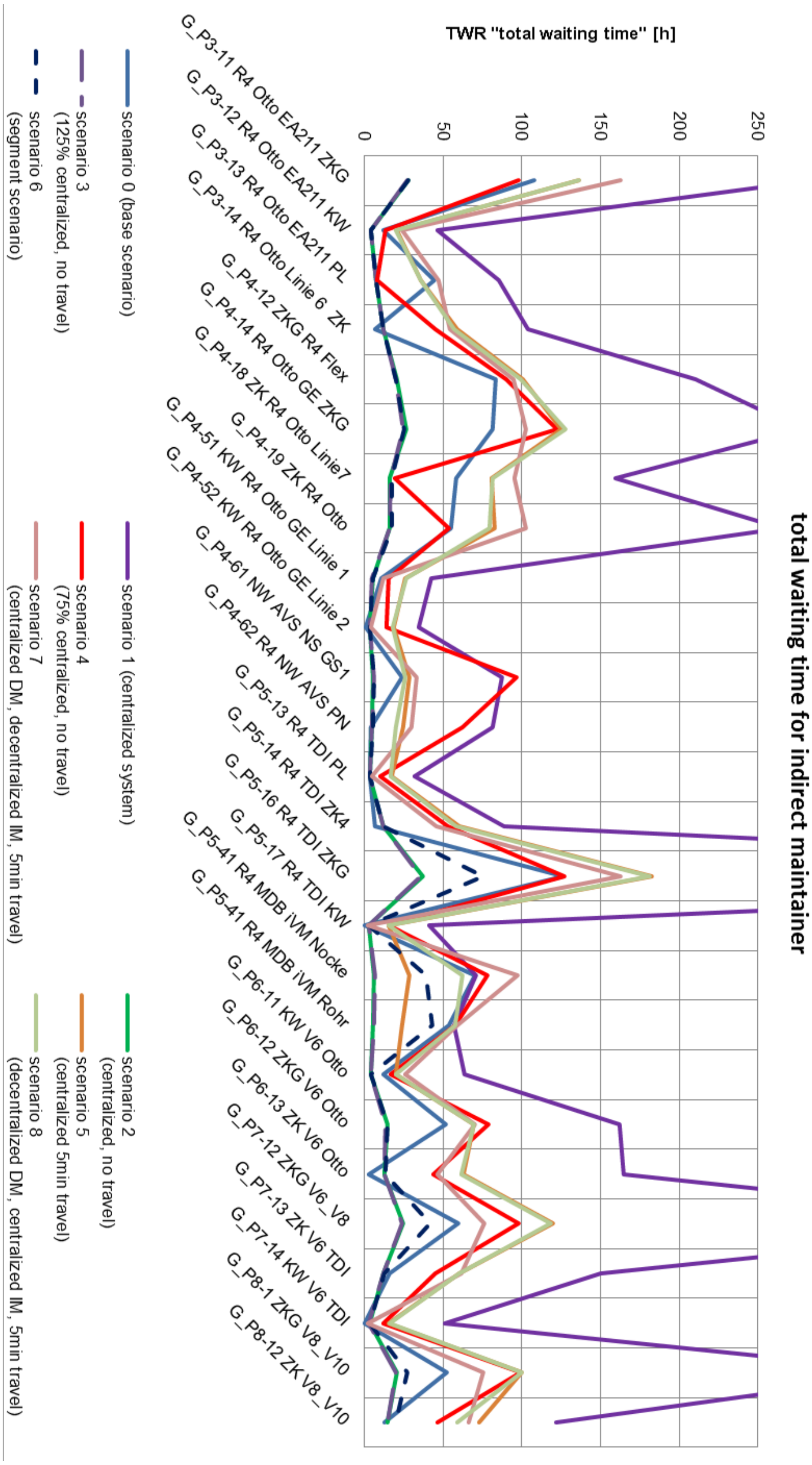


Figure 65: The visualization of the "*total waiting for repair time*" for indirect maintainers

As can be seen in Figure 65, the total waiting time for indirect maintainers are in a lower range, as the total waiting time of direct maintainers. The x- and y-coordinates are the same.

Production line output (PLO):

The production line output is a combination of the line cycle time and its production time during the simulated year. The results are:

production line output									
Production line / scenario	scenario 0 (base scenario)	scenario 1 (centralized system)	scenario 2 (centralized, no travel)	scenario 3 (125% centralized, no travel)	scenario 4 (75% centralized, no travel)	scenario 5 (centralized 5min travel)	scenario 6 (segment scenario)	scenario 7 (centralized DM, decentralized IM, 5min travel)	scenario 8 (decentralized DM, centralized IM, 5min travel)
G_P3-11 R4 Otto EA211 ZKG	476452	452836	479549	479227	473831	474286	480298	471897	474041
G_P3-12 R4 Otto EA211 KW	340419	338363	342816	339470	338893	341738	341818	340587	340188
G_P3-13 R4 Otto EA211 PL	1298043	1292136	1299850	1300815	1295713	1290739	1295976	1294254	1298829
G_P3-14 R4 Otto Linie 6 ZK	356941	362097	366332	366212	366208	363090	360596	365953	362856
G_P4-12 ZKG R4 Flex	141278	149129	158920	159194	155158	153848	157130	156894	157476
G_P4-14 R4 Otto GE ZKG	445730	419315	461860	463111	440209	432471	459914	443001	442049
G_P4-18 ZK R4 Otto Linie7	410026	411283	421944	414488	416430	412255	418979	420171	409496
G_P4-19 ZK R4 Otto	136074	135314	138878	137733	137838	137195	139688	135978	136995
G_P4-51 KW R4 Otto GE Linie 1	325518	322967	326646	325143	324834	323415	322388	321212	322773
G_P4-52 KW R4 Otto GE Linie 2	244002	242922	246836	243620	243630	243747	244948	244903	242592
G_P4-61 NW AVS NS GS1	892362	863030	901483	898421	846593	889515	895344	879314	892526
G_P4-62 R4 NW AVS PN	521583	503439	525551	525474	501391	517817	522826	509997	524943
G_P5-13 R4 TDI PL	2026613	2014874	2042080	2053466	2033239	1998148	2029192	2045889	2062422
G_P5-14 R4 TDI ZK4	439758	447607	458115	452790	451069	442981	454748	455804	442591
G_P5-16 R4 TDI ZKG	501132	439371	509298	514735	493203	491124	499993	505034	490757
G_P5-17 R4 TDI KW	445865	442528	449274	456773	453118	445943	451750	462178	443800
G_P5-41 R4 MDB iVM Nocke	7009333	7075120	7437972	7377498	6804670	7326930	7039223	7277365	6973879
G_P5-41 R4 MDB iVM Rohr	868975	880967	904280	900422	857619	903873	870449	899345	867097
G_P6-11 KW V6 Otto	104363	103580	104914	105348	104706	104120	104604	104004	104293
G_P6-12 ZKG V6 Otto	156335	150085	157971	160971	156564	155625	155744	156290	158579
G_P6-13 ZK V6 Otto	343789	342391	346691	355048	347058	353795	354874	353328	347862
G_P7-12 ZKG V6_V8	182381	185361	205163	208241	202129	202329	202238	201076	192607
G_P7-13 ZK V6 TDI	338433	339105	346705	345784	340813	345123	342836	342742	333246
G_P7-14 KW V6 TDI	267037	262927	269308	269697	266589	263753	265976	262300	263501
G_P8-1 ZKG V8_V10	15141	15859	16832	16870	16630	16592	16722	16529	16732
G_P8-12 ZK V8_V10	1433	1441	1443	1444	1441	1445	1445	1444	1424

Table 8: The production line outputs of one year

Since the production outputs are expected to be high numbers and the differentiation are more likely low numbers, outputs are not illustrated in a chart. Instead a ratio is introduced, which compares each scenario with the base scenario. If the result of this particular ratio is bigger than one, the scenario is better than the base scenario. If the ration happens to be smaller than one, it is considered to be worse. The results for this ratio are listed below:

production line output ratio (=output scenario x / output base scenario)									
Production line / scenario	scenario 0 (base scenario)	scenario 1 (centralized system)	scenario 2 (centralized, no travel)	scenario 3 (125% centralized, no travel)	scenario 4 (75% centralized, no travel)	scenario 5 (centralized 5min travel)	scenario 6 (segment scenario)	scenario 7 (centralized DM, decentralized IM, 5min travel)	scenario 8 (decentralized DM, centralized IM, 5min travel)
G_P3-11 R4 Otto EA211 ZKG	1	0,950434434	1,006500708	1,005823901	0,994498927	0,995453655	1,008072796	0,990439193	0,994939173
G_P3-12 R4 Otto EA211 KW	1	0,99396054	1,007041946	0,997212922	0,995518757	1,003876141	1,004109237	1,000495131	0,999322979
G_P3-13 R4 Otto EA211 PL	1	0,99544949	1,001391771	1,002135431	0,998205069	0,994372822	0,998407501	0,997080724	1,000605486
G_P3-14 R4 Otto Linie 6 ZK	1	1,014445457	1,026309994	1,025974099	1,025962508	1,017228206	1,01024006	1,025249117	1,016572792
G_P4-12 ZKG R4 Flex	1	1,055570189	1,124871119	1,126812761	1,098241476	1,088973494	1,11220058	1,11053378	1,114650413
G_P4-14 R4 Otto GE ZKG	1	0,940738434	1,036188322	1,038996446	0,987615306	0,970253292	1,031822283	0,993878232	0,991743507
G_P4-18 ZK R4 Otto Linie7	1	1,003065571	1,029066951	1,010880454	1,015617599	1,005435619	1,021833487	1,024742816	0,998706963
G_P4-19 ZK R4 Otto	1	0,994414794	1,02060856	1,012195038	1,012967934	1,00823903	1,02656119	0,999293957	1,006767567
G_P4-51 KW R4 Otto GE Linie 1	1	0,99216606	1,003466975	0,998847976	0,997901079	0,993540284	0,990386182	0,98677371	0,991568045
G_P4-52 KW R4 Otto GE Linie 2	1	0,995572973	1,011614811	0,99843348	0,998475844	0,998954521	1,003875291	1,003692754	0,994222687
G_P4-61 NW AVS NS GS1	1	0,967130253	1,010221823	1,006790197	0,948710598	0,996809338	1,003341553	0,985378436	1,000183691
G_P4-62 R4 NW AVS PN	1	0,965212882	1,007607871	1,007458962	0,961286329	0,992779497	1,002381983	0,977786373	1,006441879
G_P5-13 R4 TDI PL	1	0,994207692	1,007632058	1,013250036	1,003269377	0,985954259	1,001272538	1,009511449	1,017669497
G_P5-14 R4 TDI ZK4	1	1,017848207	1,041743596	1,029635031	1,025721442	1,007328706	1,034087202	1,03648975	1,006443094
G_P5-16 R4 TDI ZKG	1	0,876756824	1,016294524	1,027145041	0,984178586	0,980028636	0,997727775	1,007786777	0,979297854
G_P5-17 R4 TDI KW	1	0,992514502	1,007645317	1,02446279	1,016266906	1,000173406	1,013196896	1,036586346	0,995367818
G_P5-41 R4 MDB iVM Nocke	1	1,009385617	1,06115265	1,052525048	0,970801476	1,045310578	1,004264423	1,038239293	0,994941949
G_P5-41 R4 MDB iVM Rohr	1	1,013799896	1,040628041	1,036188359	0,986931698	1,040159243	1,001695187	1,034949131	0,997838714
G_P6-11 KW V6 Otto	1	0,992498242	1,005284005	1,009442223	1,003290088	0,997672017	1,002313045	0,99656667	0,999332289
G_P6-12 ZKG V6 Otto	1	0,960025679	1,010466029	1,029653578	1,001463885	0,995458614	0,996218078	0,999712865	1,01435408
G_P6-13 ZK V6 Otto	1	0,995934038	1,008442905	1,032751913	1,009509577	1,029106555	1,032244043	1,027748601	1,011848328
G_P7-12 ZKG V6_V8	1	1,016337727	1,124912728	1,141789757	1,108274701	1,109371141	1,108873861	1,102504004	1,056066551
G_P7-13 ZK V6 TDI	1	1,001986135	1,024441904	1,021719777	1,007031567	1,01976652	1,013010658	1,012733629	0,984674304
G_P7-14 KW V6 TDI	1	0,984609557	1,008507186	1,009962451	0,998322971	0,987702383	0,996028404	0,982262251	0,986758014
G_P8-1 ZKG V8_V10	1	1,047428088	1,111704428	1,114224531	1,098345439	1,095877816	1,104464006	1,091690952	1,10513159
G_P8-12 ZK V8_V10	1	1,005508223	1,006954067	1,00788434	1,005368824	1,008743969	1,00822912	1,007673631	0,993777907

Table 9: The production output ratio (=PLO of scenario x / PLO of base scenario)

Out of this consideration the following chart can be formed:

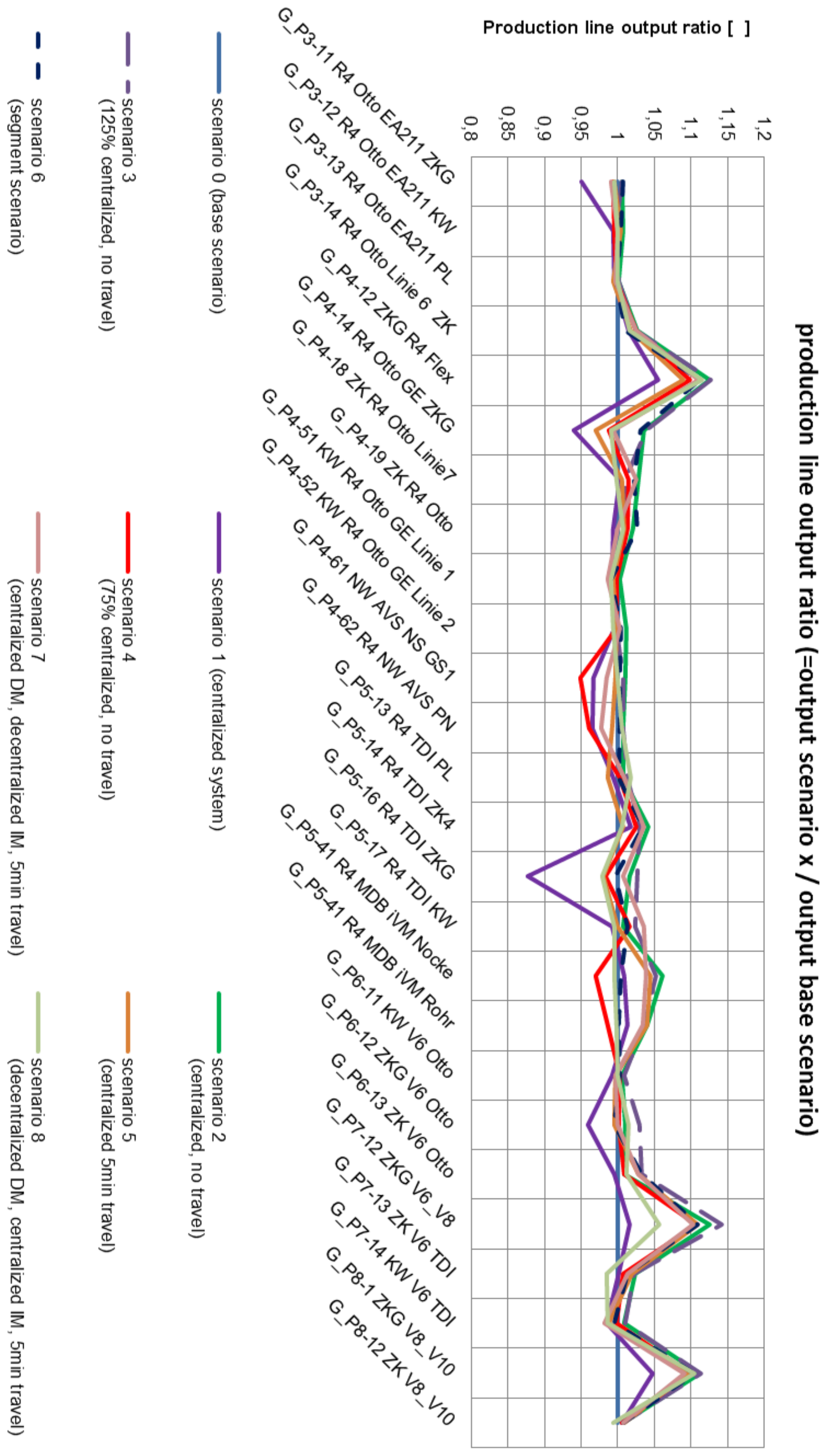


Figure 66: The illustration of the production output ratio

6.8.2 Discussion

In this chapter, results are discussed and interpreted. Each result will be thoroughly checked and relevant findings, which could possibly help the decision maker, will be listed. The first chart in Figure 62 shows that average waiting times for the direct maintainers can get reduced by centralization as long as travel times do not exceed. By including travel times, average waiting times increase. One more fact becomes clear: utilization becomes harmonized by centralization which can be seen by fewer and lower amplitudes of the curve.

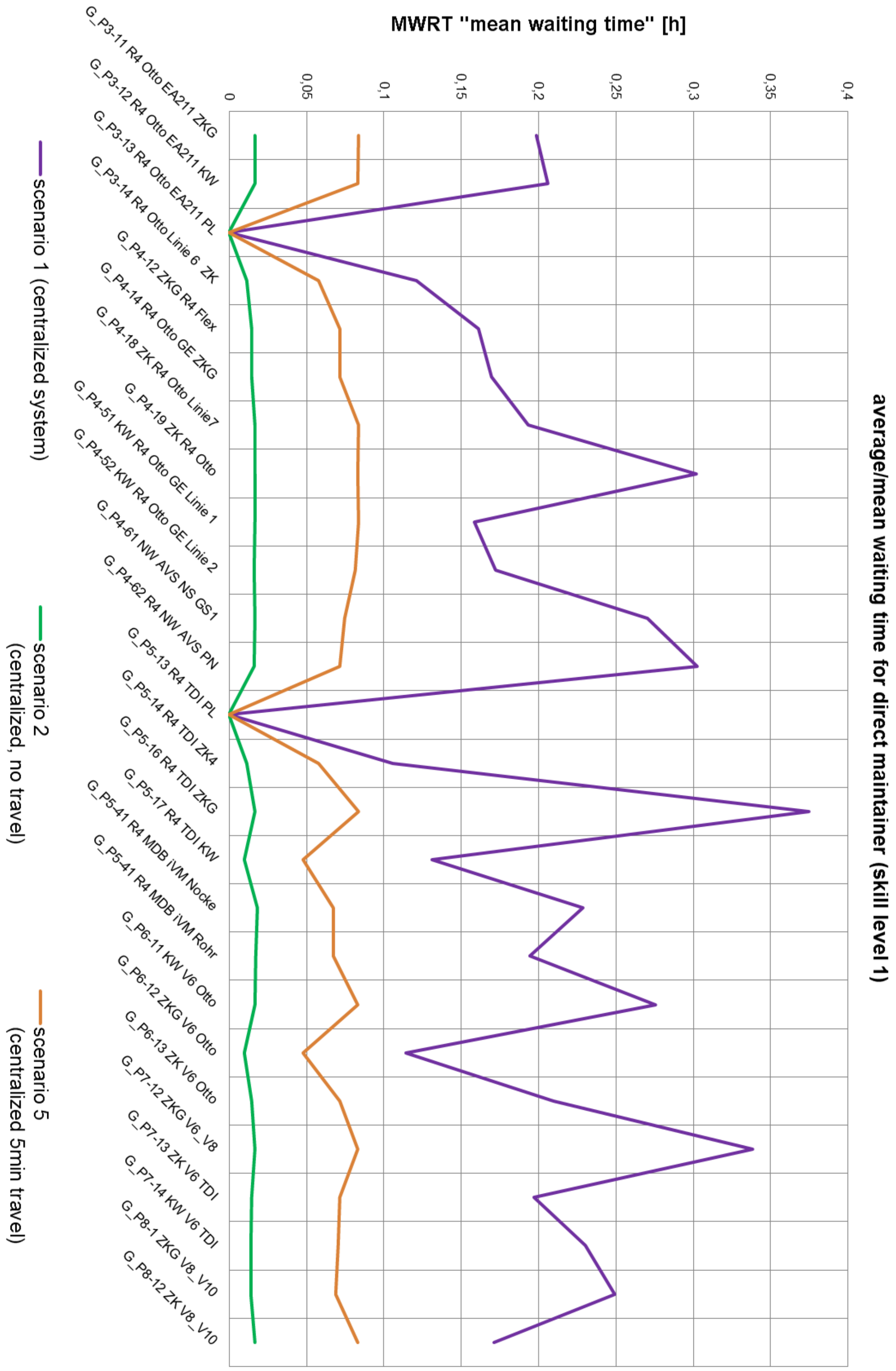


Figure 67: Influence of travel time due to the huge size of the factory

The same understanding goes for indirect maintainers: The more the system gets centralized, the more balanced the maintainer workload becomes. On the contrary side, waiting times increase when implementing the travel times, which can be seen when comparing scenario 2 and 5 in Figure 63 and Figure 62. This leads to the second finding: when physically placing maintainers at the Technical Service, walking times increase and therefore lead to worse results, as can also be seen in Figure 66.

Also, waiting times of direct and indirect maintainers show: direct maintainers are a more critical resource than indirect maintainers due to longer waiting times.

Another important outcome is the need of presence of enough maintainers. The increase of maintainers by 25% hardly influences the results, while a decrease led to a relevant output reduction and waiting time increase (see Figure 68). This shows that the decision maker needs to know that decreasing staff leads to decreasing production outputs due to longer waiting periods for machines.

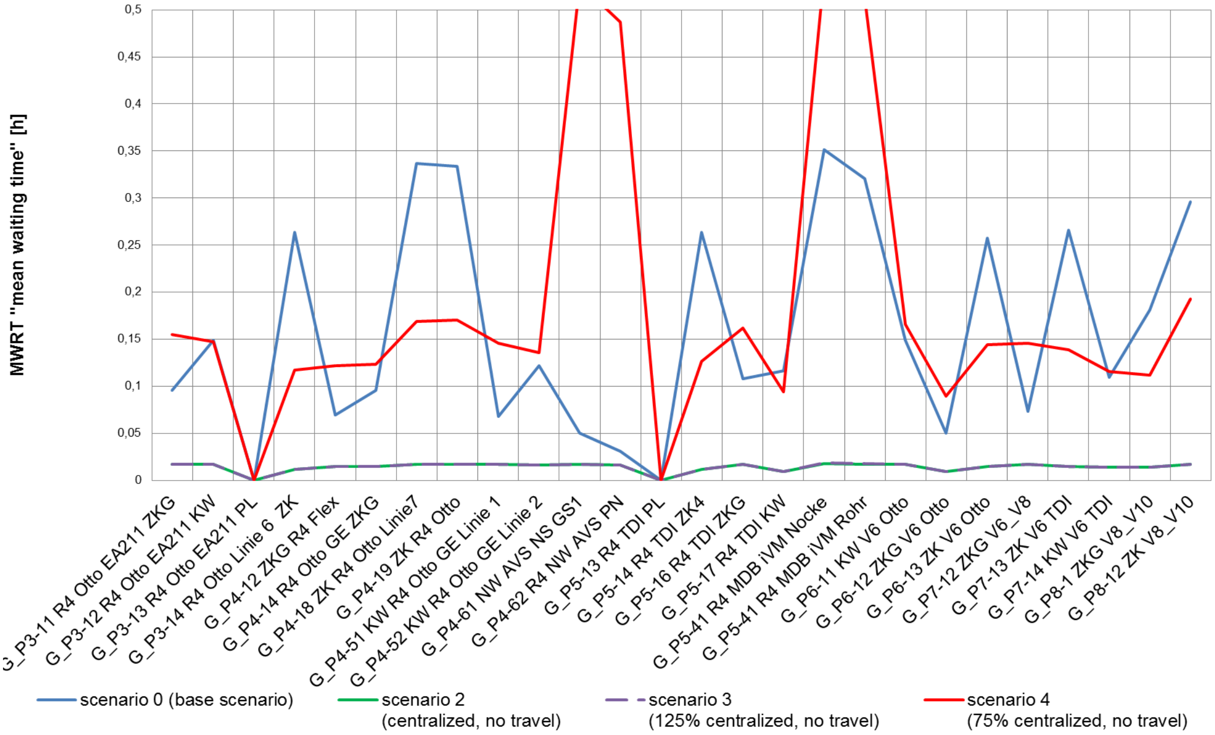


Figure 68: The effect of staff reduction/increase shown on the MWRT of DM

To sum these results up:

- The utilization of maintainers can become harmonized by centralization.
- Physical centralization leads to longer waiting times.
- Direct maintainers are a more critical resource than indirect maintainers.
- When centralizing the system, an increase of staff will not increase the production outcome. On the contrary a decrease will lower the performance and therefore the production outcome.

7 Conclusion

In chapter 3.1 we concluded that a sociotechnical system:

- Is the holistic view on both: the social- and technical factors
- Is used to design and optimize work systems, especially organizational structures and technical processes
- Mostly optimizes one of the two issues (social or technical issues) is not the optimum for the joint consideration
- Is open to its environment

Comparing the first two main characteristics with the simulation model of the use case in chapter 6 a usability of the model for simulating sociotechnical systems can be derived.

- Regarding the holistic view: The model was considering technical aspects with facts like skills, MTBF, MTTR and others. But also social factors like how to gain low utilizations, how to provide perspectives for the maintainers and the restriction of no employee firing were considered. Though, when thinking of other social factors like employee satisfaction regarding the control structure (singe- or matrix structure), change management (related to how extreme the change is compared to the current state) and others, other inputs would have to be found to abstract these factors. This could be considered for a further work.
- Optimization: It was used to optimize the organizational structure, other contemplations, like the operational structure will follow.

This leads to the conclusion of a good usability for using modeling and simulation to evaluate sociotechnical systems. Though, there is room for improvement regarding the consideration of social factors.

When thinking of the main problems in the Audi use case (utilization, future-perspective, knowledge specification, knowledge isolation and transfer) it can be said that:

- Utilization: The utilization of the direct and indirect maintainers can be decreased significantly by introducing a centralized control structure. Problems that arise with this step, like for example the fact that maintainers would have to learn to work with way more different machines, were not considered. Furthermore the results have shown that a physical centralization works counterproductive due to the huge size of the factory. Therefore a physical decentralization at the production lines should be considered.

- Future-perspective, knowledge specialization and knowledge isolation and transfer: In terms of the other factors it can be said, that a wider area of operations, that comes with the centralization, would lead to a great challenge of the maintainers at the first place. But it could also extend their expertise and therefore strengthen their position in the company. The knowledge transfer would get definitely improved, but further thoughts about these factors were not part of this work
- Transparency and controllability: A centralized control would improve the transparency, but on the other hand side the effort of control would increase also tremendously. A centralized control unit which has to control 39 production lines needs a lot of resources, knowhow and for sure supportive IT tools.

The conclusion for the Audi use case, clearly advises a centralized control system. Resources though, should not be placed centralized due to the huge size of the engine production in Györ. To find a final, realizable and conceivable solution for Audi, some more iterative loops with the responsible decision makers will be necessary in the future. Still, the main problem, defined in chapter 6.5 of underperformance and utilization differences can be eliminated! Another interesting aspect of the modeling and simulation approach, the evaluation of the operational structure, will shortly be described in the outlook.

8 Outlook

Any further scenario requested by the client can be simulated. Tendencies, shown in chapter 6.8.1, point out one scenario that is of special interest: a scenario with a centralized control to gain the effect of utilization harmonization and a decentralized placement of maintainers at the production lines to avoid the effect of long travel times (like the scenario 9 explained in chapter 6.7.2). This scenario is pretty similar to the scenario 5 (see chapter 6.7.2) and should therefore combine the positive effects of the previous results. It would furthermore enable the possibility of a matrix structure, which could be really interesting for the future. Some other scenarios that could be interesting are segment controlled and line placed combination, or the switch to functional segments. In this case this level in organigram would change from a divisional to a functional structure.

Another important aspect that is of great interest is the usage of the simulation model to optimize the operational structure. If the repair processes get changed in the future, this could gain an improvement as well. As an example the escalation times could get reduced in order to always faster get the right resource and therefore reduce the repair times. Maybe the indirect maintainer’s main future task will be the coordination of errors which could lead in most cases to a direct call of the necessary skill level and not a run through the whole process chain until the right maintainer is at place.

One thing that has been shown in general is that modeling and simulation turns out to be a promising way of quantifying organizational- and maybe even operational structures. However, a validation of its output has to be awaited until results from the real life performance are available.

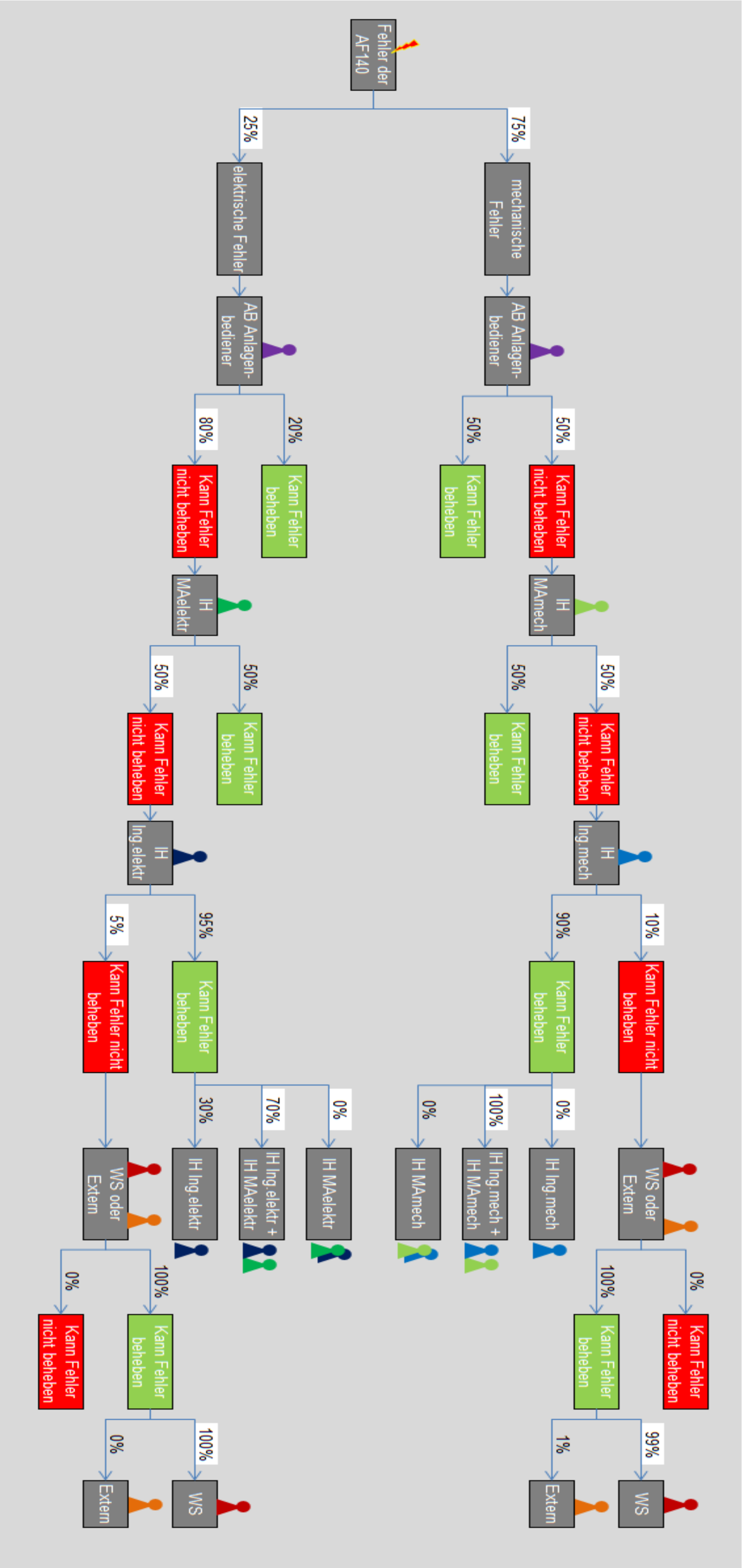
9 List of figures

10 List of tables

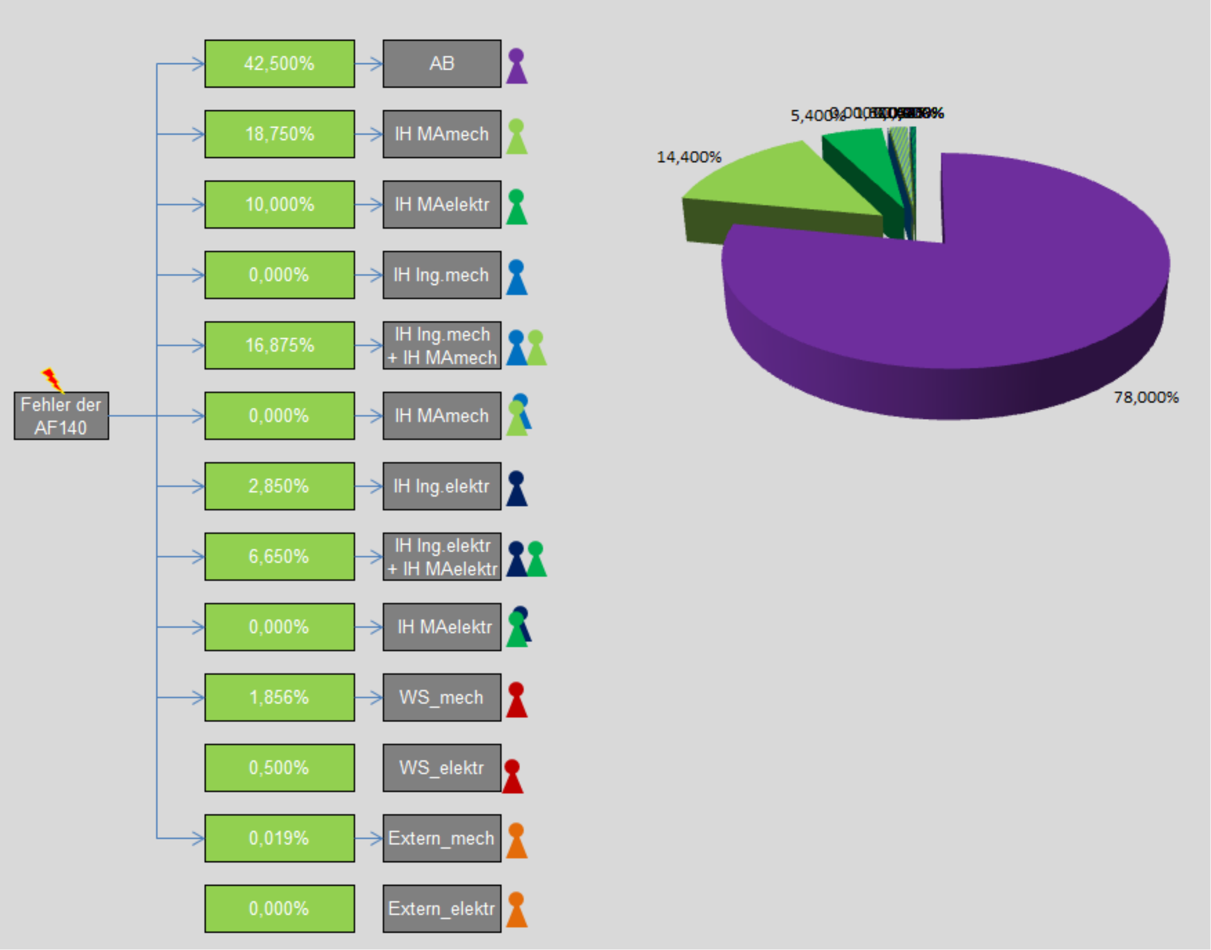
11 List of abbreviations

DSS	Decision Support System
KPI	Key Performance Indicator
ARIS	Architecture of integrated Information Systems
OEM	Original Equipment Manufacturer
VDI	Verein Deutscher Ingenieure
TPM	Total Productive Maintenance
DIN	Deutsches Institut für Normung
5S	Sort, Set in order, Shine, Standardize, Sustain
OEE	Overall Equipment Effectiveness
STS	Sociotechnical System
OD	Organizational Development
DES	Discrete Event Simulation
TTR	Time to Repair
TBF	Time between Failure
CU	Control Unit
AH	Audi Hungaria
MWRT	Mean waiting for repair time
TWR	Time waiting for repair
PLO	Production line Output
UML	Unified Modeling Language
HCCM	Hierarchical Control Conceptual Model
HCFG	Hierarchical Control Flow Graph Model

12 Appendix



Appendix 1: Survey for the processes



Appendix 2: Result of a survey

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