Ingenuin Stephan Alton, BSc

DESIGN OF A DIGITAL MANAGEMENT PROCESS USING SYSTEMS ENGINEERING AND REQUIREMENTS ENGINEERING

Master's Thesis

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Supervisor

Dipl-Ing. Dietmar Neubacher// Dipl-Ing. Dr.techn. Nikolaus Furian// Dipl-Ing. Birgit Mösl

Institute of Engineering and Business Informatics
Head: Univ.-Prof. Dipl-Ing. Dr.techn. Siegfried Vössner

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This master thesis is written in cooperation with Durst, a machine construction company located in South Tyrol - Northern Italy. The company's homepage may be found online here: https://www.durst-group.com.

This thesis is written in order to achieve the Austrian academic degree *'Diplom-Ingenieur'* (Dipl.Ing.), equivalent to the international *'Master of Science'* (MSc).

Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to TUGRAZonline is identical to the present master's thesis.

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Acknowledgement

In the spring of 2017 I was searching for a possible topic for my master's thesis. An important criterion was to find a project that is industry-relevant, so that I could learn working modes already outside the university as well. I also liked the idea of gaining further knowledge in the fields of digitalisation and production control. Therefore, I contacted various companies for possible topics which resulted in several interview invites. As I had the goal to select the most promising topic for myself, I decided to choose Durst. The company offered me a project in the field of production mode and -control with an interface to an IT and a hardware project. The institute of engineering and business informatics seemed to be the best option for supporting this topic on behalf of the university. I am grateful the institute invited me to a preliminary talk and gave me afterwards the possibility to collaborate. After an informative kick-off meeting with Dietmar Neubacher and Nikolaus Furian from the institute at the company's headquarter in Brixen, I started one of the most educational self-learning researches I have ever conducted. In the following demanding process I learned to implement techniques and knowledge, collected during the last four years at the technical university of Graz as well as through my own interests, and I was even able to deepen and develop my skills even further. I am grateful Durst entrusted me with this project, giving me this great opportunity. Every employee supported me by giving me hints, possible solution options or by providing me with useful material; therefore, I would like to personally thank everybody working there. Special thanks go to Rico Sauerborn, COO of Durst, as my main company-internal supervisor of the project, and Michael Mitterrutzner, storage manager and first contact person for requirements. I would also like to thank the Institute for its excellent mentoring; thereby special thanks go to Dietmar Neubacher, in his function as my main supervisor supporting me with suggestions for structuring, guiding and possible future steps, to Nikolaus Furian, providing me great support during analysis, and to Birgit Mösl for her services, support and technical knowledge in solving problems. Thank you all!

Abstract

In the age of digitization, companies are increasingly relying on new technologies to improve workflows. This is especially true in the context of lean inter-logistics processes, where unnecessary material movement and storage are considered evitable waste. These new technologies offer different solutions assisting the material flow management. The identification of matching solutions is usually entrusted to management, which is struggling to find the ideal options due to the huge amount of different possibilities on the market. One of the greatest challenges is to identify the real problem causes on which the decisions for change are based, and to make an objective choice. This requires a systematic approach like Systems Engineering (SE), a holistic, integrative discipline, in which the contributions of different fields of application are evaluated and balanced one against the other, to identify possible future scenarios and take decisions on them. Therefore, this approach has become a standard tool in many fields, including reliability engineering, security engineering, interface design and software development. In order to avoid undesirable developments, SE is supported by requirements engineering dedicated to finding the real causes of problems and establishing requirements for a problem-solving decision. This thesis shows how these methods can be used to support the evaluation and design of real life intra-logistics processes. An industrial partner, requiring changes on the actual material flow process, is consulted. With the help of SE's top-down approach, it was possible to provide insights in the segments of organizational structures, picking modes and information systems. Due to the industrial partner's specific demand, the focus is set on the development of a new information system meant to making processes transparent for further changes. Finally, concrete recommendations for actions are provided, which the company has already started to partially implement.

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1 Introduction

Today competition between production companies has increased by falling quotes of profit. In order to remain competitive and up-to-date, companies are trying to improve all sectors and processes in by also lowering their costs. One of the sectors being improved on is intra-logistics which is a sub-component of overall logistics. Logistics is defined as a discipline of supply chain focusing on planning and coordinating the flow of material and information (Financial Times, 2018) by connecting customer, companies and suppliers. Similar to this definition, the term of intra-logistics is defined by Martin (2014) as a scientific field, focusing on the planning and control of material and information within the boundaries of a company, including the whole production logistics and partly the procurement and distribution logistics, acting as interface to the external one. Figure 1.1 shows these segmentations and introduces reverse logistics as another discipline which represents a material flow backwards to the 'normal' one, similar to cash flow. Furthermore, presented disciplines are supported by the four main functions of packaging, transport logistics, warehouse logistics and picking. This thesis wants to provide deeper insights into the last two points, highlighting transport logistics a little in the picking studies on a functional level. For warehouse logistics and picking process, markets are offering many solutions, promising more competition and resulting benefits in speed and costs towards industry competitors by investing in their technologies. The trend of evolving into an industrial 4.0 company is encouraging that process. Within this mindset, digitalization of exiting procedures plays a key role, improving information systems and actual working modes. A major problem of these projects is, that actual systems are often not containing the required data for actually changing the intra-logistics functions. This would require a time-consuming analysis on determined time slots. Real issues are not detected, and investments squandered on wrong problem ideas. Obviously, this way bugs are not solved, and expectations are not fulfilled. Therefore, the real causes of problems have to be detected first, by making existing processes transparent, supported by widespread databases. This makes it imaginable that improvements and redesigns may become complex and confusing. A systematic approach is required not only to solve main problems, but also to not miss the mission scope or to get lost during problem solution development. One of the most frequently used and well-known methods is systems engineering, supported by principles of requirements engineering, narrowing-down topics little by little, in a top-down approach. Basically, systems are built on different levels of view and abstraction, offering very good insight into the actual workflows, the real causes of problems, and the fundamental requirements on change processes. On each level of abstraction, the cycle of finding problems and requirements for a certain stage, of designing different solution options, of evaluating them and of deciding for the most promising one has to be passed through.

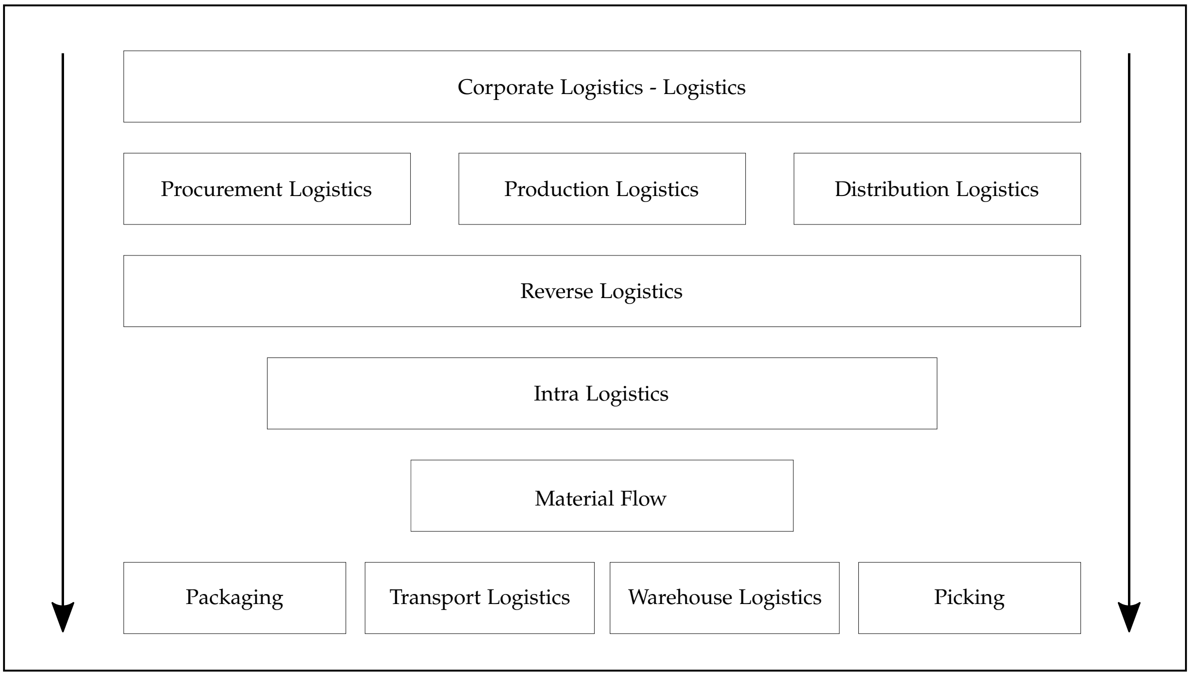

Figure 1.1: Classification of the term logistic (Martin, 2014, p.4)

The further elaboration is structured as follows: section one provides a basic overview of the thesis; section two focuses on the overall intra-logistics, giving insights into the material and information flow as two basic processes, by exposing the warehouse logistics, the picking process and connected information flows; section three represents two development methodologies for new products, focusing on different implementation strategies, with background information and the integrity of both processes to each other; section four is based on a real company case, elaborating different picking improvement strategies and possibilities by using the methods under real-life conditions, developing systems on different stages for the picking process and the information flow, by giving an outlook for further steps implementing a running system; section five focuses on interfaces and proposals for further projects of the industrial partner;section six is dedicated to a short summary and gives an outlook on further research fields; while section six provides deeper insights and background information to certain points which are not necessary for the understanding of this thesis or going beyond the scope of this work by impairing its comprehensibility.

2 Intra logistics

The word logistics has many different meanings. People unfamiliar with this sector think that it is only the action of transport, goods traffic, handling and storage. In reality it is so much more than those processes. The employed applications are starting with networking, designing and usage of logistics infrastructure, lowering their energy consumption, automate and digitalize existing processes in order to become or remain competitive. Logistics is the process of planning, implementing and controlling procedures for the transportation, storage of goods including services and necessary information from the point of origin to the point of consumption (Gudehus, 2010). In this context intra-logistics is a subsystem of the overall term logistics. It is focusing on the organisation, controlling, carrying out and optimization of the intra-company material and information flows (Hausladen, 2016, p.6). So, it is an enclosing to the external logistics (Martin, 2014)

2.1 Classification of Intra Logistics

Looking at the intra-logistics disciplines shown in figure 1.1 it is possible to distinguish between two main subcategories within this field of application, assuming that material flows in one direction and that the reverse logistics represents an additional process, not generating profit and therefore not belonging to a company's core competences (Martin, 2014, p.9):

- Material flow: regarding the VDI guideline 3300 material flow is the spatial, temporal and organisational chain of processes for the production, edition and distribution of goods within a pre-notated area not restricted to the internal logistics. Out of a company's view it can be distinguished between an external flow of goods and an internal flow of material. The second option has the task to connect the procurement with production and assembly and to provide the supply and the disposal (ten Hompel, Beck, et al., 2011).

  - Packaging: Is the act of making goods ready for transportation by protecting it from damage (Dictionary.com, 2018).
  - Transport- and change logistics: the transport logistics includes all the work and information steps necessary to fulfil the transportation job. Its task is to distribute and provide the right goods at the right time to the right place at the lowest possible cost. It tries to maximize the utilization capacity by optimizing the loading, unloading, delivery and identification (Martin, 2014, p.97). Changing logistics is not restricted only to the intra-logistics but works as interface between the internal and the external one, including processes outside the company's boundaries. The switching and changing points between the two types of logistics are the incoming and outgoing goods department. With different strategies a decentralization is possible using methods as just in time or similar (Martin, 2014, p.300).
  - Warehouse logistics: is the sum of all goods movements and information within a stockroom, including activities like receiving, storage, order picking, accumulation, sorting and shipping (Aragon, 2017).
  - Picking: obviously the picking logistics is part of the warehouse logistics. A main reason therefore is that picking takes place in the same spot as warehousing. Focusing on the last sector, it is easy to detect the sub-disciplines data collection, transmission and processing, automation, guiding, storing, terms of storage and picking technology (Murray, 2017).

- Reverse logistics: By law, companies are obligated to dispose of packing and other trash in an environmentally friendly way. Thermal recovery is not permitted, but it is mandatory to sort waste by material. That process is expensive and is therefore an important factor in a company's cost plan. So reverse logistics is dealing with the optimization of this process and the reduction of wast while keeping costs low. This second goal can be achieved by waste prevention and reduction. Another possibility is the reuse, further use and further utilization. It is part of a material flow process without a product value adding effect, not restricted on the intra-logistics field and therefore representing its own category (Martin, 2014, p.8).

- Information logistics: it is responsible for providing right information at the right time to the right place, collaborating closely with the material flow. Therefore, functions such as information collection, -storage, -processing and -output are required (Martin, 2014). It is obviously that information is fundamentally necessary in production areas.

Truly, until now only a general overview of intra-logistics functions is presented here, and not all elements can be analysed in detail in this thesis, therefore some boundaries are required. It is known that reverse logistics is regulated by law and therefore varies in all countries; so, it has been decided to focus only on the information logistics and the material flow. An overview of these flow processes related to a company's view is represented in figure 2.1.

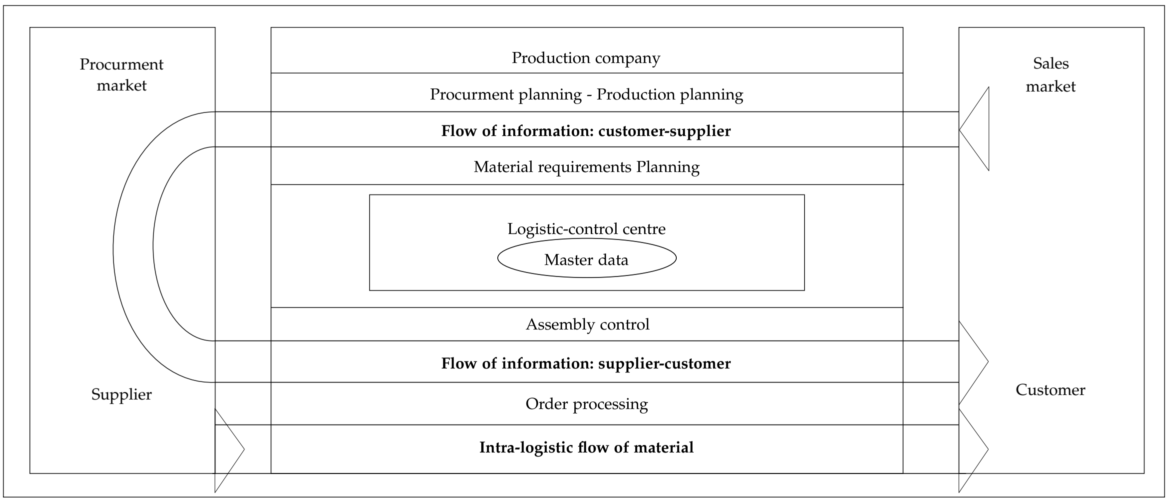

Figure 2.1: Connecting points between material- and information-flow (Martin, 2014, p.4)

2.2 Task of Material Flow

Regarding the material flow definition presented in section 2.1, it is focused on intra-company areas. Basically, literature distinguish between two types of material flow systems: historically the first one is the line flow process, where the parts start flowing from source to sink in a simple line. With the rising customer claim of individualized and customized products, the number of produced variants increased. In order to keeping production costs low and satisfying customer demands, product developers started to produce in a modular way. As a traditional line production was no longer possible, they started to produce in parallel sequences, the second material flow type. It is obvious, that even the material supply had to be adapted to this kind of production mode, using supply networks. Depending on the overall company's goal, market position, production mode, warehouse strategy and customer demands this network had to be established. In this thesis the type of connections between different systems, such as picking process and information flow is called network or netting. The higher the demand for/on it, the better systems have to collaborate and the more complicated it is to deal with them in a scientific way. Therefore, working with simplified models and heuristics became popular. In the following subsections we are focusing on the two main functions, warehouse logistics and picking by introducing heuristics, key values, strategies and classifications.

2.2.1 Warehouse Logistics

Warehouse logistics is focused on storage and its functions. Reference books such as Merriam-Webster are defining a warehouse as a structure or room for the storage of merchandise or commodities (Merriam-Webster, 2017). This definition seems to be a little old-fashioned, as nowadays we are talking of virtual warehouses enlarging product range with stocks on manufacturer or supplier side (Hausladen, 2016). This makes it difficult to decide if it is part of intra- or extra logistics. But, as we are focusing on the intra-logistics, answering this question would require focus also on the external one. This will not be answered here and consented to the previously stated definition, because this would go beyond the scope of this thesis. Getting a deeper knowledge of classical warehouses requires the understanding of different classification options.

2.2.1.1 Classification of warehouses

Generally speaking, there are two main categories of warehouses: retail and production warehouses. However, authors as Farahani et al. (2011) or Rushton et al. (2014) are classifying them in a more detailed way. The following list should give a short overview of the most important divisions:

- Stage in the supply chain: the warehouse is classified by the actual product or material stage, using mainly divisions as raw material, work in progress or finished goods storage.
- Product type: the storage is assigned to individual products or a class of products as electrical parts.
- Ownership: there are two main subcategories: first one is private warehouses owned or occupied on long-term leases. This is the classical warehouse for production companies that are stable and able to fill them to a certain quantity. Companies affected by fluctuations or uncertainty are using mainly the second option, meaning public warehouses that can be rented and allow for scalable storage capacity.
- Systems: this class is related to the level of automation used in a warehouse and therefore divided in the two classes: manual and automated warehouses. System classification describes the used technology and is influenced by the different types of strategies. Later in section 2.2.2 we will see such an influence factor as person to stock and stock to person applications.

As already stated, there exist other strategies as well and here only a few are presented. Further information may be found in Farahani et al. (2011) or Bartholdi et al. (2014). Nevertheless, these are some overall classifications which are not influencing warehouses basic functions yet are important to know for adapting strategies.

2.2.1.2 Functions

In a classical warehouse we can basically detect the following functions: incoming goods, store, swap, picking, packing and delivering. In the following pages we will see basic tasks for these functions. As picking is one of the warehouse's key processes and improved within the last years, we are focusing on it separately in subsection 2.2.2. The here presented standard processes can be found in every warehouse either for commerce or assembly (ten Hompel and T. Schmidt, 2010).

Incoming Goods

Following a classical intra-company material flow, it is logical to start with the incoming goods department: a managing clerk is ordering the needed goods and setting up the time frames in which the deliveries should arrive at the warehouse. It is necessary to level the in-house workload and to reduce costs by avoiding long waiting times. In big warehouses the delivery plan has to be adapted several times a day, to take into consideration factors such as traffic or official preparation time, showing the dependence of external to internal logistics. With a planning advisor's help, the incoming goods department can plan the daily workload in advance and prepare information carrier like part labels for the in-house goods identification, a connecting point to the previously mentioned information logistics. It would make sense to establish overall recognition standards, reducing lead times and cost by the support of supply chain management. Next, the same department has to assess the goods. Usually this is done to check the type of delivered goods and their quantity. For certain equipment there might exist special test specifications for saving quality. This can be taken over by the part labels or by digital supported systems. Until the assessment is completed, and satisfaction of necessary properties is established, goods remain physical blocked. Bad parts are returned to the supplier. Sometimes the following material flow needs more information as sizes, weight or expiry date for perishables. It is part of the incoming goods department's work to collect such data. This approach could be improved by inter-company data exchange. Last but not least, the gathered data can be used to build storage unit's data controlled, not needing experiences from operators and fulfilling the special warehouse requirements (ten Hompel and T. Schmidt, 2010).

Store

As soon as the registration of incoming goods is fulfilled, they have to be taken to their storage places. First of all, however, a check of their actual need in another sector is to be considered. If this is the case, the product may be taken immediately to the department in question. If that is not the case, goods have to be stored by transporting them from the incoming department to the intended storage location. This can be done manually, partly automated or fully automated. To keep it simple, let's assume at first that goods are stored with the support of different strategies in a warehouse. To avoid errors and to fulfil the requirement of complete documentation of material flow, information systems are used. If the product identification is not checked in the incoming goods department, it has to be done in this step. Checking data and checking delivered goods represents a docking and synchronization point between material and information flow. These checkpoints are important for dependent technical systems to work and to maintain transparency of the current situation. Different demands such as shelf load are to be taken into account to minimize errors. A full list can be found in figure 2.2 (ten Hompel and T. Schmidt, 2010).

Organizing and optimizing a storage area requires basic strategies consistent to the technologies and production modes used. Figure 2.3 shows some of these basic strategies relevant for different objectives.

Parameter	**Requirements**
Technical Requirements	Take into consideration shelf- and bay-load
	Optimize use of storage volume
	Uniform loading on the rack and avoiding one-sided strain
Operational Optimisation	Minimize drive ways and transport routs
	Maximize handling capacity
	Maximize use of storage capacity
	Hight availability even if something breaks down
	Fast part identification in manual storages
Saftey-related and Legal Requirements	Specialized storing for dangerous goods
	Separated storage
	Batched groups

Figure 2.2: Substantial parameters for storage location assignment (ten Hompel and T. Schmidt, 2010, p.31)

Name	**Strategy**	**Obejctive**
Fixed storage	Assigning fix storage places to each item	Acess security if managemet system are broken down Fast acess in manual picking systems
Chaotic storage	Using a free storage spot for each arriving item	Maximal use of storage capacity
Zoning	Chooging storage spot by cange-over rate	Raising change-over performance by reducing roats
Lateral distribuiton	Spread storage of one article in different bearing ways	Item is still available if a stacker crane breaks down Raising trunover-rate throw parallel processes
Family of parts clustering	Adjacent storage for often combined parts	Raising picking performance by reducing connection sets
Shortest road	Taking the storage place with the shortest road	Raising turnover rate by reducing connction sets
Anticipator buffering	Preparing stuff for peak periods in closer storage spots	Reducing the risk for backlogs by raising performance

Figure 2.3: Storing Strategies (ten Hompel and T. Schmidt, 2010, p.32)

Removal

Removing is the process of taking parts from the storage. Checking their availability to fulfil the picking task, as well as previewing reservations are preparations for this process. Markets are offering a high variety of organizational structures trying to fulfil different goals and stakeholders' requirements. It is necessary to adapt their warehouse organization and their approach of removal to this structure. Well known removal strategies are:

- FIFO - First-In-First-Out: is the process to remove first the parts that are longer stored in order to reduce the aging risk.
- LIFO - Last-In-First-Out: is the process of removal first the last stored parts avoiding rearrangements.
- Quantity Customization: s the removal of full and opened packages raising the performance in handling goods.
- Prioritize opened packages: is optimizing the storage capacity.
- Shorter routes: is a strategy of removing the load unit with the shortest connection way raising the performance in handling goods.
- Terminated: planning the point in time of removal regarding the demand date reducing shunt and transshipment.
- Forwarding: restoring soon-needed goods near the transfer point minimizing reaction time.

Using an appropriate strategy helps to structure the warehouse in its desired way (ten Hompel and T. Schmidt, 2010; Bichler et al., 2013; Gudehus, 2010).

Packing

The packing department assembles the picked goods by checking the completeness following certain criteria. This process exists for both shipping and producing warehouses. It has to be structured in an optimized manner, as to ensure the correct usage of package size or material. Many companies are shifting the choosing competence to experienced operators, being aware that sometimes repeated packing is necessary. Therefore, warehouse management systems (WMS) providers are implementing volume calculation options, choosing the right package size and packing patterns. Last but not least, a goods-leaving inspection occurs in which the operator checks the completeness of the order and the shipping units' quality (ten Hompel and T. Schmidt, 2010).

Delivering

The task of the delivering department is the assembly of shipping units regarding the order and the loading of the transport media. Besides this physical task many further organizational duties have to be performed, such as choosing the optimum shipping method, choosing the right transport service provider or providing the right shipping documents.

2.2.1.3 Warehouse Performance Indicators

Warehouse logistics tries to improve the described functions. The support of key figures makes changes visible. Depending on the IT technology employed, data can be provided live or static, restricted to a certain point of time, as a measurement for availability influencing flexibility to the process. Live data offer the possibility for real time error detection. The following list attempts to give a short overview of the most important values every logistics stakeholder should know:

- Carrying cost of inventory:

$$Inventory\,Carrying\,Rate\,(\%) * Average\,Inventory\,Value\,(€) \tag{2.1}$$

  This value shows what the inventory actually costs, formed by multiplying inventory carrying rate and average inventory value (Legacy, 2018). The rate includes costs as capital, inventory risk, inventory service and obsolescence and helps to make smarter forecasting and buying decisions.

- Inventory turnover:

$$Cost\,of\,outgoing\,Goods\,(€)\,/\,Average\,Inventory\,(pcs.) \tag{2.2}$$

Is the quotient of used goods in production and average amount of inventory. The value measures how many times per year a storage is able to go through its inventory (Legacy, 2018).

- Storage area costs:

$$Total\,Storage\,Costs\,(€)\,/\,Storage\,Area\,(m^2) \tag{2.3}$$

The quotient of total storage costs and storage area shows the actual costs for storing goods by a certain size influencing the choice of used storage technology. Usually this value is taken of a monthly or yearly time frame (Gudehus, 2010).

- Picking density:

$$Picked\,Article\,(pcs.)\,/\,Access\,Area\,(m^2) \tag{2.4}$$

Is the quotient of picked articles and access area (ten Hompel and T. Schmidt, 2010). It gives an idea of picking performance and if the process could be sped-up by reorganizing storage.

- Picking road per position:

$$Average\,Picking\,Road\,(m)\,/\,Average\,Articles\,(pcs.) \tag{2.5}$$

The quotient of the average picking road and the average articles assesses the limits of potential picking methods. Thereby the average picking road is the quotient of all roads divided by the number of roads and the average articles the quotient of the sum of all ordered articles by orders (ten Hompel and T. Schmidt, 2010). This key value is hard to ascertain if the ways for picking orders are not tracked.

- Space utilisation level:

$$Used\ Storage\ Area\ (m^2)\ /\ Available\ Storage\ Area\ (m^2) \tag{2.6}$$

  This key values goal is to optimize the storage space usage, formed by the quotient of net used storage area and gross storage area (Lager-Software.net, 2018).

- Room utilisation level:

$$Used\ Storage\ Room\ (m^2)\ /\ Available\ Storage\ Room\ (m^2) \tag{2.7}$$

  Literature describes this value as quotient of the overall volume sum of storage units (100% filled) and available storage room determined by construction volumes (Logistik KNOWHOW, 2018). This value shows, if it is still enough room available or if room modifications are necessary by increasing inventory.

Within this list we have already seen some picking key-values as 'the picking road per position'. Literature describes picking as independent function of intra-logistics, but it can be regarded also as a warehouse function. Due to its importance and widespread changing possibilities it is treated here as an independent function.

2.2.2 Picking

In the following text the term customers is used interchangeably for clients and intra-company stakeholders, because the main picking process is the same for both. Customers are requiring goods provided by the warehouse, usually not corresponding in quantity to the storage units. Therefore, it is necessary to transform storage units in need-oriented transport units. This process is called picking and is defined in the VDI-guideline 3590 as a process with the goal to transform a total quantity of goods into a subset fulfilling customers' requirements[1] (Dallari et al., 2008). Before getting into this topic, first we need to describe some definitions for picking:

[1]Kommissionieren hat das Ziel, aus einer Gesamtmenge von Guetern *Sortiment* Teilmengen *Artikel*auf Grund von Anforderungen (Aufträgen)zusammenzustellen.

- storage unit: is a loading aid occupying a storage spot. It can be formed by many articles (Lager- & Logistik-Wiki, 2008).
- transport unit: are called joints ready for transportation (Wikilogistik, 2018).
- extraction unit: is called the quantity of picked units from the provided material unit (ten Hompel and Heidenblut, 2011b).
- extraction unit: is called the quantity of picked units from the provided material unit (ten Hompel and Heidenblut, 2011a).
- picking unit: is called the sum of extraction units required from a picking request (ten Hompel and Heidenblut, 2011c) .

2.2.2.1 Picking Process

Until now we have encountered some definitions of picking, but have no knowledge of the actual working mode. Before we can start to take a closer look at this principle - or better - at these principles we need to distinguish between the following two approaches: the first approach is the material-driven perspective, while the second is the information-driven. First, let us focus on the first perspective. It is possible to start describing the material flow with resource extractions and the following processing, but as this would go beyond the scope of this study, and as we are focusing on intra-logistics processes we will start with the incoming goods department. There the transport medium is unloaded, and the availability of a certain quantity inserted/input into the system. Afterwards, units are transported to the storage, where they form the provided material units. With the availability the actual picking process is started. Depending on the technical systems and the picking strategy it works in different modes (see section 2.2.2.3). Putting the process details aside, in the end picking units are put together and prepared for further editing. Here the process splits up again according to how and where the picking unit is needed. Common fields of usage are mail order businesses or in-house production. Now we will focus on the picking process influenced by the information flow. Basically, this is a data driven process. The customer orders and the work preparation arrange the picking orders. Afterwards the disposals are assembled, and the work confirmed. Details on the picking information flow can be found in section 2.3.2.

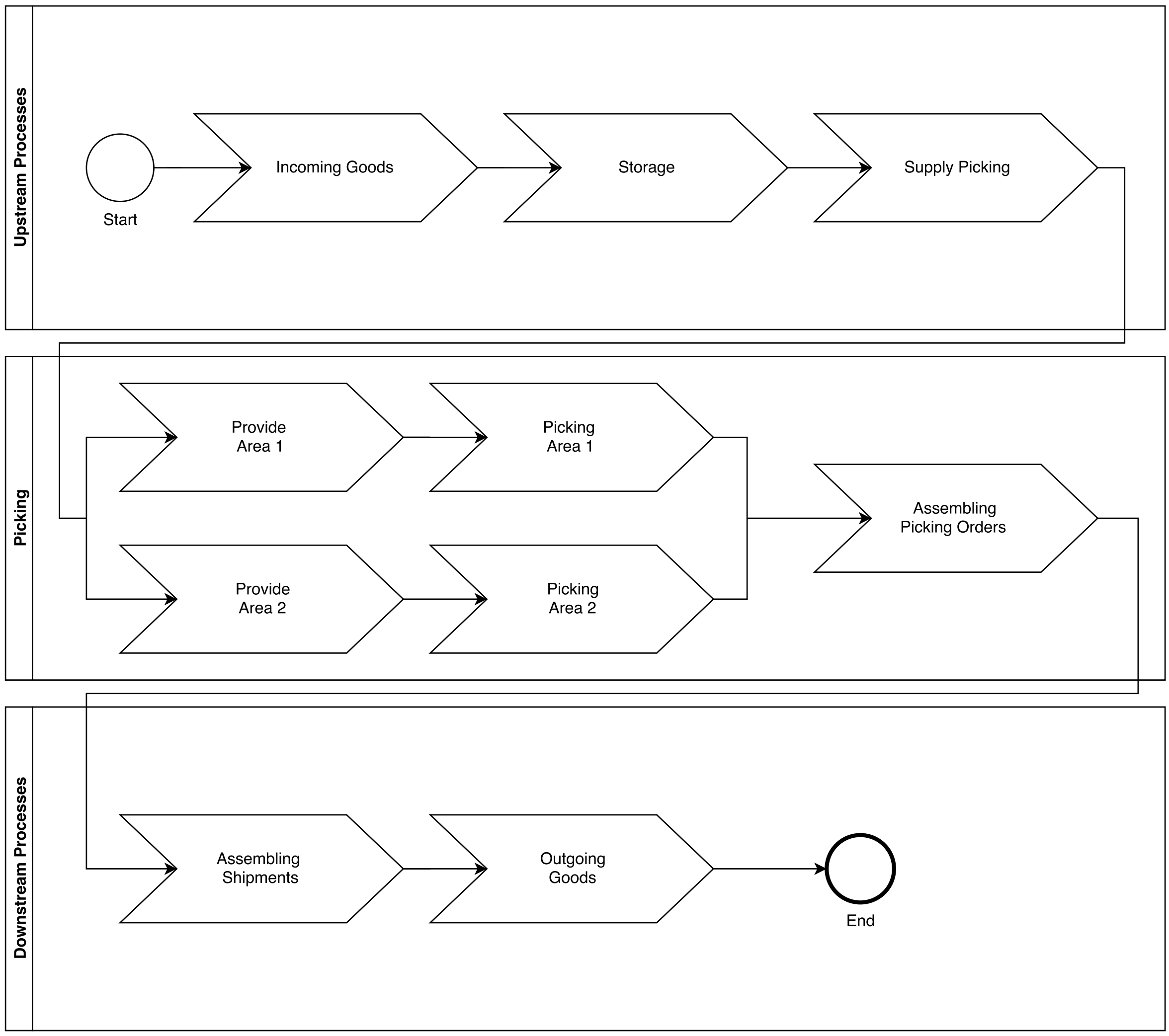

Figure 2.4: Material Flow meets Picking*=

*= In compliance with ten Hompel, Beck, et al. (2011)'s figure 2.2 at page 10

2.2.2.2 Influence Factors on Picking Systems

Please note that the picking process can be influenced from different sites. According to ten Hompel, Beck, et al. (2011) these factors of influence can be divided in external and internal ones:

- external factors: they are determined by different stakeholders outside the company's boundaries. Among these factors are the Governments trying to set rules for philanthropic working places (ergonomic standards, ...) or regulating earnings. Therefore, the technology and strategy employed depend on governmental frameworks. Thinking of the supply chain, a company's position in the delivery row, and the applied influence power, they are setting frameworks on picking modes and technologies used. The stronger a position is, the more flexibility can be ordered, guaranteeing in-time supply and a decrease in warehouse size. Last but not least, we need to mention the external factors, such as customers setting requirements on lead time and therefore on production mode, and all pre-processes as the picking.
- internal factors: they comprise all internal requirements on a system. We already mentioned the factor of production mode. One of the most important company-internal stakeholders is management, setting financial goals and visions that have to be achieved by measurable key figures.

This section shows, that systems can be become quite complicated and comprehensive if all details are taken into consideration. Therefore, a systematic approach is required as presented in chapter 3.

2.2.2.3 Picking Mode

Section 2.2.2.1 showed an overall picking process but omitted its categorization and its specific strategies. The two main principles are *Person to Stock* and *Stock to Person*. It is obvious, that also a combination of both systems is possible. Furthermore, both principles can be executed manually, partially automated and fully automated. The two principles with related implementation strategies are visualized in figure 2.5.

Person to Stock

In a Person to Stock system the inventory stays statically unmoved in its storage place and a picker moves from spot to spot to pick the requested parts. The simplest way

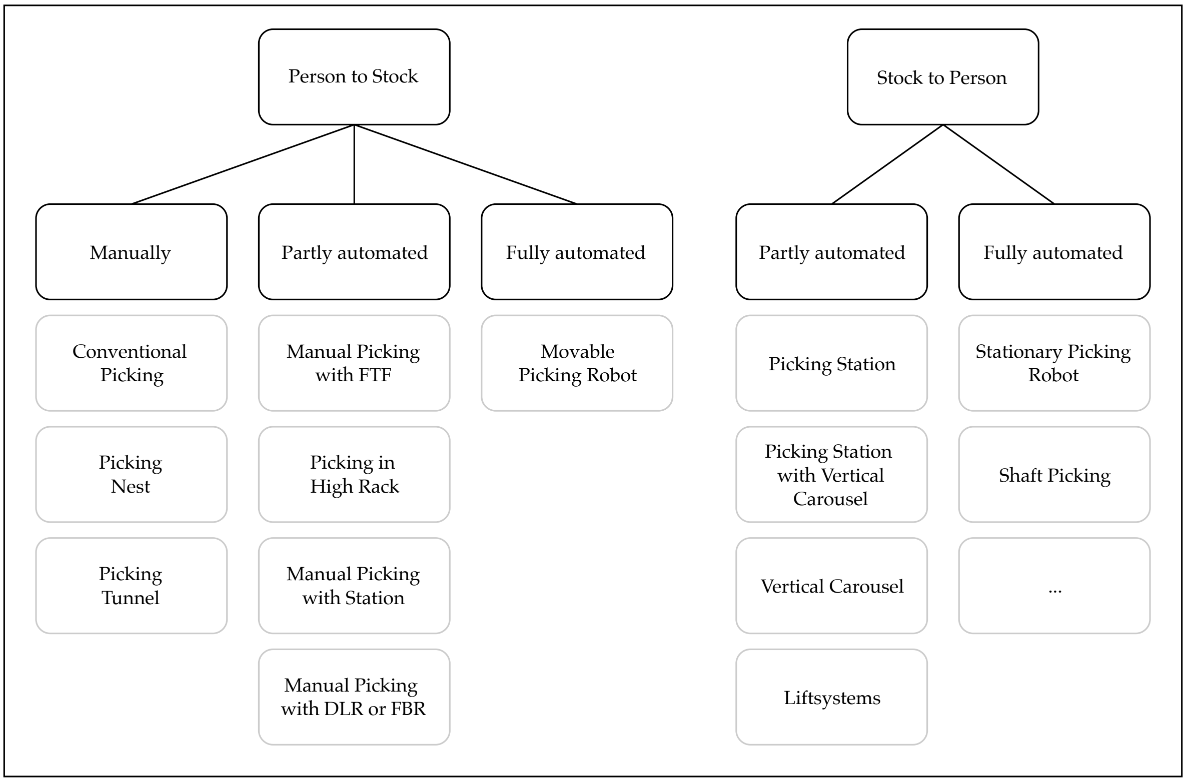

Figure 2.5: Main Picking Principles

to perform this action is conventional picking in which the picker moves through streets surrounded by palettes or shelves, loading a collecting carriage. Once the picking process is completed the container is brought to a transfer point. For a limited quantity of small parts, so-called picking nests are a simple and cheap possibility to increase the number of picks per hour. This method has the big advantage that the picker does not need to move around a lot around, but rather is surrounded by everything needed. Please note that in a conventional picking system more than 50% of a picker's time is devoted to moving. The picking tunnel is basically the same as conventional picking, but with an added supply storage for picking in a higher deposit. Until now we have spoken only of manual systems as figure 2.5 shows, whereas the possibility of a partially-automated realization exists. We are talking of manual picking with driverless transport vehicles[2] (DTV), picking in high rack or manual picking with stations. The first possibility provides the same features as conventional picking, however, with the advantage of not caring around the medium

[2]In German speaking countries: Fahrerlose Transportfahrzeuge (FTF)

by a human. The picking in high racks operates in a similar fashion, where two-dimensional moving is necessarily provided by an order-picking lift truck (Dallari et al., 2008, p.66-76).

Stock to Person

The Stock to Person principle describes systems in which the material unit provided for picking orders is transported to the picking area. The picker is in this case the static element, while the goods are moved. In this category, the most-used systems are picking stations supplied by an automated warehouse. The transportation is carried out by shuttles or a combination of stacker cranes and continuous carriers. Figure 7.4 gives a short overview of storage advices.

2.2.2.4 Optimizing of Picking Systems

Until now we have spoken only of the possibilities of establishing a new picking system and what can be used to implement it. However, there is potential to improve already-existing systems through the implementation of routing strategies, using sorting tactics induced by turnover rate, weighting sequences of new tasks or improving quality with ergonomic work spaces or reduction of picking errors.

Storage location assignment

The storage location assignment is a first strategy to increase productivity. Basically, it can be differentiated in two main categories: fixed- and free place principle. The first one assigns a fixed storage place to each article. The second one, on the other hand, assigns incoming goods always the next free available storage place. Such a seemingly chaotic approach requires an IT system similar to WMS, as very specific data such as storage spot location, size and road is needed. This assignment principle is supported by different technologies like forklifts, shuttles or stacker cranes. An additional criterion can be the changing rate, meaning, storing parts with a high fluctuation near the point of departure, or even offering the possibility to divide parts into an ABC classification developed by Dickie (1951), zoning the warehouse into this pattern. The following list represents some organizational structures:

- Radium scheme: outward the basis, A parts are assigned to the nearest and smallest ration. B parts are located in the second, bigger circle centralised in the base of first one.
- Segment scheme: here the classification and division are made over row of shelves assigning A parts division next to the basis, B parts beside them, whereas the rest of storage is allocated to C parts.
- Strips scheme: the segmentation is done by strips over the rows. Thereby A parts are assigned to the start of each row, followed by B parts and then C parts.
- Edge scheme: this is a similar method to the strips scheme, with the additional attribute of having starts on both sides of the row.

The continuous storage location assignment can be broadly defined as the sorting of articles after creation of an access frequency, and matching automatic numbers and reposition of the warehouse. The parts with the highest access frequency are to be found near the base and with increasing distance also the frequency of access decreases. It is obviously that not every strategy fits each system and sometimes even combinations of strategies are used. Before changing strategies, however, it is imperative to evaluate its potential to fit to the company's positioning.

Routing Strategies

Closely related to this topic, and being influenced, or influencing the storage location assignment, are the routing strategies. There are many possibilities to optimize ways, but the starting point for all is the formulation of the so-called travelling salesman principle. To precisely solve it, high computing power and long lead-times are needed. Therefore, it is common to work with heuristics to deliver a solution to the problem, but it is never guaranteed that it is the optimal solution. In any case, the goal is to achieve the minimum of the average route. Following below a few often-used heuristics are presented:

- Grinding strategy without skipping: also known as passage strategy or Maänder heuristics. The picker is moving in grids through each aisle, even if there is no part to pick (ten Hompel and Heidenblut, 2011d). It is used when nearly all streets have to be taken, or when they are so small to not allow oncoming traffic (Gudehus, 2010).
- Grinding strategy with skipping: it is basically the same procedure as the previous one. The difference is, however, that aisles without parts are skipped. The big advantage, is of course the reduction of way, at the expense of a worse utilization of space. This, due to the broader storage ways required for allowing oncoming traffic (Gudehus, 2010).
- Picking went by sampling with multiple aisle visits: the picker is moving on the rack face, taking only the aisles where he has to pick and returning to same rack face. The picker can go into the aisle once for each article needed. This strategy is used if the streets are too small for the picking vehicle (Gudehus, 2010).
- Picking went by sampling with single aisle visits: basically, the same strategy as multiple aisle visits with the difference that the picker takes each row only once, picking all needed parts in sequence (Gudehus, 2010).
- Middle point heuristics: it is similar to the picking went by sampling with single aisle visits. Thereby the picker is not moving through the whole street, but returns at the latest when he has reached the middle of each aisle. The rest he picks from the other rack face. This is an attempt to reduce route and makes only sense in combination with sorted storages by turnover rate (ten Hompel, Beck, et al., 2011).
- Largest gab heuristics: virtually the same strategy as the middle point heuristics, with the difference of moving deepness. The picker moves as far as the biggest non-picking zone occurs into an aisle and picks the rest from the other rack face (ten Hompel, Beck, et al., 2011).

Combining this routing strategies and the already described zoning, the dependence in reference to each other is obvious and individual use would make sense. Therefore, it is intended to change both possibilities at the same time. Please note however, the represented way-strategies only make sense in person to stock systems as the stock to person system, supported by automatic material supply, eliminates ways. By generalizing the guiding and focusing not only on the picking process in a warehouse, the so-called milk run principle is a commonly-used approach to optimize routing. The name is derived from the milk deliveries in rural areas, where the milkman brings new bottles to the houses while picking-up the empty ones as well. This way he uses the most of his loading capacity by cutting down ways, leaving out an extra tour for the empty bottles, thereby reducing costs. This principle can be transferred to the industrial sector in different ways. Often it is used in extra logistics sectors to optimize a supply chain or a delivery between different stakeholders. But as the focus is set on intra-logistics, it is not an analysed usage within the external sector. In intra-logistics it is mostly used for the supply of production or assembly stations. Thereby a tugger delivers new material to each station as well as taking away used transport boxes or bringing processed parts to the next work location. Furthermore, we can distinguish between variable milk runs and every part every-day milk runs. This is basically similar to the storage location assignment possibilities presented in section 2.2.2.4. The every-day every part concept is fixed-routed, and as the word is saying, provides the same parts to the same stations by taking every day at same times the same routes. It is obvious that such a system is used the most for mass production (Hausladen, 2016).

Production Control

Production Control has a big influence on the material provision and therefore on the material flow. Two of its main control features are the push and the pull system, they are responsible for the production mode and how the supply of material is required. According to Goddard and Brooks push means 'to take action in anticipation of a need' and pull means 'to take action on request' (Goddard et al., 1984). In the sense of providing material in a push system, goods are coming periodically and planned. This is why this possibility is associated with an material requirements planning (MRP) system, in which everything is determined in advance. When describing a pull system, many authors are associating it with a typical *kanban* system (Dickmann, 2015), just as Lee had done it in his book (Lee, 1989). In reality, however, systems are not build up with such sharp borders.

2.3 Information Systems

Information Systems are delivering necessary data for different stakeholders. The material flow needs information, otherwise it would not be capable to correctly fulfil its given tasks. A material flow goes more or less in one direction, but information has to be exchanged between many stakeholders and can – if necessary - be simplified to at least a bidirectional process. Focusing on two directions, one information flow is always streaming in the same direction as the material flow, supporting it with data of actual needs and tasks. The other one goes in the opposite direction to request of parts, changes and or new developments.

2.3.1 Information Logistics

The information flow is not restricted to the material flow, aiming for an efficient and effective production, supporting the value-added chain with optimal resources. Today many companies are trying to improve that process by digitalization. However, we need to be careful when using this term. According to i-SCOOP (2018) digitization is transforming physical information into digital data, as well as the use of digital technologies and creating revenue through data. Knowing this, one may distinguish between two main steps transforming a paper-based industry into a digital company:

- transforming data into bits and bytes
- using this data to create value

Evans (2015) and Wagner (2017) elaborated five steps necessary to transform a company into a digital institution:

1. Identification of the transformation objectives: starting with finding terms of target business outcome is the phase to decide which parts should be transformed.
2. Market study for possible enablers: identify which solution the market is currently offering, and which would suit to the transformation objects best.
3. Establishing a vision for the future digital platform: what should be reached, and which components suit the chosen objectives?
4. Reducing risk by mapping connections between strategies, operations and business entities that might be siloed (isolated).
5. Implement the future platform: this is a hybrid step, because old systems have to temporarily co-exist with new one, making a full integration collaboration necessary.

By starting these processes, companies have to adapt towards constant change actively supported by the board's role. Focusing on the steps of the second transformation, it is important to differentiate between three basic types of software suppliers, here represented in the context to WMS suppliers. Additionally, it is necessary to divide between 3 different supplier categories (IML, 2017a):

- Pure supplier: is only a software provider for warehouse related tasks, usually having informal cooperation with ERP- and logistics-vendors with limited functionality. The software is supporting complex processes in manual and also highly automated storages.
- Suite supplier: the WMS functionality is only a module of one big overall so-called software suite[3]. Usually these suppliers come from business economics areas, providing tools for controlling, purchasing and other departments using ERP systems as data source. A reason for implementing such a software is that everything is available from a single source, reducing cost-intensive customisation. Core competence of such software is manual and partially automated storages, even available for complex systems.

[3]*'A software suite or application suite is a collection of computer programs —usually application software or programming software— of related functionality, often sharing a similar user interface and the ability to easily exchange data with each other (Computer Hope, 2017).'*

- Bearing technology supplier: these have their roots in the metal industry. As storage automation was gaining importance in that field, they started to develop software for storage machinery penetrating the field of WMS. Nowadays this software is mostly used for the optimal use of transport media and similar technologies used in warehouses with limited WMS functions. Such systems are therefore sold mostly in cooperation with a technical storage structure, sometimes working with another WMS system together using their own application as black-box for the machine interaction. Their core competence is the implementation of highly automated warehouses, focusing on the hardware advices.

Knowing these classifications is helpful when looking for possible providers for software projects that are not just warehouse-related. To show the potential of implementing or adapting digital information systems, Bilefield (2016) states that only four percent of global 500 companies have a board ready for digital support using edited data for management decision assistance.

2.3.2 Information Flow for Picking Process

Corresponding to the material flow in a production company is the information flow. Figure 2.1 shows the material flow as a process starting by the supplier, adding value in intra-logistics processes, with the final outgoing to the customers. This process requires a bidirectional information flow. Sales market requirements are starting in-house processes of developing new products, or of producing and adapting existing ones. The actual pre-process depends on the market position, production strategies and customer expectations. Nevertheless, the company is ordering on the procurement market. At this point, the second direction starts accompanying the material flow. Figure 2.6 shows the overall information flow for the in section 2.2.2.1 previously described picking process and related upstream and downstream processes. The company is establishing an order at the supplier side, by making contracts for framework of collaboration. As soon as goods are received and stored in warehouses, the next information input is given when said goods are actually needed. An order is created, and information of requirements transmitted to the picking

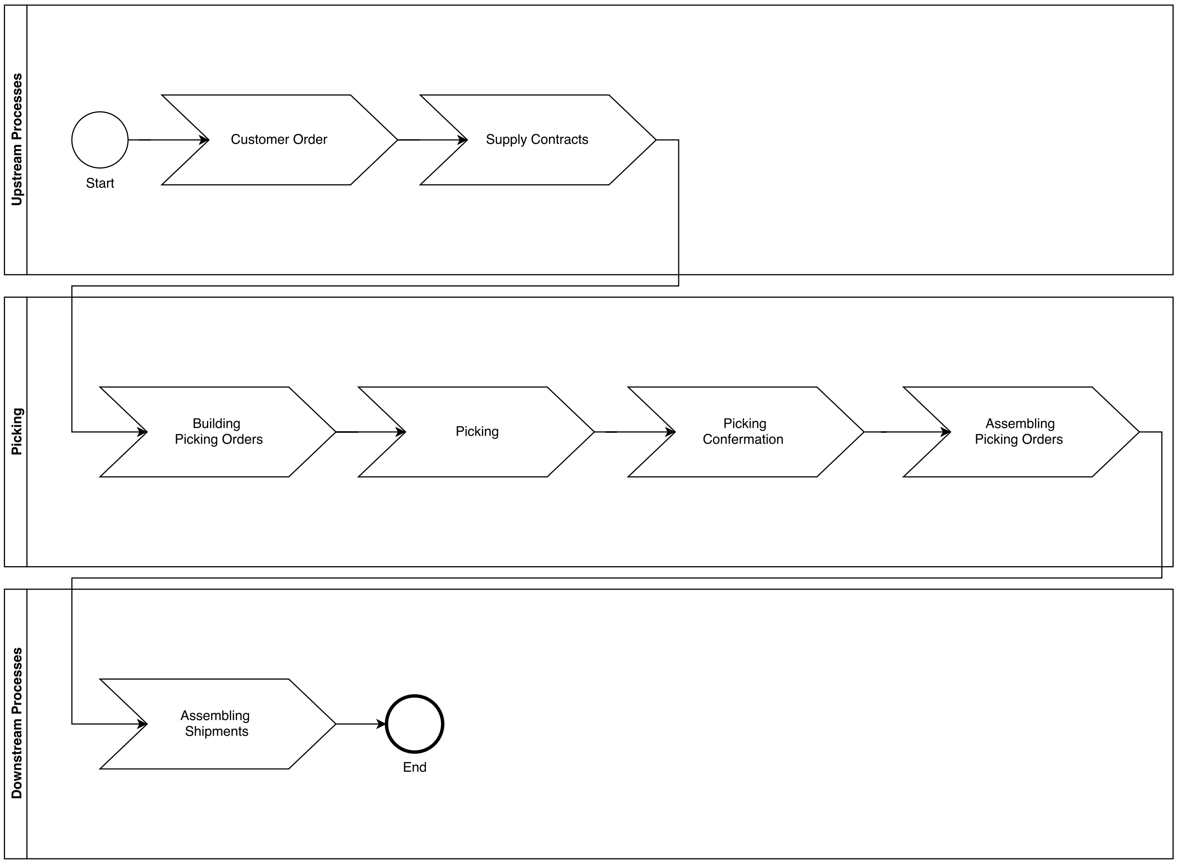

Figure 2.6: Information Flow supports Picking Process *=
*= In compliance with ten Hompel, Beck, et al. (2011)'s figure 2.3 at page 11

advice (machine or human as we already discussed in section 2.2.2.3), as soon as the process is finished and confirmed, the associated stakeholder are informed that parts are now available. Since we have already described that both processes are working in a parallel way with several connections points, and solving or changing issues, many other problems can occur in surrounding systems. Therefore clean interfaces between both processes and surrounding elements have to be implemented as to not lose focus and as to avoid new problems. Yet never forget the complexity of possible adaptations remains unmanageable as the clarity of the right starting point often remains unknown. Therefore it is imperative that changing or developing processes in the intra-logistics field require a careful methodical approach.

3 Methodology

In this chapter we are going to present applied methods for a systematic approach, this to not lose focus when changing intra-logistics processes. In chapter 1 we already mentioned different possibilities for improving material and information flow processes, by adapting strategies based on one's own requirements. Markets offer complete solutions with many possible working modes supported by various technologies, decision-makers are therefore struggling to find the right options and projects are thereby losing focus. This is the reason why we decided to use systems engineering (SE) combined with requirements engineering within the framework of this work.

3.1 Method: Systems Engineering

SE was developed by *ETH Zuerich* in 1972 and is a standard method to work on complex projects in different sectors. It is a way of thinking, a method to simplify complex problems by breaking systems into smaller units and by setting boundaries. The problem is defined as the difference between the actual state and the nominal condition (Haberfellner et al., 2015). Figure 3.1 shows the whole concept in a simplified fashion. The core competence of it all is the problem-solving process with the problem as input and the solution as output. It is influenced and supported by the SE-Philosophy with their central building blocks being systematic thinking and process model. Systematic thinking supports holistic thinking within connections and definition, structure and classification of the system. The process model supports the project settlement.

3.1.1 Philosophy

The word system stands for connectivity, it is made of different parts that are in relationship with each other. These parts are known as elements and possess properties and functions. Using the top down approach, these elements can be seen as new and smaller systems. Therefore, it can be said that every large, complex system may be reduced step by step into singular and easier-to-understand elements. Elements may not only have relationships with each other within the same system, but may also have them with surrounding systems and elements. In order to reduce the overall complexity and to focus on the problems of greater relevance, boundaries need to be set. Figure 3.1 shows the basic concepts of SE. To summarize, it can be said that the philosophy is made up by systematic thinking and process models. These are two fundamental approaches and are therefore described in two separate sections. Simply speaking, it is the procedure of using systems on different levels starting with a simple overview and breaking it down to more focused stages (Haberfellner et al., 2015).

3.1.2 System Thinking

In order to analyze systems in a structured way, it is necessary to start thinking in systems on different levels supported by different techniques. One fundamental principle is using model-like graphs illustrating complex relationships. A model is a simplification, an abstraction of the reality showing partial aspects only, thus making it necessary to check if it is still meaningful enough. When solving a new problem, it can be helpful to start with the environmental perspective: the system itself has to be neglected and is seen simply as a black box. In this phase the focus lies on the environment and its connections to the black box. This approach supports the modelling of structures and places real problems in the focus of attention. Another helpful tool is the input output view where the system itself is thought of as a black box, influencing and being influenced by inputs and outputs including goods, data or ways of thinking. Last but not least, the structured views are showing details and elements with their relationships and operating principles visualizing fields of thinking. All these possibilities are used in conjunction with graphs or matrices.

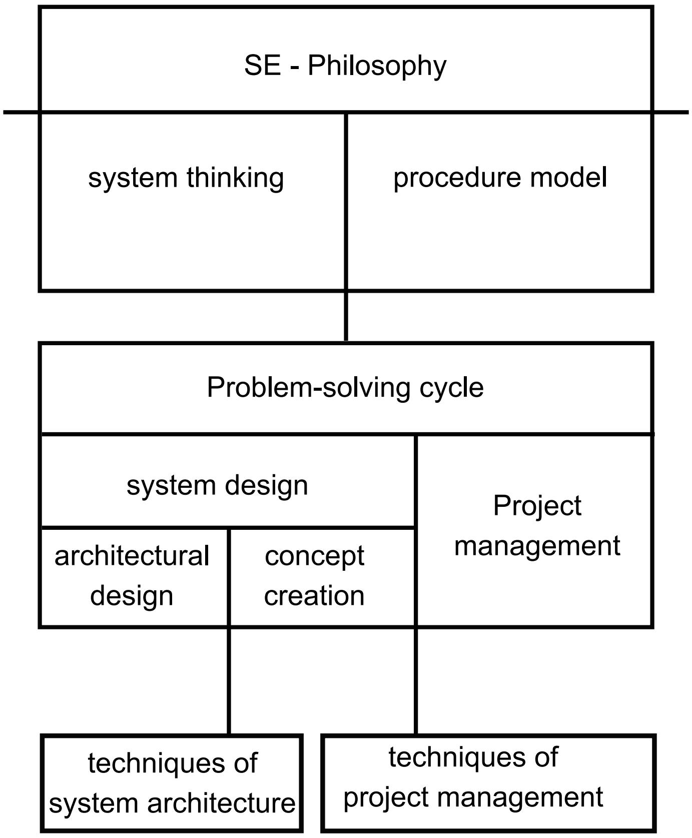

Figure 3.1: Systems engineering concept (Haberfellner et al., 2015, p.26)

Many projects are asking not for stiff models or finished products, but are seeking for approaches adaptable to their necessity, just as agile systems or dynamic processes provide. In this context a dynamic process includes the use of graphical languages (Haberfellner et al., 2015, p. 53).

3.1.3 Process Models

Combining system thinking with a the philosophical approach, it is possible to establish procedure models. Haberfellner et al. (2015) and Boehm et al. (2004) have collected in their books different models, organized in plan driven methods (PDM) and agile methods (AGM). PDM has the advantage of being clearly structured, following rules and determined plans in contrast to AGM fulfilling the demand for flexibility and adaptability in different phases. Literature attaches to the first group the Hall and BWI process, the waterfall model, the V-Model, Simultaneous Engineering, construction methodology after VDI 2221 and many others. To the second group it assigns spiral model, agile manifesto, SCRUM and others. Due to the fact that most processes can be customized it is possible to transform a PDM into an AGM.

3.1.3.1 Hall and BWI

The procedure of Hall and BWI is generally usable and - as it is made of four components - modularly combinable. The proceeding starts from an outline and goes into greater levels of detail by a so-called top-down approach. In this phase the user begins with a wide observation field, and narrows it down little by little, gradually transferring general objectives into detail targets. The procedure's second component is the creation of variation, demanding that it is necessary to create alternatives to a first solution, improving the development or research by having different options for fulfilling requirements on various degrees. The subsequent tool is the phase model, delivering a procedure model for planning, deciding and gradual realisation. In terms of planning this is supposed to set goals for each phase which need to be achieved. Out of these goals, tasks are derived with the intent to analyse and realise said goals. Last but not least the problem-solving cycle is a micro strategy supplying the phase model in each stage, and it is used to solve a problem whenever it might occur.

Module 1: Top-Down Approach Section 3.1.1 gives us already some insights on how this module is working. When starting a project, it is necessary to specify the surveyed area on a supervising level, detecting system errors and surrounding systems influencing the own one. The best course of action is to follow a kind of grandfather, father and son principle, meaning solving problems first on the 'grandfather level' the outermost layer, so to avoid the risk to transfer them on the more detailed 'father level'. Continuing with that comparison, it is obvious that the 'son level' is seen as the deepest level compared to the two levels before. Starting a project on the 'son level' means risking the development of a costly new functioning application that ultimately is not solving the problems at their roots, thereby wasting

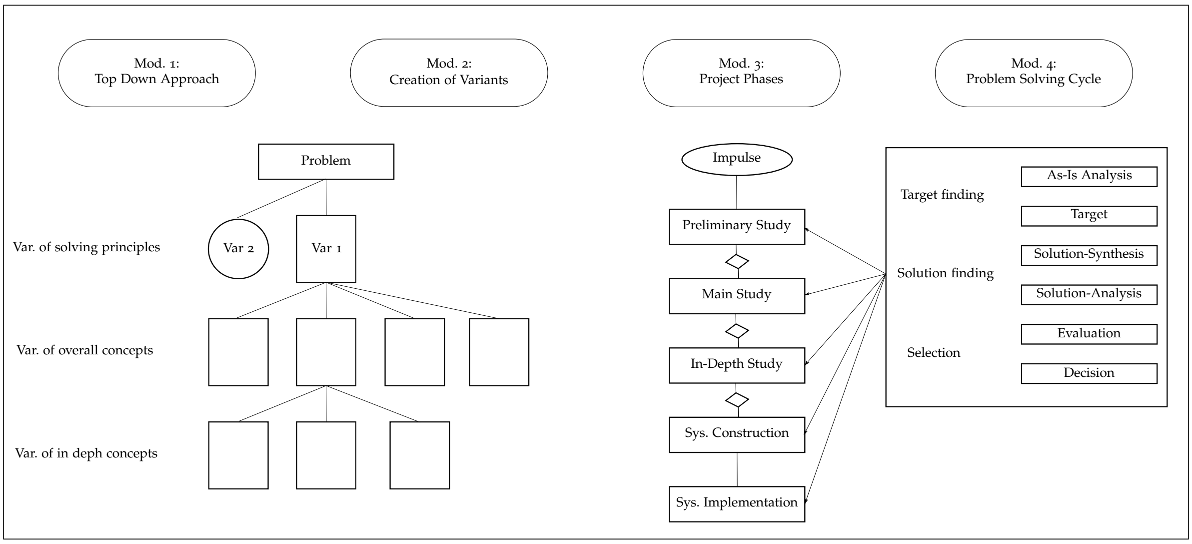

Figure 3.2: Overview of the Hall and BWI process (Haberfellner et al., 2015, p.109)

a lot of time and money in a futile project. Einstein's announcement *'If I were given one hour to save the planet, I would spend 59 minutes defining the problem and one minute resolving it'* (Spradlin, 2012) teaches to look at a problem from different angles in order to get a better picture of what the real reasons are. It should also remind to not rush through the problem definition phase, so it highlights its importance. Using this approach requires a definition of the surveyed area with related constituting factors (elements) and their relationships as shown in figure 4.4. As soon as the problem field is clearly structured on a first level for all project participants, it is appropriate to start with the same work on a deeper level, using original system elements as new subsystems, assigning them new elements (Haberfellner et al., 2015).

Module 2: Creation of Variants A famous proverb says that all roads lead to Rome. Adapting it to SE, one might better say many roads lead to Rome meaning that there is not a single solution to solve a certain problem, but rather various options that have different solving quality, meaning some are fulfilling better or have more requirements than others. This forces to find on each level a basic idea capable to address the requirements and functional for generalization or abstraction in order to find further options. The creation of variation is not a single action, it fits to each project phase and makes SE to such a powerful tool, providing the potential to work even on broad projects in a structured way. Each creation of variation on a top level will deliver more possible solutions on a subsequent deeper level, increasing solution options exponentially to an unmanageable amount. These, however, need to be examined, evaluated and confirmed in order to find the best option for the next deeper level. Human beings are guided by feelings and are influenced by different factors, thereby making impartial validation impossible. To reduce this impact, various techniques can be used as the evaluation matrix. Due to their importance they are represented in section 3.3. Avoiding this module entirely would raise the risk of detecting fundamentally different, better-fitting solving principles in later project phases, thus sometimes making time-consuming changes necessary (Haberfellner et al., 2015). A commonly used creative and structuring technique is the morphological analysis[1]. It helps to gather variants by creating abstract functions with related solving options assembled in a matrix fulfilling requirements. Once established, each option can be combined with another one from the next line, so creating a new variant. This means that a four times four matrix creates 16 different options (Ritchey, 2013). In section 4.4 this approach can be seen in different studies.

Module 3: Project Phases This is a realisation method of module 1 and 2, delivering a process structure with gradual stages and gates, offering the possibility of an exit during the development phases which are edified in preliminary, main and in-depth study. In the following list one may find a description of the process steps presented in figure 3.2:

- Impulse: is an unstructured step in which a certain idea related to a problem or an inspiration for an improving feature occurs. It is important that a person, capable of decision, gives permission to start the project by providing the necessary funds for a preliminary study.
- Preliminary study: in this phase the survey area is broadly established. Connecting it with the top-down approach it represents the first level, in this thesis called 'grandfather level'. Furthermore, problems are assigned to chances and

[1] A *' [...] Morphological Analysis [...] was developed by Fritz Zwicky [...] as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes'* (Ritchey, 2013).

requirements evaluated. In section 3.2 the focus lies on how this can be done, supported by requirements engineering. Thinking of module 2, solution options on a simple level need to be established, setting targets for areas like efficiency, socio-economics or time frames.

- Main study: this main task is to concretise the structure based on a chosen solving principle. Goals and requirements help to evaluate and built variants supported by module 2 and 4. Further information can be found in section 3.2 on structuring and choosing the right option determining further action.
- In-depth study: during that phase some elements from the main study are isolated chosen to concretise. Most requirements and goals can be derived from the whole system simplifying the in-depth study. The goal is to design or find an option, developed until a certain point, easy to implement in the overall system.
- System construction: is the phase delivering the final product. For software projects it requires to write a programme, for a building project to build a construction or a machine. Therefore, it can be seen as the realization phase, making innovations real. It is recommended to test it before starting with the implementation.
- System implementation: is the final step before the project is usable and should be done as soon as risks are minimized. Implementation can be done little by little or all at once, depending on the project's complexity. The task is to transfer knowledge from the development team to the operators preparing them for the future work.

Seeing this development method more as a total product life cycle, the phases project completion, product service and product decommissioning are missing. As service is an important point in today's purchase decisions and a source of income for companies, it has to be already taken into account during development. In Hills process this can be fulfilled by implementing 'total product management life cycle requirements'. Additionally, a project manager has to decide if he uses all phases, more phases or less phases, all depending on the project's scope and complexity.

Module 4: Problem Solving Process Developed from Dewey[2], the problem-solving cycle represents a micro logic used for each project phase as soon as a problem occurs. Figure 3.2 shows a basic version of module 4, representing a structured approach which we will describe below:

- As-is analysis: the goal is to understand the starting situation with its related problem definition and the formulation of targets. In its early stages the focus is set on understanding the problem with all of its chances and dangers, whereas in its late stages the focus is set on which concrete starting point fits to the actual solution. Part of the analysis is setting boundary conditions, or frames with insides of surrounding systems, early decisions, expectations of the client and the unchangeable part of the actual situation.

- Target: as the word already says it is vital to define a certain target or targets which have to be achieved. Connecting it with module 3, it is obvious that the target definition relates on the project phase. Targets in the early stages are more qualitative and unspecific, whilst getting more and more quantitative in later stages. These targets have to be formulated in order to fulfil certain criteria as solution neutrality, completeness, precision, understandability and practicality. They help to give objectivity to the project and simplify arguing for certain decisions. Last but not least, these targets have to be classified or evaluated with the help of a MoSCoW analysis or similar methods, because it is not said that all targets may be achieved with a certain solution, focusing first on a highly requested one.

- Solution-synthesis: previously we have already talked in section 3.1.3.1 of the creativity technique of using morphological analysis to create variants. They are built in each project phase as soon as the problem-solving cycle requires. Therefore, the solution-synthesis phase presents a creative action creating new solutions by producing variants based on the as-is analysis, problem detection and target definition.

[2]https://www.linkedin.com/pulse/dewey-sequence-dead-fish-theory-problem-solving-lauren-bacon/ (visited on 10/10/2017)

- Solution-analysis: its aim is to define if solutions are fitting to the requirements or if there are weaknesses that can be solved on early 'paper-based' project phases. It should be noted that if the formal aspects are fulfilled, variants are on the right level of concretisation, solutions may be integrated in the overall system, their functionality guaranteed, and their operational reliability promised, conditions or consequences can be evaluated regarding technical and socio-economical aspects.
- Evaluation: closely related to the solution-analysis, already-proofed variants are systematically compared to each other in the evaluation phase. To achieve this, it is advised to use methods like the arguing balance, benefits analysis, cost-benefits consideration or the economic efficiency calculation.
- Decision: is task to choose the further solution variant, based on the former evaluation.

As we have already seen in module 3, there exist a few additional steps like the information research, which are required in all steps of the problem-solving process, and the documentation improving credibility, important for self-security and future adjustments.

3.1.3.2 V-Model

The V-model is a combination of top-down and bottom-up approaches. We have already heard the meaning of using top-down in section 3.1.3.1, bottom-up is piecing together systems to give rise to a more complex on (Sabatir, 2008). The V is characteristic for piecing together a part or narrowing down a topic and assembling or flair them. Its left part represents the decomposition of customer targets to technical specifications for entire systems and subsystems using a top-down approach, whereas the right part represents the integration of parts, combining subsystems to entire systems, further combined with the necessary verification steps to compare solutions with the requirements established during the system disassembly. This assures that a technical solution is able to meet customer demands.

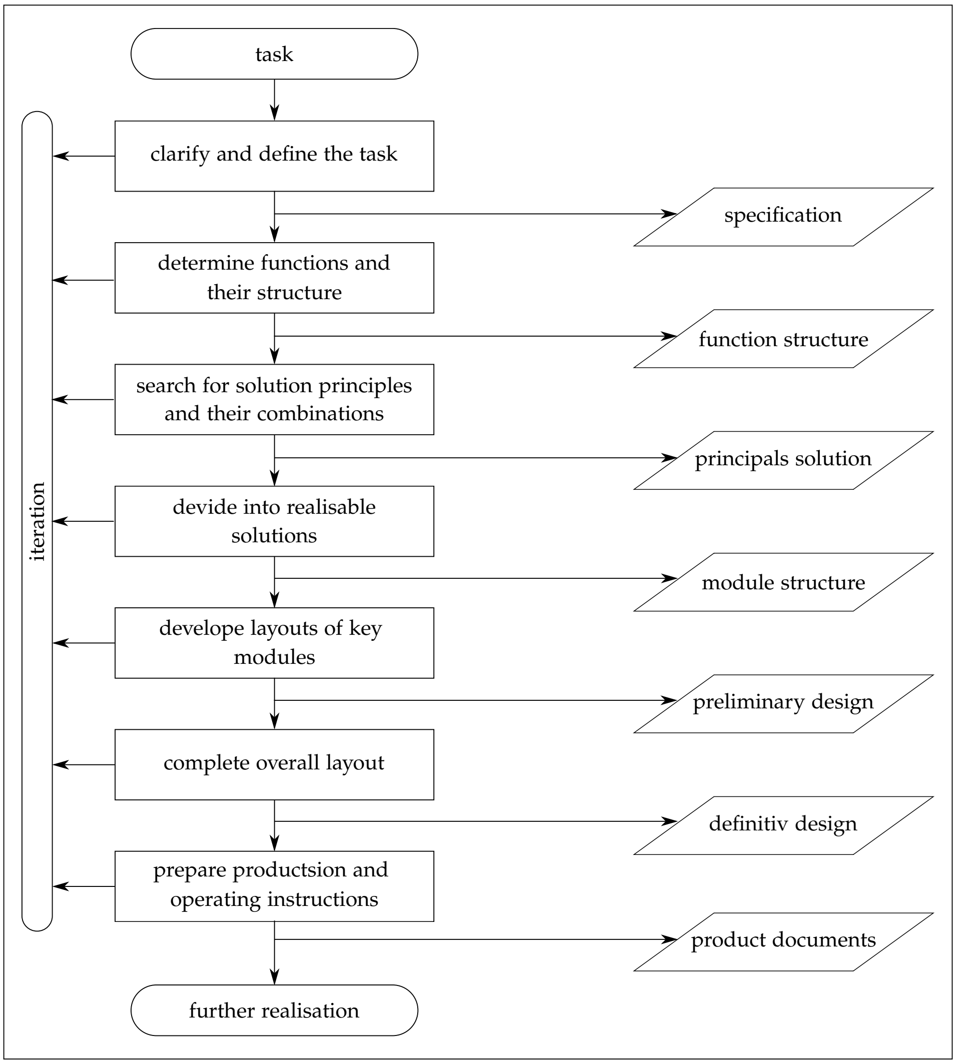

Figure 3.3: VDI 2221 Systematic approach to the development and design of technical systems and products*=

*= In compliance with Haberfellner et al. (2015)'s figure 2.13 at page 92

VDI 2221 is structuring the design process in stages, simplifying complex approaches into sub-components and systems. The four main phases, planning, conception, embodiment and detailed design are therefore previewed and structured into the seven iterative stages:

1. Clarify and define the task with the goal of a specification list.
2. Determine functions and their structure with the goal of a functional/functioning structure.
3. Search for solution principles and their options for combination.
4. Divide into achievable solutions with the goal of a modular structure.
5. Develop layouts of key modules with the goal of a preliminary design.
6. Complete overall layouts with the goal of a definitive design.
7. Prepare production and operating instructions with the goal of having product documents.

VDI 2221 is describing a well-structured top-down approach with previewed iteration steps fulfilling the overall SE initial approaches (VDI, 1993), but the handling with requirements are not adequately described (Bertram, 2008). Originating by VDI 2422 and disassembling related development disciplines into software, mechanical and electrical stages, VDI 2206 was established, today seen as the classical V-model with the characteristic presentation (VDI, 2004). This method is divided in system design and domain-specific design in mechanical, electrical and software-technical disciplines by system integration. VDI 2206 is originally a guideline for mechatronic engineering but can be adapted to any complex development project.

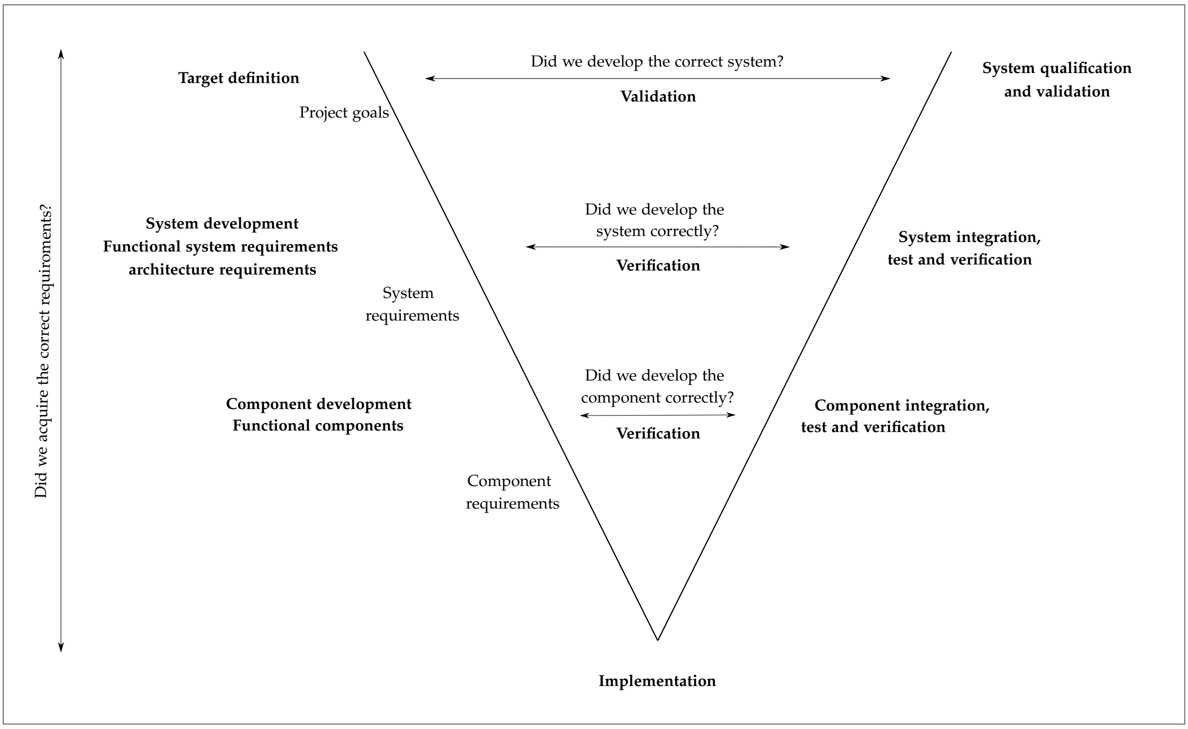

Figure 3.4: V-Model (Haberfellner et al., 2015, p.88)

Figure 3.4 shows conceptual interpretation of VDI 2206 and VDI 2221 with different process steps which are similar to the ones from Halls module 3 (see section 3.1.3.1) emphasizing the parallels of both processes. In the following list we are describing the most important targets of each point:

- Target definition: same task have to be fulfilled as the problem-solving process in section 3.1.3.1 requires.
- System development, functional requirements and architectural requirements: in this phase requirements for the system are collected using interviews or similar approaches which we will deal with in section 3.2, focused on the requirements engineering.
- Component development: this is the deepest level of the design phase. As already mentioned in Halls process and the top-down approach, it could be synthesised with the detail study, but not only on a conceptual base. The goal is to produce real components. Thinking of software developments, the interface

has to be coded, error messages listed, and input-output modules designed. It is not required that the whole system may already be working, but partial systems should.

- Implementation: this phase is referring to Halls module 3 integration represented section 3.1.3.1.
- Component integration, test and verification: the smallest, independently existing units are tested and verified on component requirements.
- System integration, test and verification: afterwards these independent components are assembled into systems which are tested and verified on the previously-established system requirements.
- System qualification and validation: in this phase the system is tested under real condition and the client is checking if the requirements are fulfilled.

In this context validation is the action of proving that something is correct (Cambridge Dictionary, 2018a) and verification the process of testing or finding out if something is true, real or accurate (Cambridge Dictionary, 2018b).

3.1.3.3 Process Combination

With the insides in two different processes, we can already see that they have similar elements. Truly, as already mentioned in section 3.1.3, there exist many other possible AGM's or PDM's and the book of Haberfellner et al. (2015) gives a good overview of them, but as they are not fundamentally different, the focus is not set on their evaluation, once represented they are sufficient for the thesis. The V-model and the Hall and BWI are counted among the PDM's. It is already shown that there are many starting points improving an inter-logistics material-flow and the need of a well-structured procedure demonstrated. Therefore, the plan-driven methods with more concrete steps are to be preferred for complex problems, even if they are criticized for slowing down development. With the 4 modules and the adaptability on individual project size the Hall and BWI already possess some agility[3] so it can

[3] '*The capability of a company to rapidly change or adapt in response to changes [...]*'BusinessDictionary, 2018

even be counted to the AGM's. Furthermore, it is possible to use more than only one method and they are even connectable among each other. The V- model has the big advantage of introducing verification loops well-suited to product development and better guidelines for system construction or testing. All these are reasons why we decided to use it in the preliminary and partly in the in-depth study.

3.1.4 Systems Modeling Language

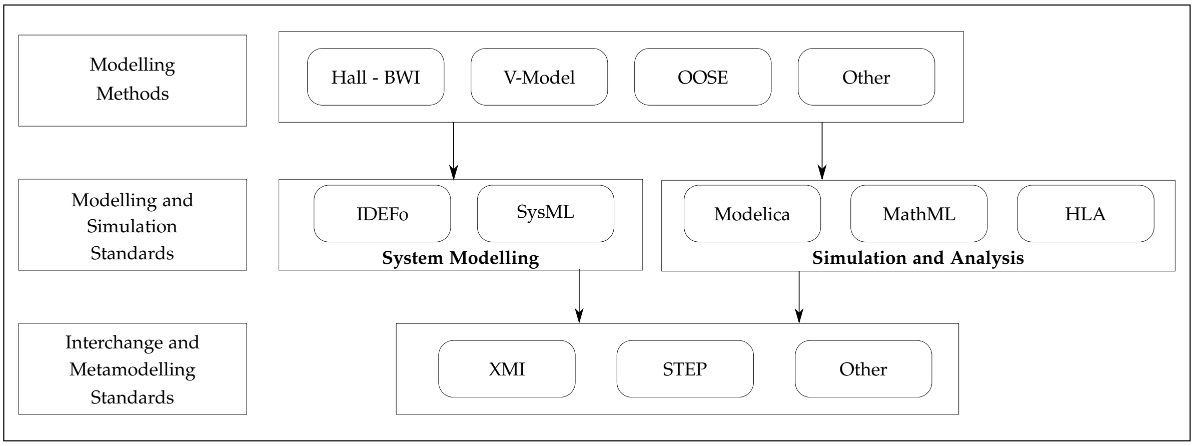

Figure 3.5: Junctures between methods and tools (Object Management Group, 2008)

The described processes are based on systems using both design and verification on each process level. These processes and steps require visualised models fulfilling related tasks. Figure 3.5 demonstrates the relationship between methods and models interchangeably by standard files. Models include system specifications, design, analysis and possible validation phases. Using standardized ones supports the accessibility of communication within a project group, since systems are clearly designed, and knowledge therefore transferred. A side effect is the reduction of developmental risk by improving quality and increasing productivity. An approved language tool is Systems Modeling Language (SysML). It is defined as a graphical modelling language, providing semantics and notations supporting the specification, analysis, design, verification and validation of systems including the fields of hardware, software, data, personnel, procedures and facilities development (Object Management Group, 2008). Therefore, the nine following diagram types are used:

- Package diagram
- Requirement diagram
- Activity diagram
- Sequence diagram
- State machine diagram
- Use case diagram
- Block definition diagram
- Internal block diagram
- Parametric diagram

Depending on the system, a certain diagram with related notations may be used. Analysing or designing processes in which some activations have to be fulfilled requires the use of an activity diagram type containing approaches as Business Process Modelling Notations (BPMN) or Data Flow Diagrams.

3.2 Method: System Requirements - Requirements Engineering

For the previously presented processes (Hall and BWI and v-model) requirements are fundamental for establishing a development's directions, goals and decision of project ultimate success. The IEEEE 1998 or the ISO 2017 are defining a requirement as *'[...] a statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability [...]'* (R. F. Schmidt et al., 1998). Therefore, it is necessary to gain some insights into this method. Requirements are at the base of all new developments. We as humans invent new things in order to fulfil our desires or needs and out of those we have to progress requirements. This is why this engineering discipline is referred to as the process of defining, documenting and maintaining requirements

(Chemuturi, 2013). Related to the engineering is the management which consists of documenting, analysing, tracing, prioritizing and agreeing on tasks or decisions. It is a basically part of the systems engineering mentioned in section 3.1, playing major roles in design, integration, verification and validation. Last words are clearly connectable to the V-model presented in figure 3.4.

3.2.1 Process Approach

The aim of this process is to transform the stakeholder[4], user-oriented view of desired services and properties into a technical view, meeting operational needs of the user (SEBoK, 2017a). As described in section 3.1.3, even this process is structured in a top-down approach developing requirements for stakeholders, systems and elements. The connection of this notation to classical SE models is obvious as figure 3.6 proves. It shows that requirements are not only important during the designing phase, but even during the test phase proving a product's properties. Guaranteeing objectivity, they have to be structured in order to be verified, to be met or to be possessed by a system, solving problems or achieving objectives, to be measured and bound by constrains defining the system's performance. Therefore, the following process is defined by ISO/IEC 15288:2008 (R. F. Schmidt et al., 1998) divided in stakeholder requirements definition and requirements analysis phases:

[4]*'An individual, group of people, organisation or other entity that has a direct or indirect interest [...] in a system.* (Dick et al., 2017)

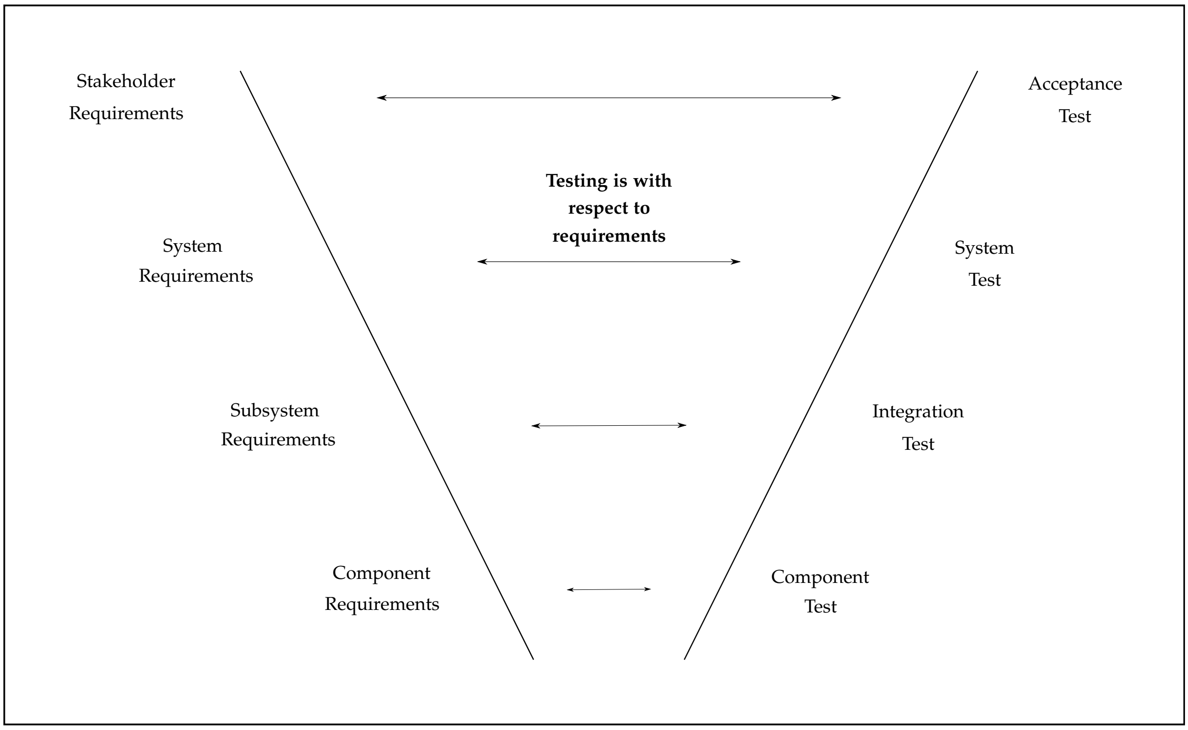

Figure 3.6: Interface between requirements and V-model (Dick et al., 2017, p.14)

3.2.1.1 Stakeholder requirements definition

The goal of this step is to define a system of requirements or needs that have to fulfil customer and stakeholders demands in a carefully defined environment. This is achieved by identifying stakeholders involved in the system and ascertaining their needs, expectations and desires. The result shows a collection of non-technical requirements, characterised by the context of use of the product functions, the constraints on the system solution, the traceability of stakeholder requirements among each other, the stakeholder requirements for validation and a definition of the stakeholder requirements themselves. The various steps listed below describe a structured way fulfilling these tasks:

- Elicit stakeholder requirements: starting this process, stakeholders who have a legitimate interest in the system have to be identified and requirements gathered from them, by using some of the common sources and techniques, like e.g.:
  - Workshops with brainstorming

– Interviews and questionnaires
– Observation of environment or work patterns
– Technical documentations
– Market analysis
– Prototypes and simulations
– Benchmarking processes
– Organizational analysis

With the help of this techniques a list of requirements is created containing information such as:

– Goals: are providing the motivation for changing systems, but are often vaguely formulated, providing a possible change process for a certain project.
– Mission profile: describes how the system needs to perform and how it will contribute to company operations.
– Performance: sets the critical parameters that a system has to fulfil. The Cambridge Dictionary (2018) defines it as the measurement of how well a person or machine is doing a piece of work or an activity.
– Operational deployment: simply speaking it answers the questions of when the system will be used or during which other / parallel processes.
– Operational scenarios: describe special scenarios that a system ought to fulfil, sets systems boundaries and helps to identify requirements that might have been overlooked.
– User and operational characters: defines who will use the system, setting up requirements for skill levels, expected workload and expectations of users.

- Define stakeholder requirements: starting this step, constraints[5] on a system solution are defined, presenting unavoidable consequences of existing agreements. Figure 3.7 shows in the external and internal environment areas potential constraining factors for the system as laws and regulations[6] or technologies. Creating a full picture of demands often needs different levels of abstraction or mechanisms of presentation that correspond to the systems engineering process of using different levels. Within this phase it is also necessary to specify requirements for human interaction, health, safety, security and other functions relating to critical qualities.

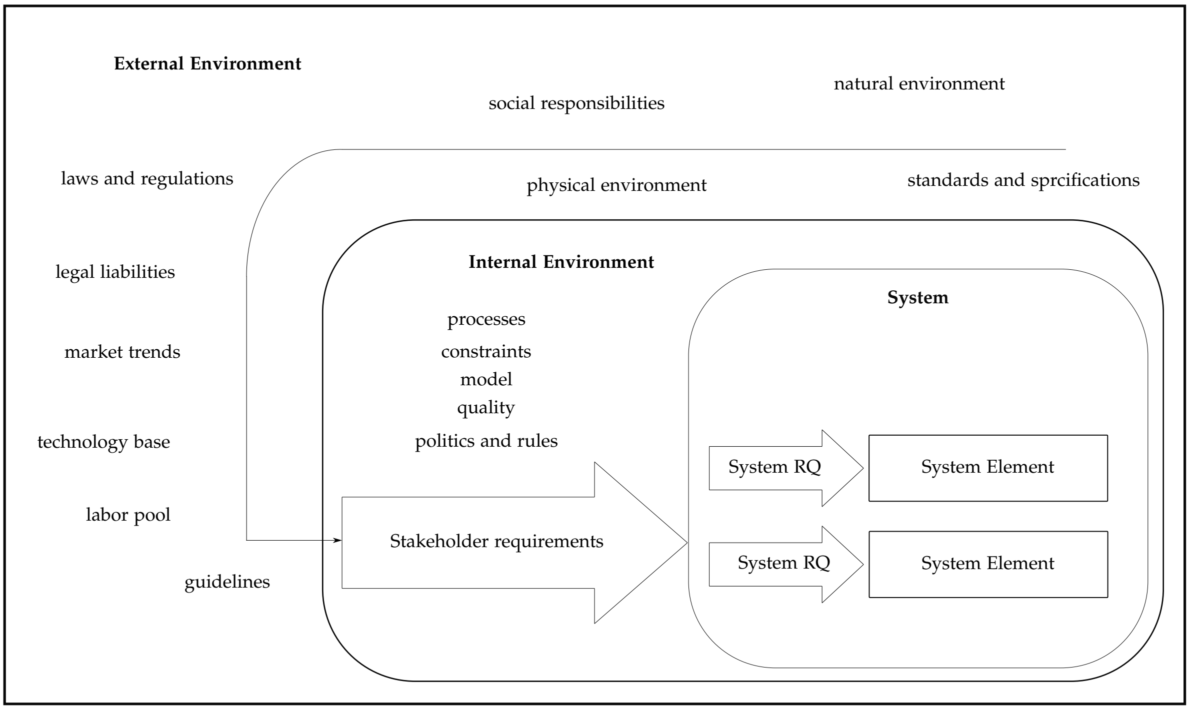

Figure 3.7: Factors influencing requirements on different development levels (Dick et al., 2017)

- Analyse and maintain stakeholder requirements: within this project phase a list of requirements is analysed in view of different criteria such as language and construction. Well-structured statements can be verified, have to be met or possessed by a system to solve a stakeholder's problem, can be qualified and are defined by system performance indicators. As soon as this is done,

[5]This are one type of requirements
[6]Dechert (2016) promotes logistics in an environmentally friendly way

the list has to be classified by grouping it up into categories like financial or performance requirements. ISO 2015 gives a short overview of different categories (SEBoK, 2017a). By categorizing the list of requirements, inconsistencies between different stakeholders demands may be visualised and solved before the development heads in the wrong direction. In most cases a consultation with people concerned/involved helps to find a consensus. This is an iterative process and has to be set in motion as soon as conflicts are detected.

3.2.1.2 Requirements analysis

The purpose of this process step is to transform the perspective of a system from a stakeholder, requirement-driven view into a technical one that is also able to deliver expectations. For this to happen there needs to be the assurance that the traceability of the system to the stakeholder requirements is achieved. The following steps are necessary to fulfil this expectation:

- Define system requirements: when starting this process, functional boundaries in terms of behaviour of the system are set. This way scope problems may be minimized, and targets refined. Once this step is met, the performance functions which are required from the system are defined, building the basis for further development. Related to these functions, additional system requirements are defined supported by arguments, providing justification for selection. Within this process step, duplicate stakeholder requirements are identified and eliminated, and ensuing design implementation evaluated with the customer. All these actions are undertaken to create a set of specifications, characteristics, attributes, functional and performance indicators, in sum the system requirements which the system needs to possess in order to satisfy the stakeholder (ISO/IEC/IEEE, 2015).

- Analyse and maintain system requirements: this process starts with an integrity analysis. This analysis ensures that each requirement is possessing overall integrity by feeding back the analysed system to the stakeholder requirements. After classification, the established list is to be analysed and prioritised using different techniques as in section 3.2.4 described (ISO/IEC/IEEE, 2015).

3.2.2 Alternative Processes

Basically, as already stated in section 3.2.1, Dick et al. (2017), Rupp (2016) and Ebert (2014) share the same process steps. Starting with a top-down approach and defining on each level new requirements derived from and influenced by the upper level are common to all. The differences may be found in the supporting tools and the approaches between the various main steps. Dick et al. (2017)is working with graphical applications starting with an iterative process introduced by a statement of needs. These needs are analysed and modelled by identifying stakeholders and creating so called usage models which require the following procedure:

- Start with the end goal
- Derive the necessary capabilities to get to that point
- Break large steps into smaller steps
- Keep the set hierarchical
- Review informally at each stage
- Be wary of defining solutions

The results of this process are usage models and stakeholder lists which are influencing the derived requirements step. Following this a structure for capturing stakeholder requirements has to be defined. As previously described in section 3.2.1.1 the capturing can be done in different ways[7]. The requirements are subsequently implemented in the chosen structure. The outcome of this process are structured stakeholder requirements which are then regarded as input for the system requirement analysis, working similar to the represented process.

[7]Dick et al. (2017) describes future details on these processes on the pages 126-132

3.2.3 Difference between Stakeholder and System Requirements

Stakeholder requirements need to be kept understandable for 'everyone'. They are therefore non-technical, but focus realistically on roles, responsibilities and stakeholder groups. They should be built up as quickly as possible, defining capabilities required by the stakeholders and expressed in unmistakable terms comfortable and familiar to the people in charge. Often occurring problems are an over-emphasis on solution, an under-emphasis on finding the real problem and misunderstanding the stakeholders. System requirements are technically influenced descriptions of what the system will do to meet the stakeholder requirements but avoiding references to any particular design. They are important for systems engineering because they form the basis for architectures, designs, integrations and verifications befitting the more concrete project levels.

3.2.4 Prioritize of Requirements

The techniques represented and discussed in the sections above have the goal to prioritize requirements as well. This task can be achieved by using some of the methods described in the following list (Analyst, 2018):

- Ranking: is the process of giving each requirement a different numerical number, based on its importance stating with 'number one' for the most important one. This technique works best for a single stakeholder as different stakeholders have different perspectives on what the priority of a requirement should be.
- Numerical assignment: requirements are grouped into different priority levels. It is important to clearly define each group so that the stakeholder cannot be misunderstood. Categories may be classes such as 'compulsory', 'very important', 'important' and 'does not matter' expressed in numbers. A disadvantage of this process may be that requirements have no unique priority assigned per requirement.

- MoSCoW analysis: is similar to the numerical assignment using, instead of numbers, the four priority groups of 'must have', 'should have', 'could have' and 'will not have'.
- Hundred-dollar method: stakeholders have in total 100 points which they can distribute among the requirements. The higher the amount of points assigned to each requirement, the higher its priority.
- Bubble sort technique: this process basically compares two requirements with each other sorting it after relevance. More important requirements are shifted to the left side and less important ones to the right one[8].
- Analytic hierarchy process: stakeholders have to decompose their aims into smaller sub-problems, which can easily be comprehended and analysed by comparing pairs of the same hierarchy level next to each other. After a decision is taken numerical values are assigned to each element of the hierarchy representing its importance.

The techniques represented above are not assigned to multi stakeholder priority applications. To deal with that problem, it is possible to use weighted averages based on stakeholders' power of influence on certain requirements.

3.3 Integrity of Requirements Engineering in Systems Engineering

This thesis has already shown that requirements engineering is part of systems engineering. Within the Hall and BWI (section 3.1.3.1) requirements engineering is done in module four's micro cycle the problem solving cycle's target definition phase and in the V-module after each design step. Figure 3.8 shows the corresponding processes starting by stakeholder requirements. Usually this is a statement of need from customers or other target groups expressed in a simple sentence or statement. Out of this announcement, stakeholder requirements are developed. The further process is

[8]Bubblesort is called a sorting algorithm. Further information can be found: `https://de.wikipedia.org/wiki/Bubblesort` (visited on 14/08/2017)

described in section 3.2.1, , even determining and influencing the development of deeper requirement levels. Claims are the basis for developments or improvements by using functions and different creativity techniques. To these functions potential solution options are subsequently added, which are evaluated by using various techniques like the ones found in the list below:

- Argumentative balance sheet: basically a pro and con list for each variant (Haberfellner et al., 2015).
- Evaluation matrix: this analysis is evaluating different potential variants which are fulfilling different goals and therefore have to be rated using a certain structure as indicated in table 4.2 shows. Simply speaking, it is a matrix with graded variants (n_{xy}) fulfilment and weighted tasks (g_x). Summing up the product of grade for task fulfilment and weight of requirement for each variant delivers a single number, shaping a measurement for variant-fitting-requirements called key figure (ZE). The variant with highest ZE is the one to prefer in the decision phase.

$$x = X; ZE_x = \sum_{y=1}^{Y} n_{xy} * g_x \tag{3.1}$$

  Equation 3.1 shows the accounting for a key figure related to a specific variant and the best solution is the one with highest overall compliance (Haberfellner et al., 2015).
- Benefit analysis: is an extension of the evaluation matrix achieved by structuring criteria to logical groups. Section 3.2.4 describes the prioritization of requirements. There are also defined must targets, not influencing the benefits analysis, as the solution has to meet those, and no overall compliance is required (Bundesverwaltungsamt, 2017) (Bundesverwaltungsamt, 2017).
- Portfolio analysis: is used for evaluation of action alternatives for strategic perspectives. Bedrock is a straight and weaknesses analysis of the organisation, and an analysis of opportunities and risks on the surrounding. The solution it may deliver are action alternatives for different fields and in which solutions have to be established (Bundesverwaltungsamt, 2017).

- Priority analysis: is used to determine weighted criteria. Starting with this process, criteria or targets have to be defined precisely and not to overall as economic efficiency. Afterwards a valuation scale is to be defined. Creating a two-dimensional matrix and placing previously determined criteria on the axis is to fill up by numbers determined by a pair to pair comparison using defined scale. The result delivers a ranking for each criterion (Bundesverwaltungsamt, 2017).

All these different types of analysis help to detect the most promising variant. SE literature provides even more processes and we are giving here only a short insight into this vast field. Based on the main decision, next system level or component level is to be taken into consideration by repeating the solution domain in figure 3.8 and related SE steps.

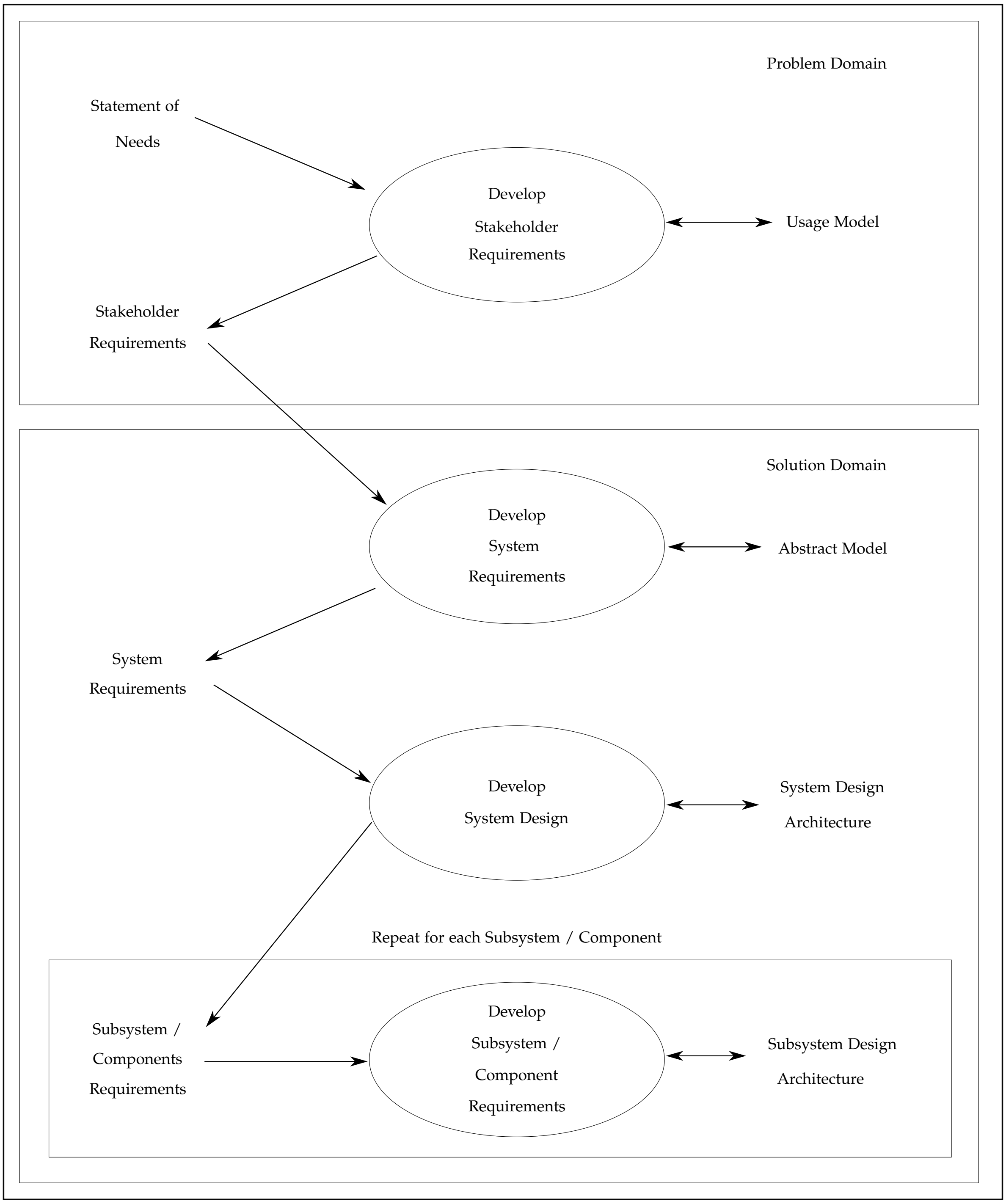

Figure 3.8: System development process combined with integrated requirements engineering (Dick et al., 2017, p.35)

3.4 Similar Scopes

The processes described are used to develop not only new products in software and hardware engineering, but are used also in developing services, enterprises, subsystems or healthcare standards. Therefore, systems engineering is a procedure model that is adaptable to nearly every project including the building of the Oeresund Bridge. Key factor of this particular project was the elicitation of stakeholder requirements and their correct understanding, taking into account complex factors like environmental compatibility (Systems Engineering Trends, 2016). Another area of application is the healthcare system in which a systematic approach supports improving actual methods. Atul Gawande, an American surgeon, discovered that in every second operation something is missed and therefore developed, with the help of Boeing's system engineers, a new methodology, using support check lists that were developed with the help of the problem-solving cycle (Trends, 2016). The process in this particular area is similar to the standard industrial area, which is starting with the problem definition, followed by an investigation of alternatives (SEBoK, 2017b). Even simple project like the construction of a house are based on systems engineering and its requirements engineering. Although the owner might not be aware of actually using this method, but by simply making decisions as where to build and what to build, he is guided by needs and set requirements, trying to fulfil them. Haberfellner et al. (2015) shows in his book a systematically use case of building a house by knowingly using systems engineering. Similar to that project, we will demonstrate in chapter 4 a systems-engineering approach by improving Durst's intra- logistics material flow.

4 Case study

4.1 Company Presentation

Durst is a trend setting producer for digital production technology. Founded as a family business 80 years ago in South Tirol its main goal is guaranteeing customer satisfaction with the use of innovative technology while retaining sustainability and quality. Currently their main business activity is the production of machines for decor printing on ceramics and Medium-Density Fibreboard(MDF) boards as well as machines for image reproduction with optical equipment based on laser or light-emitting diodes (LED).

4.1.1 History

Durst was officially founded in 1936 by the two brothers Julius and Gilbert Durst supported by the Oberrauch family as a financial investor. The two brothers have been raised in a creative and innovative surrounding with their father being a painter and hobby photographer, their mother owner of a dark room and their grandfather an engineer. This obviously sparred their early interest in the field of photography. In 1929 they decided to establish their own business, repairing and building customized photographic equipment. Two years before they officially founded Durst photo-technical AG they released the Durst copier - a machine capable of reproducing many photographs in limited copies followed by there own serially produced camera named Gil in 1938. Until 1964 they mainly focused on producing and developing new cameras and additional equipment as the enlarger. 1964 the company moved to their new plant, which is still the headquarters of Durst today. In the same year

Julius Durst died in a car accident leaving a young but well structured team behind. The teams spirit and courage helped developing new photo equipment containing extremely high precision, compactness while being exceptional easy to handle. In 1975 Durst developed the first daylight enlarger processing without a darkroom helping theme becoming a big market leader in the following years. The first digital camera, published by Kodak in 1975 (Sassion, 2007), opened a new market and by 1992 all companies presented this new sort of cameras at the photokina[1]. With big electronic companies like Sony entering the market Durst saw a rising competition and sinking margins forcing them to change their product portfolio investing intense research and development work. Finally in 1994 they presented their first large format printer (LFP) called Lamda installing more than 900 machines worldwide in the first year. It is the start of Durst‘s transformation into a digital company which is still in progress today.

4.1.2 Product Portfolio

As we have seen in Durst's history, the company is agile and flexible. In order to understand the changing ability we decided to give a short overview of the machines produced today. Furthermore, we already have seen in chapter 2, that the material providing is depending on the production mode. Emphasised by the idea of becoming a company fulfilling industrial 4.0 standards, Durst tries to change their intra logistic processes which also requires knowledge of the products and the production mode.

4.1.2.1 Large Format

This category includes all machines capable of printing large size motives. The work mode is similar to a simple inkjet printer just on a larger scale. On one side we can find a big unwinder holding the printing medium in rolls format. Rollers are guiding and preparing the material for the following printing processes. Subsequently the ink is put on the printing medium. A basic print carriage is holding the four basic inks cyan, magenta, yellow and key (black) meaning at least four printing heads

[1]This is a trade fare held in Europe: `http://www.photokina.com` (visited on 05/10/2017)

are required (single pass option). Speeding up high qualitative printing demands at least eight heads to be used. A single set of them would inhibit a bidirectional usage because on a microscopically level the small colour drops are not set one above the other in same order, creating different shade cards, depending on the printing direction. Durst currently offers two main types of alternatives (2017): the *Rho* line consists of UV inkjets printing on paper and traffic signs using water based inks, while *Rohtex* is a machine capable of printing on paper and textile, using a special inlay to switch between the two modes. The huge variety of clients from different backgrounds and with different requests demands a modular and highly customisable product.

4.1.2.2 Label

Label printing machines are used by many different customers, producing inscriptions on their products. In this field Durst offers single pass machines based on UV technology. Single pass means that only one set of printing heads is used and a bidirectional usage offering high quality is not possible. The UV light is required to harden ink layers between and after the printing, enabling a fast roll up after the process. All machines are designed for a twenty-four-seven production mode switching between contracts without high retooling times. Cutter and punch machines are not produced by Durst but offered from cooperating companies allowing to establish easy a working line production.

4.1.2.3 Ceramics

Nowadays end customers are demanding special unique products. The offset printing on ceramics offered by Durst makes the production of unique and individualized tiles possible. Therefore flexible machines, high end software solutions and efficiency are required which the so called *Gamma* line provides.

4.1.2.4 Textile

Even thought the before mentioned *Rhotex* series is capable of printing paper and textile, Durst offers dedicated textile printing machines called the *Alpha* series combining new process technologies between printing head, ink system, textile material and tissues type. This technology is used for the production of interior fittings and decorative items such as bedding, table linen and padlocks. It require a fabric preparation and a substance post-processing, drying the ink before winding. The basic working mode is similar to the large format printers with different inks and different printing heads.

4.1.2.5 Imaging

With the Imaging sector Durst goes back to its routes. The DSR Automatica Durst Sebring imaging systems is a cooperation project between Durst Phototechnik AG and Steven Sebring that aims at developing high-end, cutting edge photo technology creating four-dimensional visual content for multi-channel platforms. This shows us, that Durst as an innovative company tries to stay market leader by being explorative in new and at the same time also in old fields.

4.1.3 Production Mode

All of the described machines are produced on specific customer demands and on order with a scheduled assembly time for main assembly of one week. Due to multi component products, assembled in a complex way and small quantities, the company decided to produce in fix places. This production mode is even influenced by the fact that this kind of machines has to be orientated precisely due to the requirement of microscopical precise colour placing for high quality prints. Therefore even adjustments have to be done in temperature and air humidity controlled spaces. The production itself is divided in three main phases, starting with the mechanical assembly, followed by the electrical and hydraulic installations and finalised by the final acceptance, adjusting and programming machines. Especially interesting for the material supply is the mechanical production phase because almost 100% of the parts are required their which are already provided picked with the exception of small parts like screws which the fitter himself has to pick. The opposite is the pre-assembly where the fitter has to pick on his own in order to produce required products. This pre-production starts approximately one week before main assembly. Figure 4.9 shows the actual production area and is described later more precisely but should already give some insights in the location of storages and assembly areas. The shelves in assembly areas show also that Durst is operating with decentralised warehouses requiring long road times for picking.

4.2 System Development Approach

Producing such machines requires presented production mode which has to be continuously improved or changed, trying to cut costs which today is emphasised by industry 4.0. Adaptations and related success are requiring well structured proceeds as represented in chapter 3. Figure 4.1 represents the overall structure of the following sections with the project starting point of Durst‘s claim to change the material supply. Thereby the development of a new piking system is in focus supported by a combination of system engineering processes and requirements engineering. Preliminary study, main study and in-depth study (Hall and BWI) are the three basic steps of the used method. In the micro cycle we decided to customize it a little bit by not using the typically problem solving cycle in all phases as described in section 3.1.3.1. At the beginning of the research we used a combination of requirements engineering and the systems engineering’s V-model. Supported by Durst’s statement of need stakeholder requirements are developed as basics for further steps. A system is formed based on requirements showing overall solving principles which are then analysed in the main study supported by the classical Hall and BWI’s problem solving cycle. Even the in-death study is based on this problem solving cycle.

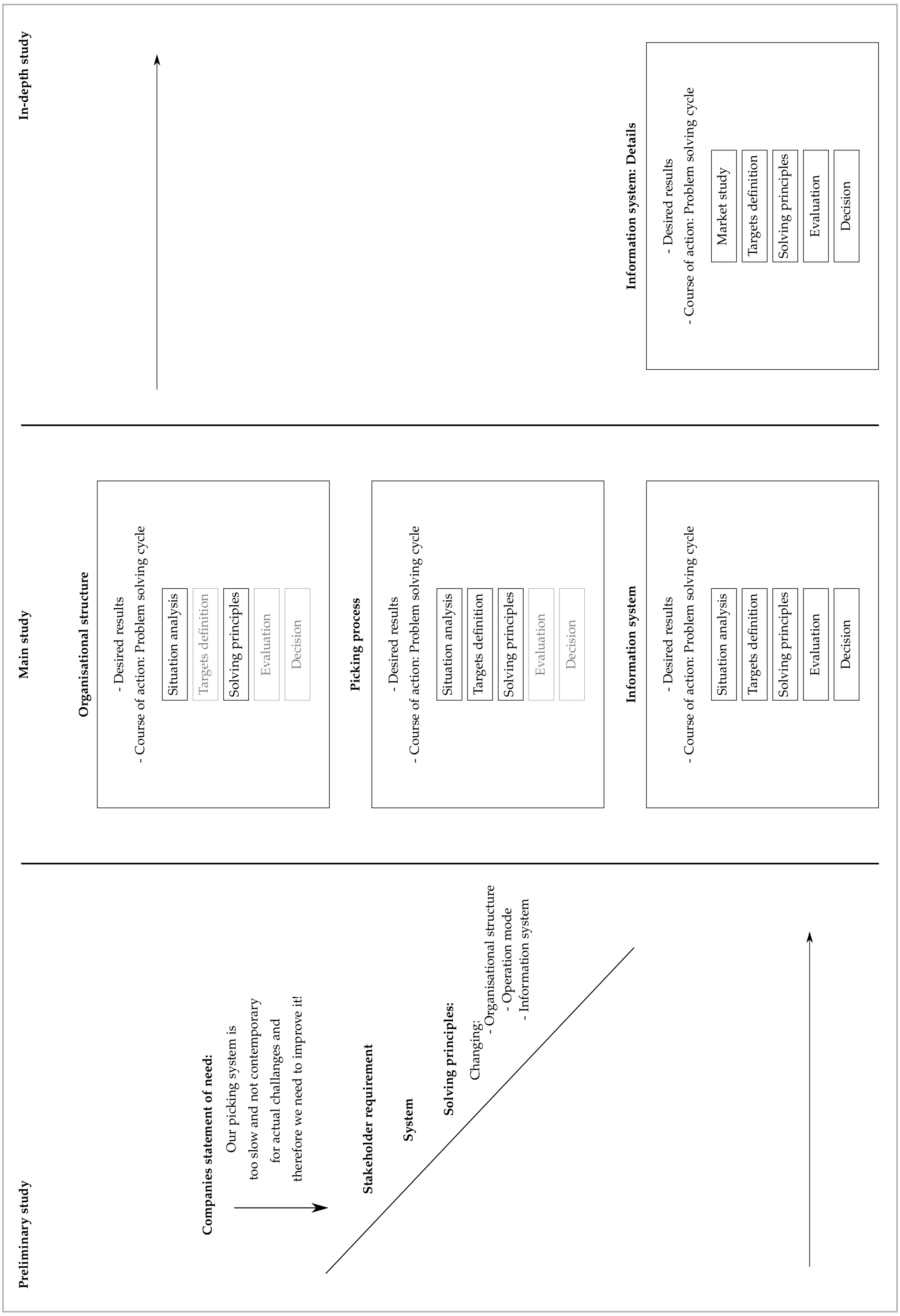

Figure 4.1: Modus operandi

4.3 Preliminary Study: Durst's Vision

For the assembly of the previously explained machines, many different materials are required and have to be provided efficiently. This requires material flow processes within the company and is a job for the intra logistics. That procedure was already improved in the last years by changing the fitters task of picking his own parts for main assembly to a partial supply. As the actual working mode is not contemporary anymore, Durst tries to improve it in order to stay market leader and competitive.

4.3.1 Stakeholder Requirements

This statement of need sets green light for starting a project to change the material supply which in this case is supported by systems and requirements engineering. The V-model shown in figures 3.4 and 3.6 starts by defining stakeholder requirements. Figure 4.2 shows how we are going to establish these requirements. The whole process starts by getting the customer's statements of needs which can be summarized by the task of improving Durst's picking system. A second starting input is the qualification strategy which is corresponding to the customers criteria if a system is acceptable or not and under which circumstances these criteria will be examined. In this case, a main element is the trigger releasing a picking order. This element can only be tested under real working conditions and therefore the qualification strategy is set on testing prototypes under real working conditions. Another qualification strategy is the scalability of the process up to 100% picking rate.

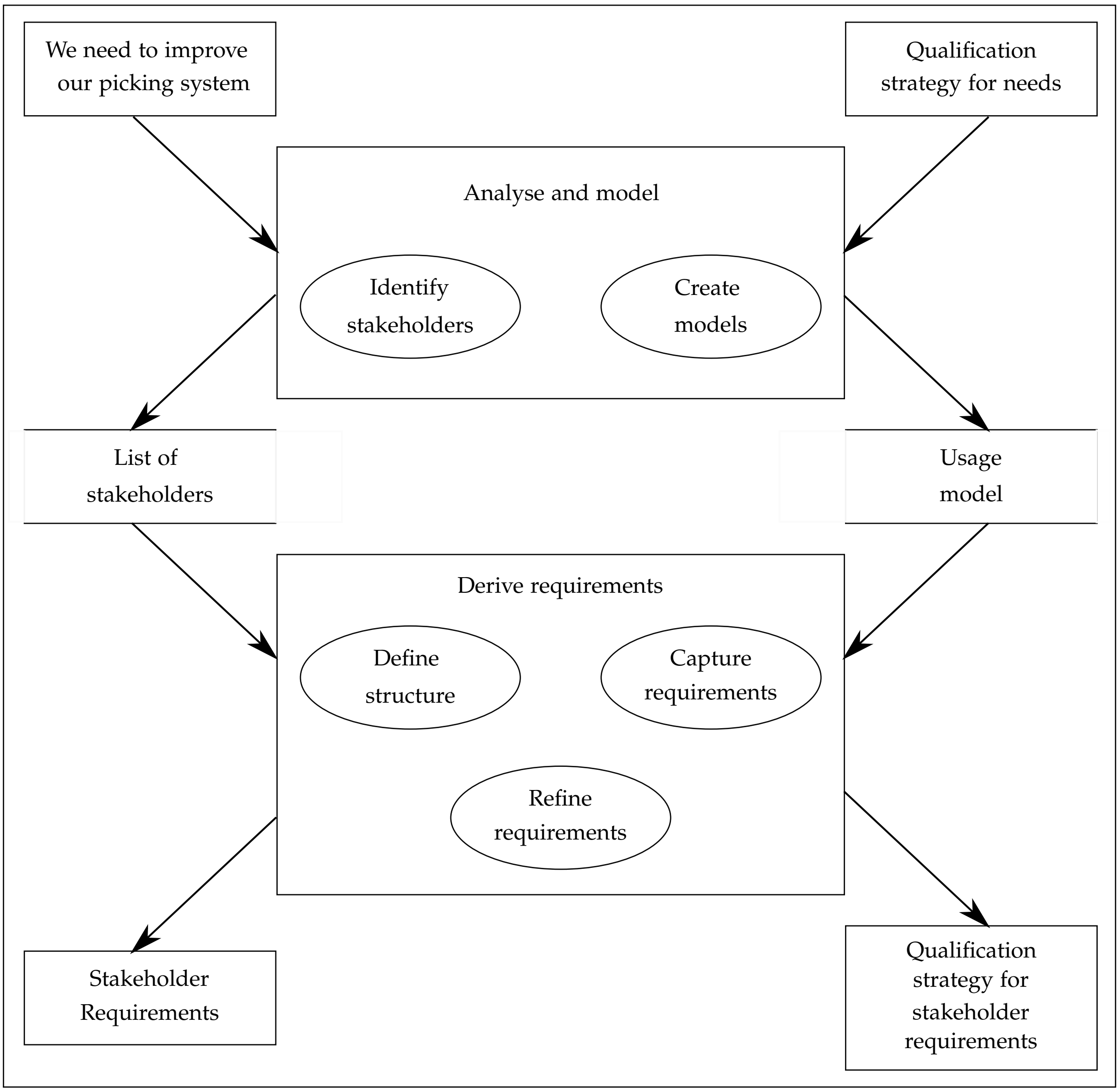

Figure 4.2: Project start: defining stakeholder requirements*=

*= In compliance with Dick et al. (2017)'s figure 2.5 at page 40

At this point the big project goal of improving the actual picking process is stated clearly and the analysis as well as the model phase can be started. First of all potential stakeholders are determined. In nearly every project, managers are main stakeholders: They have the responsibility for development and operation budgets on which the project relies. At Durst this main stakeholder is the COO responsible for the whole project, setting visions of working modes. A second stakeholder is the boss of the intra logistic department, responsible for humans working in that environment and for realizing the COO's expectations and visions. Here we are talking about a medium level manager more involved in daily business operations and working modes. The next class of stakeholders are the operators in the intra logistics department dealing with changes and using new systems. They have different expectations not necessarily corresponding to the management goals. This makes it difficult to elicit requirement from them as they are not open mined for changes, fearing more work or being replaced by machines. The last main group beside of external stakeholders (potential factors could be seen in figure 3.7) are the technicians and their supervisors of the different production lines. They require the material at a certain point of time and are dependent on the upstream picking process. Furthermore, a model has to be created which builds the basic for discussions and elicitation of requirements. In this case we decided to use a so called 'context diagram' which helps to focus on a goal by elaborating needed requirements.

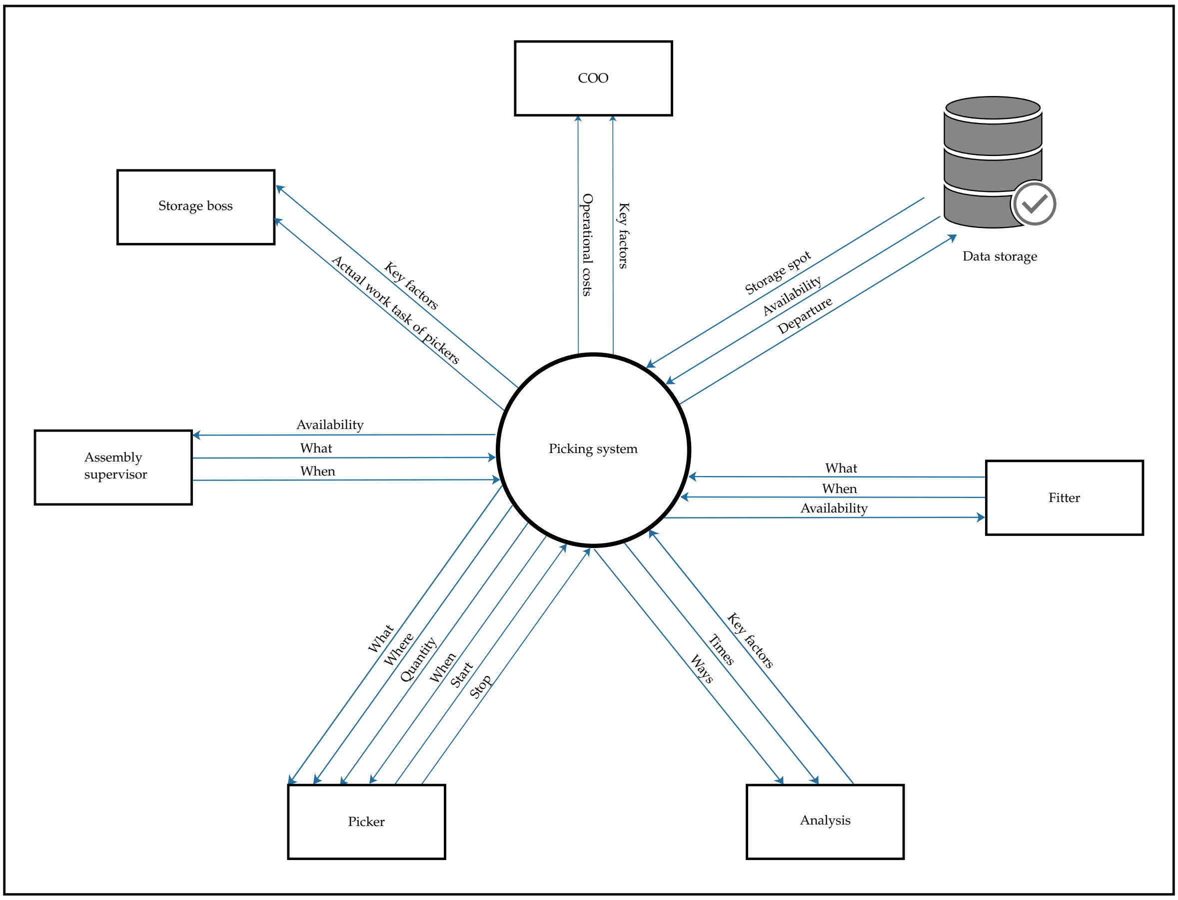

Figure 4.3: Data diagram to different stakeholders

Figure 4.3 represents such a diagram. The overall project goal is placed in the middle of it and stakeholders are defined as surrounding elements. Within this context, data storages and similar supporting elements are as well considered as a kind of stakeholders. The arrows represent connections between the elements as well as expectation, exchanges, or personal benefits that are expected due to the implementation. This structure is used for further discussions in all project levels. The structure for stakeholder requirements is chosen as a basic list not categorized as they should be clearly understandable for all stakeholders. Theory - as in section 3.2 described - says that requirements have to be measurable which at this level, in our opinion, is not mandatorily necessary, due the abstract level in the top-down approach. In following presented requirements have been elicited by a simple survey and person to person interviews in a casual discussion supported by figure 4.3 with detected stakeholders. The summarized output of it, is the following list:

- Using simple and approved technologies in order that systems are working smoothly and without errors.
- Setting a reliable trigger for starting the process right on time.
- Making the process transparent for management by gathering key values.
- Supporting assembly supervisors in preparation work.
- Costs less than 120.000€(these are the actual personal costs for two pickers in two years).
- Payback time less than two years.
- Scalable process with a ramp up possibility up to 100% picking.
- Small pictures of parts should be available beside article informations.
- Picked stuff has to be marked on the carriage (required for ISO certification).
- Material supply should go directly to the machine.
- Virtual storage guiding for the picker ('navigation system').
- Retrograde acknowledgement of parts is to eliminate.
- 100% picking by raising the performance.

These requirements are not providing many boundaries in order to narrow the topic down and therefore they are setting an open field of development and possible solution of improvement. In order to not lose focus, a system has to be established based on the system thinking and the usage of the top-down approach. Furthermore, some simplifications in order to reduce complexity are required.

4.3.2 System Formation

We have already seen, that there are many entry points and possibilities to improve the picking process. It depends on other departments, the way parts are stored, when and where the parts are needed, on the transportation system, the information system, the picking preparation and last but not least on the assembly or production mode. Starting with the work, we set extensive boundaries allowing us to get insights in all intra logistics areas. Various analyses helped to narrow down this topic. Reducing the complexity we decided to establish a system following the guidelines of the Hall and BWI Process presented in section 3.1.3.1. Therefore the focus is set on the two main intra logistic flow processes represented in section 2.1. In accordance with the SE guidelines we start with a top view increasing little by little the complexity. Figure 4.4 shows the system with two types of flows: The green lines are representing Durst's information flow and the black one their material flow. As we can see, the system is already really complex. Dashed boxes are representing elements that are not part of the system and dashed flow lines are representing connections to and between excluded elements. Focusing on included elements, the intra logistics material flow starts as soon as the supplier delivers the required material to the incoming goods department. At this station one man is responsible for the cognition of delivery. checking completeness and accuracy of the order. According to certain criteria the material is transported into the main storage, to the raw material warehouse or into the assembly line. Latter category is already at the required spot and the second group has to be picked before it can be supplied or, in case of kit products, it can be directly supplied to assembly from storage and first group is providing material to the mechanical production, which is not included in this thesis because it would go beyond the scope of it. which going beyond the scope of this thesis. As soon as the machine is assembled it is brought to the shipping department. Focusing on the information flow (green lines in figure 4.4), we can already see in figure 4.4 that most lines are leaving our system. Therefore informations are not bounded and require interfaces to subsystems and overall once as Enterprise Resource Planning (ERP). Figure 4.4 has no claim of completeness, it would lose clarity if everything would be considered and more details would not add any useful information.

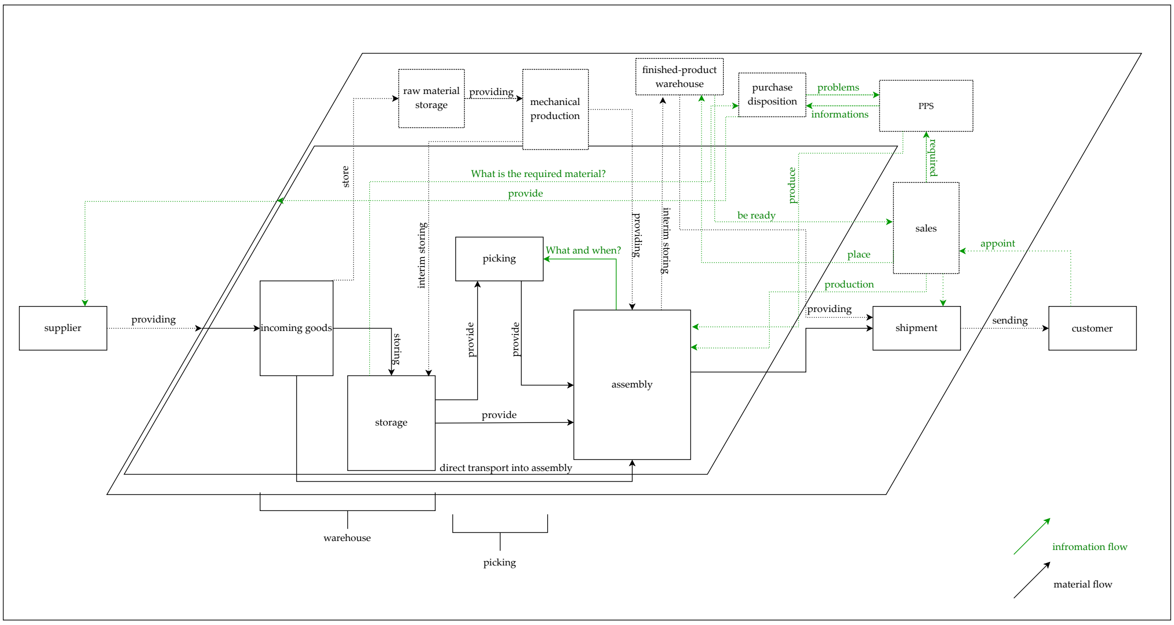

Figure 4.4: Dissolution of the system: material and information flow

4.3.3 System Simplifications and Information Problems

By describing our system we already set some boundaries but it is obvious that it is still too complex and has to be simplified further. Therefore we have decided not to exclude the type of production from the system and adapt our improvements to the current one. Still we have to take a closer look at it as it is fundamental for the material supply. Durst is a company producing customer specific variants of product types. This means that they have standard modules for certain tasks which are capable of customizing and assembling according customer demands. A high quantity of parts establishes a complex multi component product structure. Focusing on product demands machines have to be made on single orders, influenced by a mainly customer order driven disposition (a large storage would reduce liquidity and raise the risk of obsolete parts). Due to cost intensive production factors in South Tirol, the company decided to mainly outsource the mechanical production to specialists and focuses on core competences by raising flexibility in not bounding capital to production machines. Focusing on the assembly, Durst is producing small series on fixed-sites on an average number of two production levels. Therefore material supply has not to be batched for assembly lines, but always machine specific. These insights into Durst's production mode and its exclusion simplify the system somewhat, but the complexity of our system is still high. Reducing it further, we decided to exclude even the incoming goods department. It is obvious that the picking process is mainly influenced by the way of storing goods and by the different storing strategies as figure 2.2 shows which are determined by the incoming mode of goods. Actually one single man is accepting all deliveries, controlling them after certain criteria and booking them into the system preparing goods for the manual storing process. Subsequently, others are taking the goods to the right previewed storage spot, if there already exists one in the system. Otherwise another man is taking the goods into custody, looking for a free storage spot manually and assigning it to the part.

4.3.4 Solving Principles

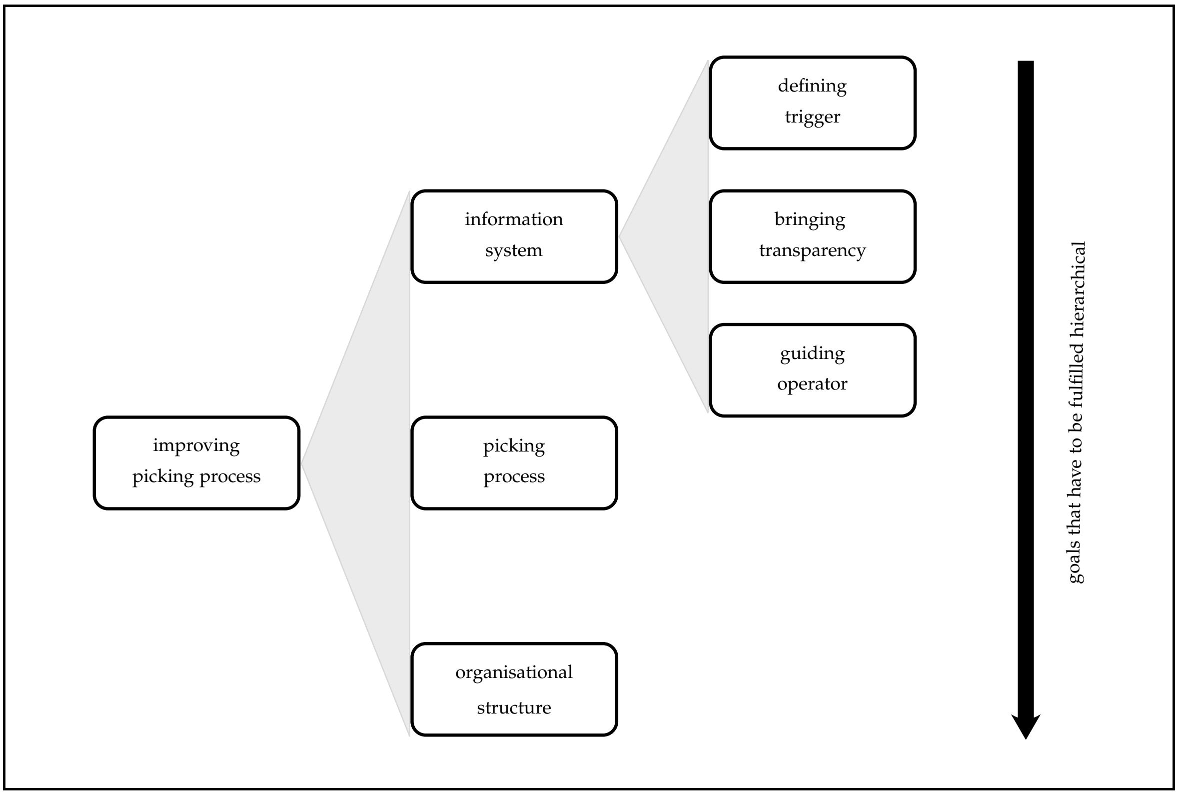

Figure 4.5: System goals in a hierarchical fulfilment order

We can now see two main starting points for improvements. On one hand the material flow and on the other the information flow in the picking process. After a short literature review in ten Hompel, Beck, et al. (2011) a third possibility is offered by improving the organisational system on which storing technologies and depending organisation are relying. Here are short descriptions of the three basic solving possibilities:

- Organisational structure: the focus is on controlling the logistical processes and influencing the dependent structures. This determines the type of cooperation and the basic forms of the warehouse structure. Usually this improvement area is divided into the fields of organisational structures, process and business organizations.
- Picking process: this field is addressing the physical compiling of picking orders. Changes on it requires adaptations in infrastructures and supporting technology. Adapting it, stakeholder requirements of higher performance may be fulfilled.
- Information systems: changes on that system would improve information handling and in this case addressing most stakeholder requirements by making the actual process transparent, triggering it based on a defined actuator.

4.4 Main Study

Previously we mentioned different possibilities for optimizing intralogisic processes by splitting them into material flow, information flow and organisational structures. Due to the fact that there are many possibilities, we decided in consensus with Durst to focus mainly on the information flow and to some extents of the material flow. In the following section we will also introduce a study on organisational structures and the material flow's components of picking. Figure 7.3 offers a complete overview of possible improvement solutions. Thereby the claimed complexity can be seen by the quantity of different improvement options. In chapter 2 we have already seen the two basic types of flow processes: the material flow represented in figure 2.4 and the bidirectional information flow (figure 2.6). Figure 4.6 presents the combination of those two processes and how they are interacting.

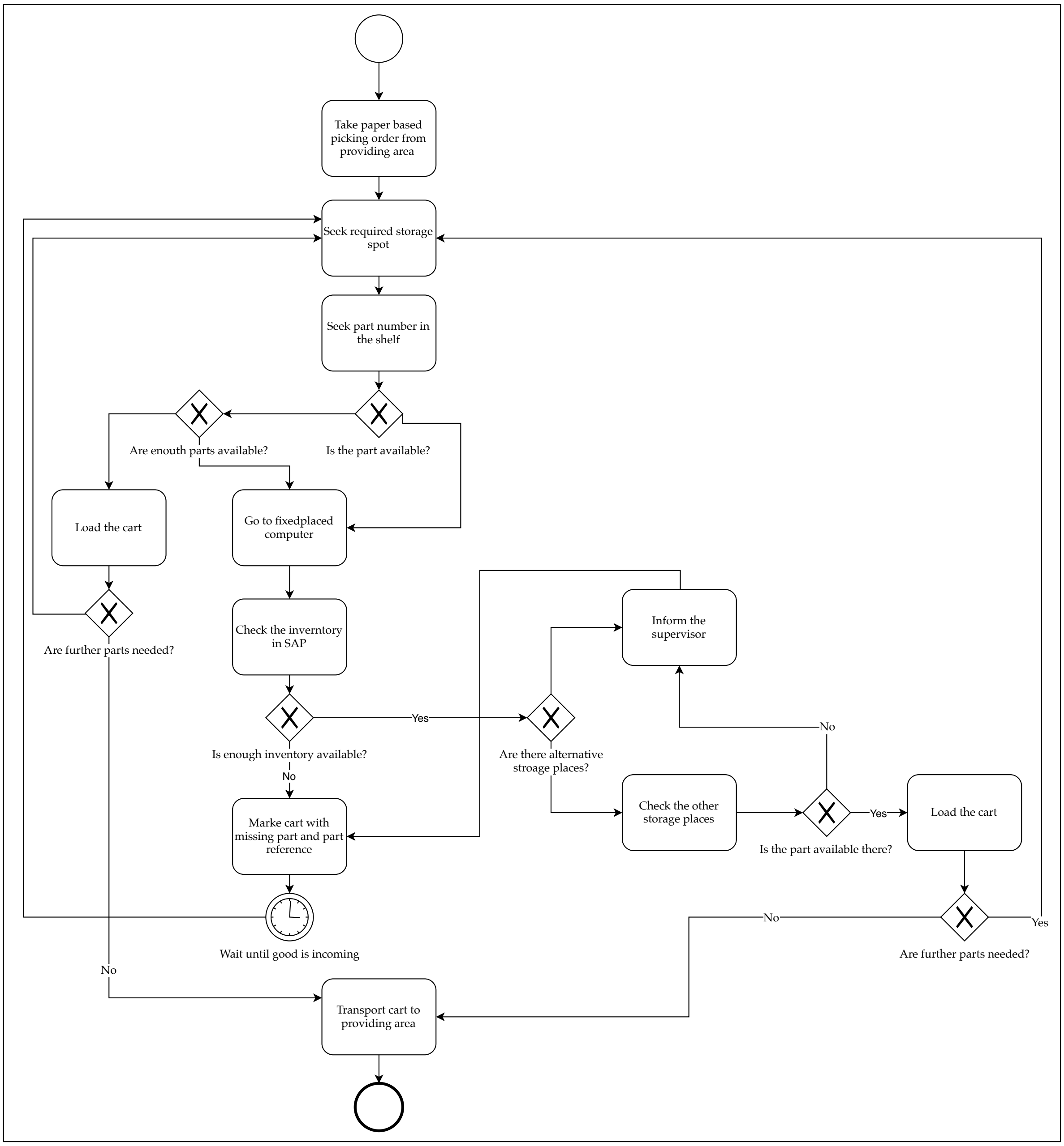

Figure 4.6: The actual picking mode*=

*= Elicited by assisting in the intra logistics at Durst

4.4.1 Organisational Structure

As we already mentioned the first possibility would be to improve the organisational structure which is addressing possible changes in actual process arrangements. For the picking process we distinguished the three functions of organisational structures, process organisation and business organization. According to ten Hompel and T. Schmidt (2010) there exist different possibilities to improve the first category offering various settings for the type of articles staging and for the connection of different systems. Single zoning is the use of only one zone with the same structure, the same technology and the same category of parts. Such a zone could be an automated high rack storing everything in boxes. A company like Durst is working with different article categories and therefore it is not any more efficient to only use one zone. It is easily imaginable that large parts stored aside small parts would downgrade the space usage of actually 17.13% and the land utilization of 37.25% which would raise the yearly storage costs by closely 200€/m². Therefore it is advisable to use a multi-zone strategy dividing parts by technical or organizational properties. Another option would be focusing on the picking process trying to optimize the picking time by minimizing the time slices of road and bites. First of all it has to be decided if a singe stage process is sufficient or a two stage process should rather be used. Which of the two should be used is heavily influenced by the storage size and the organizational structure. In big warehouses with multi zones it is better to use a two stages process because thereby an order can be picked by different people profiting of area experience or technology support adapted to articles. This makes it possible to minimize roads and put a picking order together in a later process step. Usually it is used in 'men to goods systems' because way time is minimized and picking time optimized due to the learning curve. If a warehouse is small with a high turnover rate accompanied by a high level of customer satisfaction, limited range and small orders, it makes no sense to uses this kind of strategy because it would not bring any of the presented advantages, but lower lead times due to unavoidable waiting time between two processes. Next the question should be answered, if it has more sense working parallel by serial by orders. This depends on the used stages, on the order sizes, on the way time, on the customer, on the warehouse technology and last but not least on the article themselves. It is not easy to batch large picking orders

with many large parts for single customers. In such a case a two stage process is not very useful but a single stage one with serial order's processing should be preferred, giving an advantage in avoiding high bite times and an exhausting work repeat. The parallel order operation focuses on a two steps process with small parts, in big warehouses with high road times. Operating with a multi zone system brings the advantage of working in parallel zones reducing lead times. At this point we can already see the complexity and variety of possibilities of optimizing a simple picking process and the relation to customers. In this context, customers are either consumers, other companies or in house users which makes the dependence of the picking organisation to the business goals obvious. Therefore the surrounding of a new introduced process has always to be taken into consideration. Small companies with a lot of manual work are not optimizing their processes due to high improvement costs and the necessity of skilled personal. In order to keep this characteristics in this thesis low, an non optimized systems is processing orders static (in the order incoming sequence) an a optimized system changes the sequence regarding certain criteria. Digitalization helps to gather data and for this reason it commonly presents today the starting point for potential improvements. Partly digitalized systems or completely digitalized applications are already in use optimizing order processing by not utilizing chronological order input. In completely manual systems sometimes an experienced worker or the assembly supervisor tries to fulfil this task often losing the overall view due to raising demands and working loads.
Last but not least the steering mode of the company plays an important role as it can be supervised by a central steering person or by many different decentralized people. Currently Durst is working with the decentralized structure organized by the different assembly supervisors. Figure 4.7 summarizes the described process. Currently Durst is working with a multi zone organizational structure divided into organizational areas with a single stage processing serial order in a serial zones process. Durst is trying to optimize this proceeds, but as the complete process is not transparent to the management, it is hard to measure improvements. Therefore, first of all, it requires to make actual processes transparent and to gather usable initial data as run-times or performances based on a widespread database.

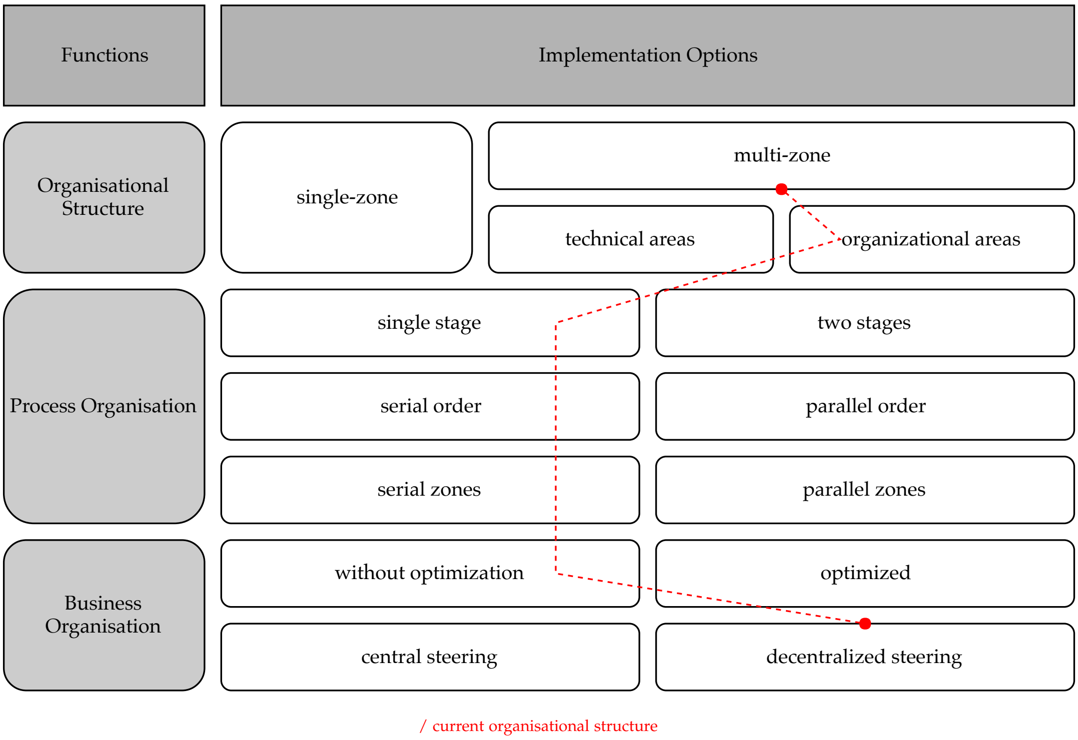

Figure 4.7: Morphological Scheme for the Organisational Structure*=
*= In compliance with ten Hompel, Beck, et al. (2011)'s table 3.5 at page 33

It is not the goal of this project to change organisational structures because time frames are placed too strict and the appropriate informative value of data is missing. Therefore other steps of the problem solving cycle are not of interest at this point and figure 4.7 can only be seen as a starting point for developments in the future. Figure 4.5 shows that the recommended system changes in a chronological structure. Starting point for deeper developments is the information study with an accurate process trigger, a transparent approach and possible guiding, followed by the picking processes and organisational structures studies. Obviously this thesis is structured in a different non chronological way focusing first on later recommended steps in order to clearly state the dependence of the three sectors among each other.

4.4.2 Picking Process

In this section the focus is set on the picking process and the recommended actions. As method the problem solving cycle, described in section 3.1.3.1, is used up to a certain point as already mentioned in section 4.2.

Actual Picking Mode

The actual picking process forces long roads due to the still standing transport mediums and the transport of single articles or parts to the medium. For understanding that problem and in order to get a feeling for the road sizes it is important to get some insights in Durst's hall layout. Figure 4.8 shows a bird's eye view of the plant in Brixen[2]. The red lines are representing the material flow of parts purchasing for assembly. On the left side of figure 4.8 lorries are unloaded, material is brought into the storage, then to the assembly and finally to the packaging as well as to the finished parts are stored on the right side, where the trucks finally are loaded by forklifts fulfilling material flow functions like picking, presented in section 2.2.1. Figure 4.9 shows the inside of the plant. The orange zone represents the mechanical production area, the beige area represents the main storage, the violet area represents the assembly, the turquoise area the actual demo centre, the brown area the finished goods storage and the blue area the raw material storage for the in-house mechanical production. On this picture we can not see storage places in the assembly area but shelf's are giving us an idea of this additional space. Such a fragmented warehouse requires to analyse the maximum piking ways and picking time distribution on different areas. Analysing picking orders and searching for biggest distances the picker has to accept up to 250 meters between different articles spending at least 3.3 seconds on the way (approximately three meters). This value is detected by using an average going speed of 3.2km/h calculating the time:

$$time = \frac{road}{average\,speed} \tag{4.1}$$

[2]source: google maps

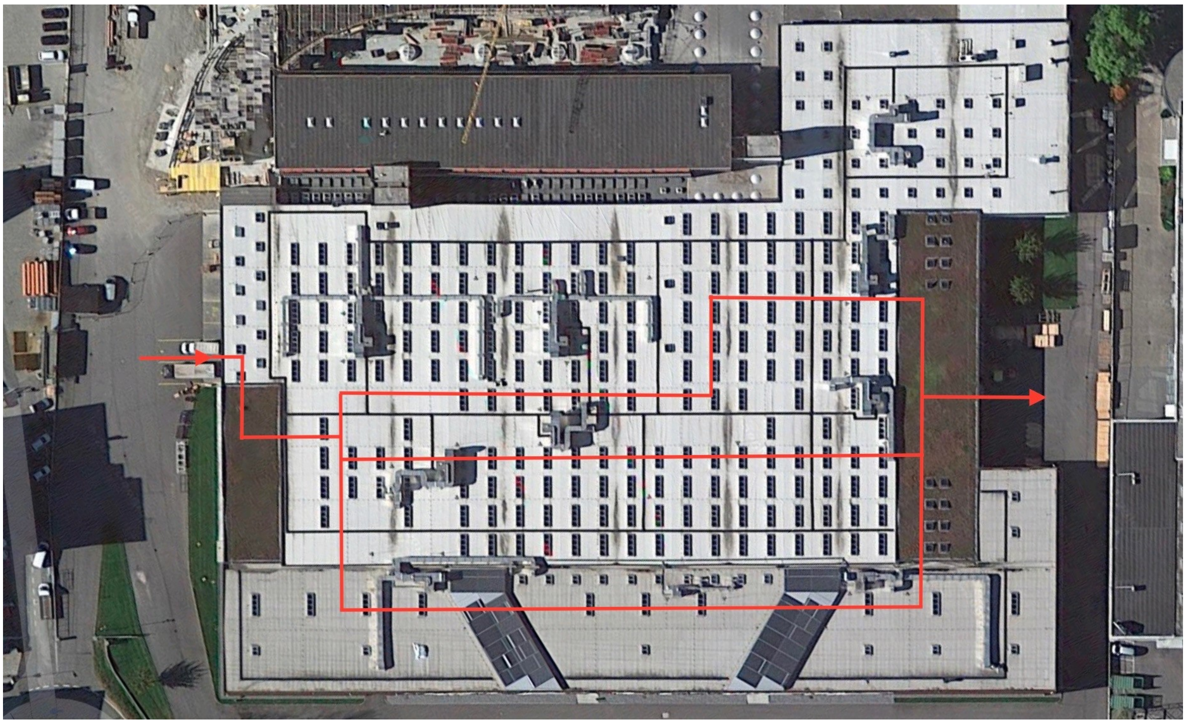

Figure 4.8: Durst's material flow over the exterior view

$$t_{max} = \frac{250[m] * 3.6}{3.2[\frac{m}{s}]} = 281.25[s]$$

Figure 4.15 demonstrates the share of time where the picker can be found. This analysis is based on the access quantity on shelves over the last year for picked articles marked in the ERP system with a 'k' (not standard) and by spreading text data up for locations, assigned to storage areas and summed up to single storage area values. However, there is a inconsistency within this study due to inaccurate data for this and similar studies. Material management is based on articles and not on storage spots and therefore access quantity of multi spot material is always assigned to the main storage spot and not to the one actually used. This study is a good example for not having adequate data for certain analysis and this requires field verifications on determined time frames with limited process insights. In figure 4.15 fields marked green are warehouse zones and assembly areas are marked in orange. Summing this figure up, the picker spends approximately 67% of the time in main storage locations and 33% in the assembly areas. Focusing on the beige main storage area, there are 1838 m^2 available, guaranteeing a storage capacity of overall 9775 m^3.

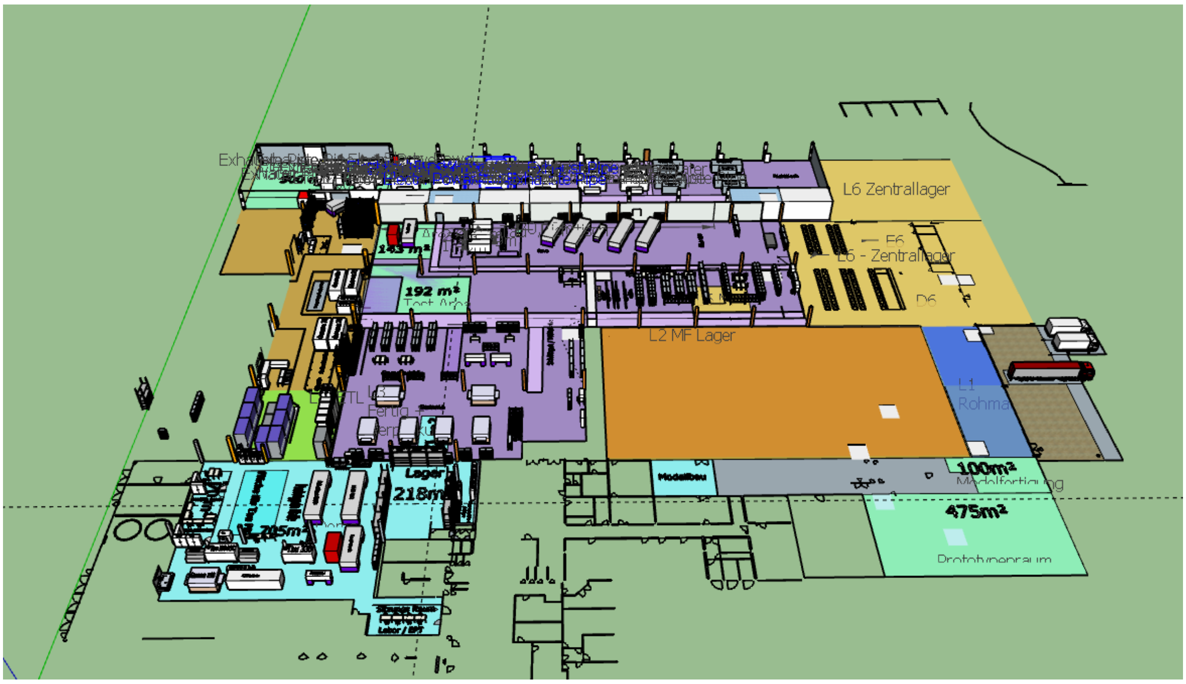

Figure 4.9: Durst's material flow over the internal view

With only a space utilization level of 37.25% and a use of space with 17,13% there is capacity available in order to get rid of picking areas within the assembly and reducing ways for picking parts. The room usage offers potential for shrinking ways but requires expensive structural changes in storage technology. Another sign for bad organized warehouse is the turnover rate[3] detected over each rack and visualized in figure 4.10 demonstrating the result of an organizational study. Thereby we used the SAP integrated value *'Turnover Rate over Valuated Stock'* recorded over one year and summed up for each shelf. Red collared boxes have a high turnover rate (up to 260 not counting the floor storage areas) and green ones with a low rate (0.02). It is obvious, that the storage is not organized on turnover rates trying to reduce ways by raising total picking performance or other storing strategies presented in figure 2.3.

But why is it so important to reduce ways for picking process optimization? According to Wisser (2009) between 10% and 35% of the overall picking time is owned to dead time. Between 25% and 35% go to the handling time, between 40% and 60% go to the road time and between 5% and 10% go to the basic time (Logistik KNOWHOW,

[3]turnover of a particular stock value/value of average stock

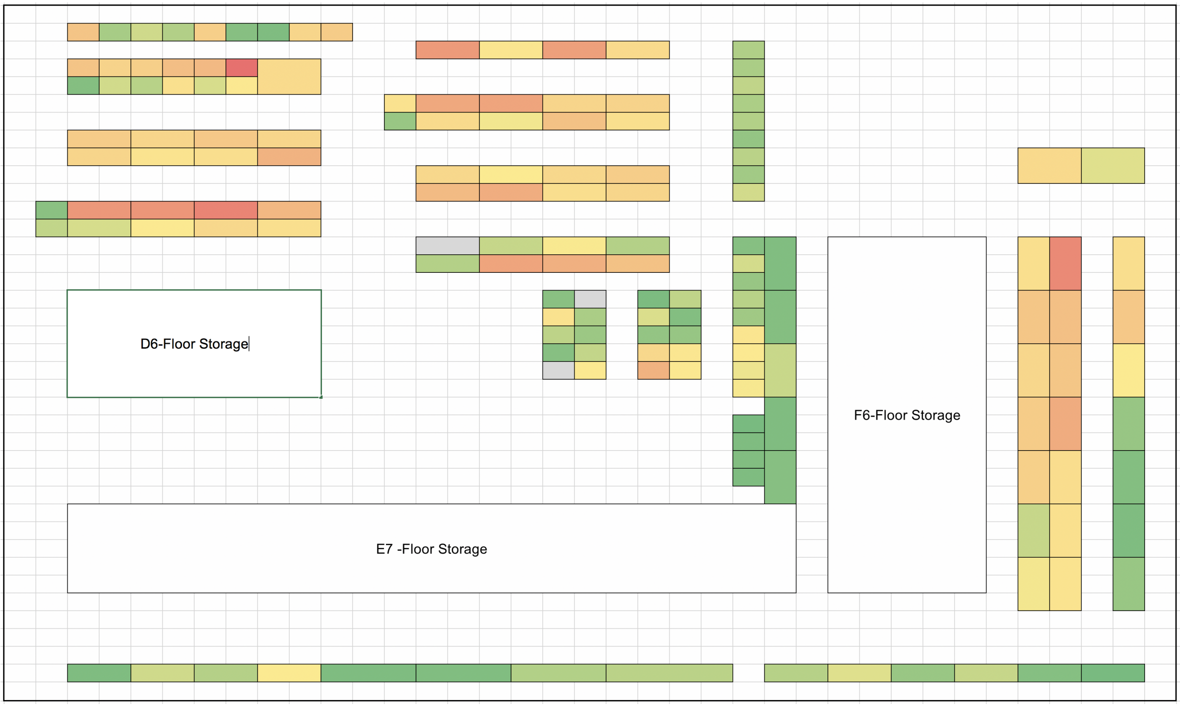

Figure 4.10: Turnover-rate in the storage - indicator for picking quantity on each shelf

2017). Optimizing the way would improve the whole process, minimizing the lead time and optimizing the performance.
Another kind of waste is the fixed placed tranport medium making it necessary to return to the base after each pick. Sure, the quantity of returns depends on the part sizes and weight because smaller parts are collected with carts and loaded afterwords on final picking mediums (organisational study: two steps process). Therefore the previously made statement is too general but should call attention on this behaviour. We are talking of transport mediums in plural because one picking order is not restricted on a certain transport medium number and preparation quantity based on experience addressing the lack of transparency for untrained operators for not knowing their exact working tasks. Until now only the standard process of finding the part at the right place is described, but figure 4.6 shows some grindings for casual unpredicted problems. As soon as the picking order is prepared, the load has to be transported to the providing area like the intra logistic material flow shows in figure 2.4 and making parts available for assembly. Here the two processes split up to line specific working modes. Orders required for the gamma line are transported by the

pickers from the storage to a non-machine specific area near assembly while *Alpha* and *Rohtex* parts are stored in a warehouse sector. For *Roh* and *Tau* the providing location is given based on experience, because some orders are brought directly to the machine assembly, others stay in warehouse and the rest is brought to a small providing areas.
Figure 4.11 shows an analysis of actual picking quantities. Dates, times, numbers and related order references have been gathered over two weeks giving insight into the actual working performance, modes and problems as base for further analysis.

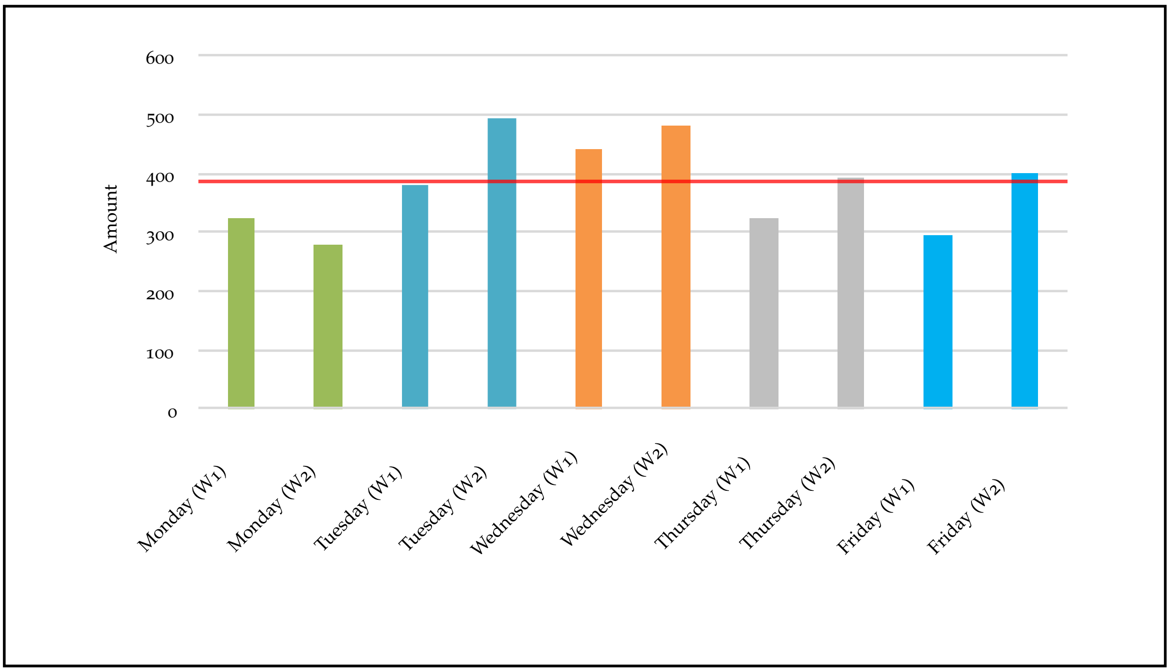

Figure 4.11: Analysis for picking quantity

Picking Problems Summary

Since the above process analyses do not clearly define all problems, they are briefly summarized below:

- Long ways due:
  - fragmented storage

  - not parts arranged storage spots
  - required media has to be transported separately
  - fixed placed transport medium
- Badly arranged storage spots are raising lead times.
- Line specific processes are requiring different specifications reducing transparency.

Picking Requirements and Goals

During the determination of the stakeholder requirements the need for improving the actual, physical working mode is claimed as one important factor for this project. Therefore, similar by the stakeholder requirements, the system requirements for the picking process are developed. As input factors stakeholder requirements are chosen and combined with the as-is analysis as well as with the found problems, requirements and goals are elaborated. Following the requirement analysis a model is established, shown in figure 4.12. It is obvious that such a system depends on infrastructures, storage- and supporting technologies. A typical picking process starts with the material supply for the process, then the picker is fulfilling his task by extracting units from provided material putting it together to picking units. As soon as this task is fulfilled, the goods can be returned to the related area.

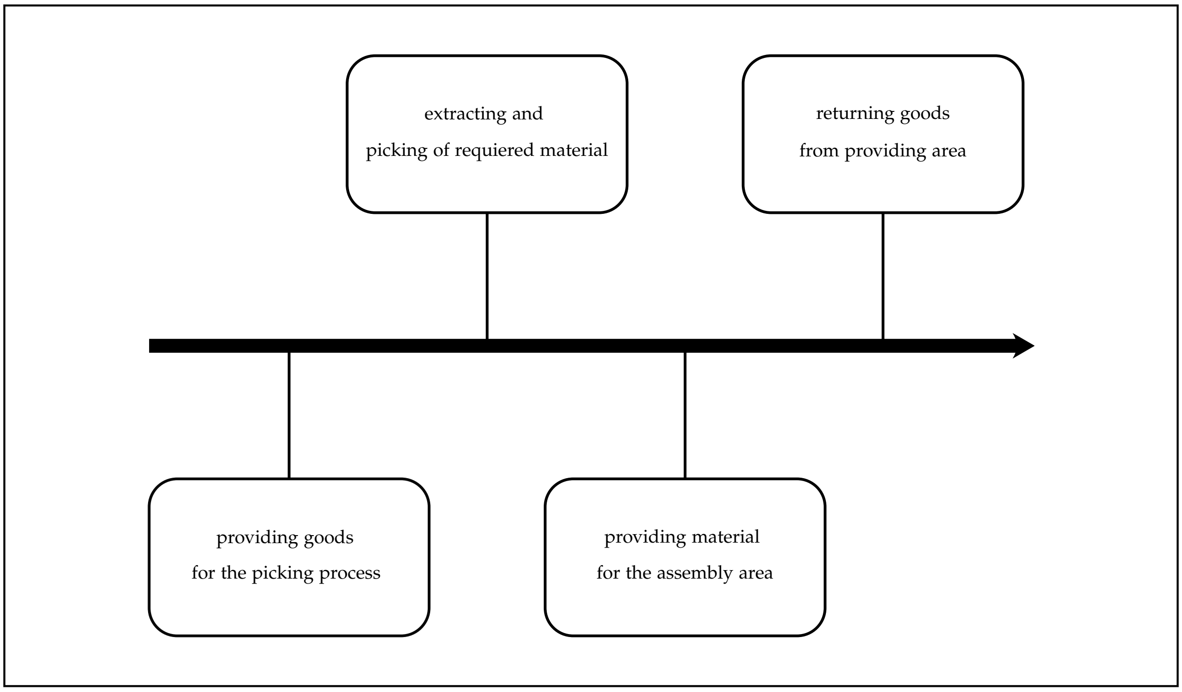

Figure 4.12: Process model for picking

It is already claimed that ways have to be minimized in order to fulfill customers demand of making process scalable and reaching a 100% picking quote. With these requirements and goals in mind different movable options can be compared against each other: First - as in a person to good system - the movable part is the person, alternatively the movable part is the good in goods to person systems. Actually picking one article takes 1:44 minutes[4] in the person to goods system which was verified by stopwatch and time lists for pickers. This research can not prove the theory of Wisser (2009) because with the actual average picking time of 1:44 minutes and way times between 0:03 minutes and 4:05 minutes, no meaningful share of road time can be determined (mainly more than 65% of the time share). However, due to weak data bases and therefore non adequate analysis, this difference could be explained.

$$\sum Picking\ time / \sum Picked\ articles \tag{4.2}$$

Assuming that one picker works eight hours each day, approx. 320 articles per person are possible. Looking at the actual value each person picks on average 190 articles

[4]This time includes the basic time, the moving time, the action time and the death time.

(shown in figure 4.11). Taking into consideration that only 27% (explanation in section 4.4.3) of needed material is picked and further assuming that a picker has only 285 minutes of picking time available and the fixed number of actually two operators, the picking time has to be reduced to 0:28 minutes fulfilling stakeholders demand of 100% picking.

$$Actual\ Picking\ Time * Percentage\ of\ Picked\ Parts \tag{4.3}$$

$$1 : 44(min) * 0.27 = 0 : 28(min)$$

Due to the fact, that most time is owed to ways, they have to be reduced in first place. Focusing again on figure 4.12 a combination of must and could functions can be detected forming functional requirements for the system. Following list represents them chronologically:

- Goods are moving to the providing area (could)
- How the goods are available on the providing area for the picker (must)
- The picker movement on the providing area (could)
- Modus of taking goods out of the providing medium (must)
- Transportation of the extraction unit to the delivery (could)
- Modus of delivering the extraction unit (must)
- Transportation of the picking unit to the providing area (could)
- Modus of delivering the picking unit (must)
- Returning goods from the providing area (could)

The here represented functional requirements are the basis for finding different solution options in the following problem solving cycle steps. The solution has to fulfil must functions while could functions are only optional. Summing up elicited requirements from both developments stages, following list can be established:

- Costs less than 120.000€.

- Reducing picking time to 0:28 minutes per article enabling 100% picking.
- Change storage layout reducing ways.
- Setting up standardized processes for all lines.
- Defining picking process where storage medium is not fixed placed in order to reduce times.

Picking Functions and Implementation Options

Section 2.2.2 provides us with two main strategies on how to pick: the person to stock strategy and the stock to person strategy. Thereby we can identify different moving elements. In first case the person is moved and goods are resting unmoved or are only moved to a providing area. Books as 'Kommissionierung' (ten Hompel, Beck, et al., 2011), 'Fahrerlose Transportsysteme' (Ullrich, 2014), 'Inustrie 4.0 in Produktion, Automatisierung und Logistik' (Bauernhansl et al., 2014) and journals as 'Materialfluss' is showing a trend to fully automated systems for the realisation of new projects. Taking this into consideration and combining this knowledge with detected requirements, we established figure 4.13 with the help of ten Hompel, Beck, et al. (2011) and ten Hompel and T. Schmidt (2010). First of all there are identified different general functions for the picking task. At the beginning of this analysis the question of the providing mode is raised and represents also the first function. Implementing this option we found two main possibilities: let the parts where they are so no motion is necessary or moving the parts to a providing area. For moving there are offered various options: beginning with the motion dimensions, a regular room gives us the three alternatives of one-dimensional, two-dimensional and three-dimensional movements. Next, the activity type can be classified:

- manual: *'worked or done by hand and not by machine [...]'* (Merriam-Webster, 2018b). In this context articles are moved around by persons supported by handcarts or similar machines.
- mechanical: *'of or relating to machinery [...] or tolls [...]'* (Merriam-Webster, 2018c). Another word would be semi-automated. This is an option in the sense of

industry 4.0 as human and machines are working hand in hand together. Today it is realised by human-supervised or -steered machine utilization like forklifts, picking stations or similar gadgets.

- automatic: *'having a self-action or self-regulating mechanism [...]'* (Merriam-Webster, 2018a). Humans do not take actively part in the motion activity. Only machines are moving around autonomously.

The second function identifies the supply possibilities in the sense of how stuff can be found for picking. Therefore two ways are possible: the static supply is characterised by a non-movement of parts between storage and removal while the dynamic supply is characterised by a transport of goods between the two previously named processes (Timm, 1973). A related topic is the central and decentralized supply dividing between fix picking spots next to each other (central supply) and picking spots spread out across many places. Combining this two supplying possibilities it can be found four providing applications:

	static	**dynamic**
centralised	picking nest	rack front at an automatic small parts store
decentralised	shelving rack storage	hay-bay pre-storage area

Different possibilities of storing, warehouse technology and related explanations can be found in section 2.2.1. The last distinctive feature is related to a level or value of arrangements dividing storages into sorted, semi-ordered and unsorted. Usually manual systems are working with multiple levels in conflict with automated ons, usually based on one level because technologies, IT systems and working modes have to be adapted requiring expansive changes. Next function 'picker-motion at the providing area' is dedicated on how the picker moves on this area and is depending on how goods are supplied for picking. It is obvious that a picker has not to move over a picking area if he gets supplied with goods at a central picking station where he can put stuff from box to box. The implementation options for motion are similar to the ones of 'goods moving to the providing area'. As soon as the picker has found the required part he has to take it out from a box, shelf or similar providing medium and therefore the function 'extraction' is established. It can be done either manually, mechanically or fully automated. First possibility requires a human doing it by man power, second one is a cooperation between human and machine, and the last one requires only a machine for task fulfilment. It is easy to understand the complexity in this morphological scheme because some previously made determinations are excluded later choosing options by logic. For a further implementation option for these function, it has to be decided between single or multi cargo. Single cargo is a union of one complete transport medium as one euro pallet or a carriage while multi cargo is used for extractions loaded more than one transport medium (Philipi et al., 2011, p.173). After extraction the unit has to be transported to a delivery station representing the fifth function. The different implementation possibilities are similar to the first function extended by the option of who is performing the motion. Thereby we can distinguish between the picker himself or different options of subsidies with various levels of automation. The next functions are the 'delivery of the extraction unit', the 'transport of the transport unit to the delivery', the 'delivery of the transport unit' and the 'returning of goods from the providing area'. Figure 4.13 summarise the now described structure and gives a good overview of all options without promoting usable gadgets.

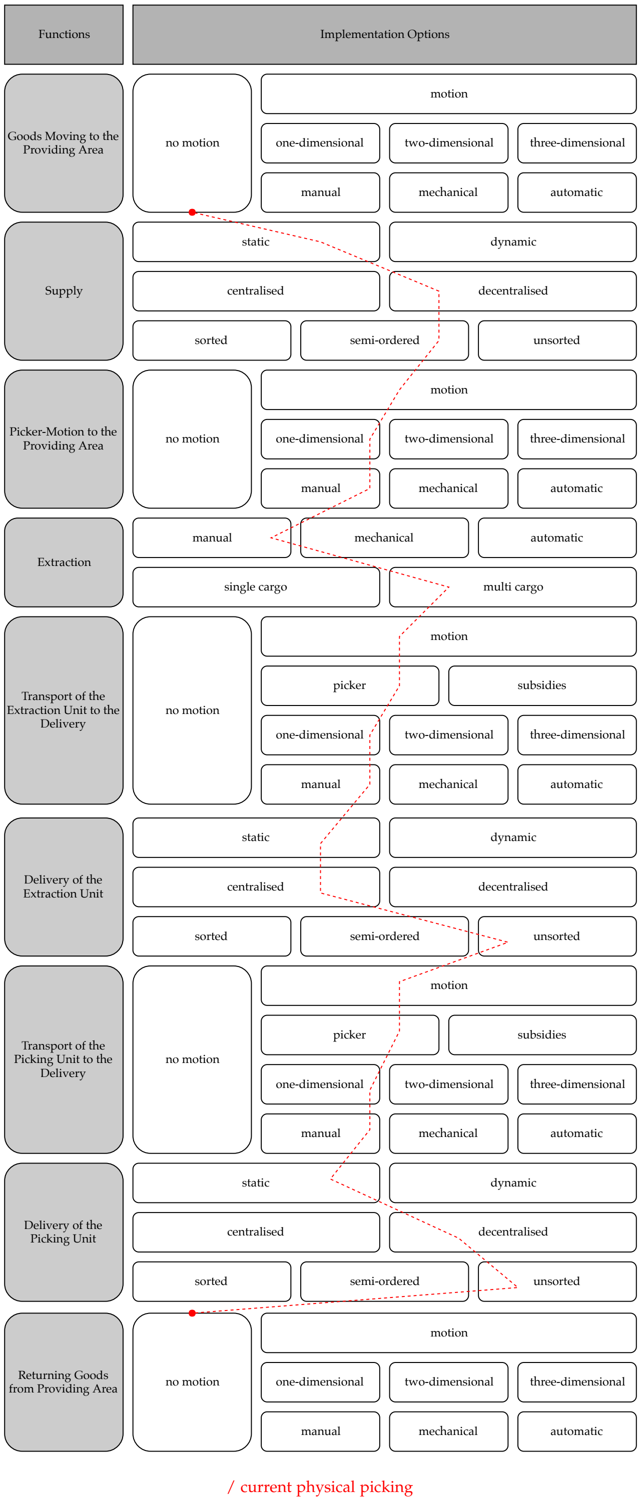

Figure 4.13: Morphological Scheme for the Picking Process*=

*= In compliance with ten Hompel and T. Schmidt (2010)'s table 2.5 at page 36

Picking Implementation Option

Basic functions and possible implementation options are now structured in a morphological schema combining solution possibilities from row to row variants can be created. If the schema has been developed for change or improvement projects, the current process can usually also be found. Categorizing the current one at Durst yields figure 4.14. As in the section 'actual picking mode' is described, goods are standing-still in the storage and are not moved for picking determining a static decentralised (splitted storage) semi ordered product supply. In that area a picker is moving around, extracting units and transporting them manually and one-dimensionally to the still-standing centralised transport medium and loading it on the carriage. As soon as all needed parts are picked the carriage is brought by man and one-dimensionally to the picking delivery, defined differently on each production line. Other options

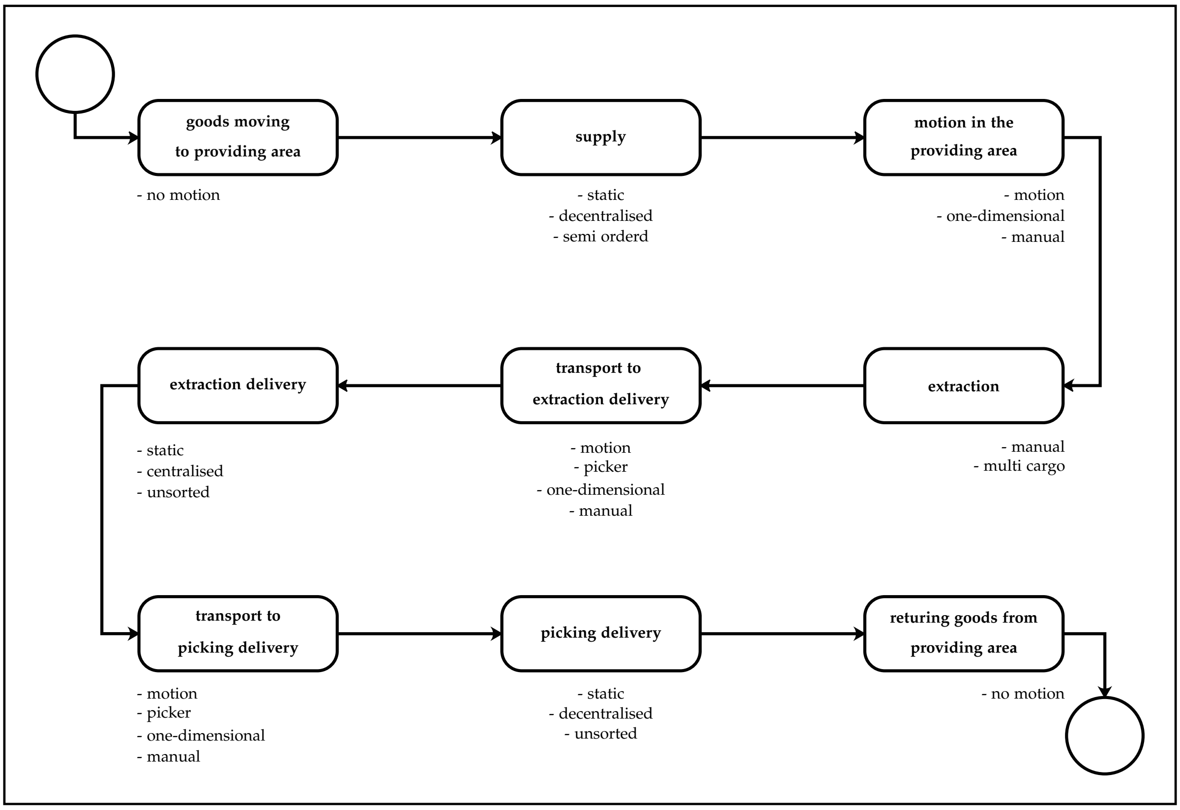

Figure 4.14: Durst's current physical picking mode

are not analysed due to the fact, that the customer is focusing in first place on the information system. Developing a new picking system would go beyond the scope of this work as some million implementation options (approximately $1,76x10^{12}$) would be possible (shown in figure 4.13) and for the required implementation arguments the provided data is delivering to low quality and therefore misses even required transparency.

4.4.3 Information System

In order to get the required process transparency the focus is laid on the main information study. As figure 4.4 proves, beside the material flow, there is the information flow delivering a process support for the individual tasks. They are triggering and starting all processes, letting different persons know what to do and how to do it. Therefore they are fundamental for an increase in value during production and even required in order to fulfil the seven main goals of logistics:

- the right part
- at the right costs
- at the right location
- at the right time
- with the right quality
- in the right quantity
- with the right information

The last goal is reached as soon as all necessary information is gathered before starting with the next step.

Actual Information System

Figure 4.6 demonstrates the paper-based picking process at Durst. Basically the assembly supervisor prepares structured lists regarding the needed material. These lists are then brought from the office into the storage where a picker scans the lists and based on his experience prepare the required transport mediums. The loading arrangement is already defined, but information of right practice is also based on experience. Afterwards he starts to go through the lists by picking parts. Thereby starting point is the shelf with lowest number. Taking a closer look at the picking list, parts are sorted as letters and not as numbers and therefore it starts with number one followed by ten, eleven and so one. The reason can be found in the sorting algorithm comparing always the first byte and if they share the same value next number is taken into consideration.
If during material picking a part is not available or too few are available on the main storage spot, the picker has to go to a fixed place terminal checking possible other storage places and availability of missing quantity (see figure 4.6). If all those criteria are fulfilled, he goes to the place and picks the needed parts. In case of missing parts, he has to print another picking label, mark the specific part as missing on the transport medium for the fitter and check iteratively availability. As soon as it is available, the function 'delivering in addition' has to be performed.
When visiting Durst's storage, one of the first impressions is that picked stuff is blocking shelves slowing down the picker when forcing him to remove carriages in order to access needed parts. Therefore we decided to analyse the stand still time in different sectors and table 4.1 shows the result for loaded carriages stored in sector F6.
Table 4.1 shows the average standstill time of approximately four days which is nearly one working week. Taking only this value into account, would distort the real behaviour by taking all outliers into consideration. Therefore we have even to consider the median, splitting the higher half of data sample from the lower half. This illustrates that 50% of carts are packed within less than 2.7 working-days and demonstrates, that a few carts have a really high standing-still time raising the average so dramatically. This data has been recorded within two weeks, equipping picked boxes with the exact times, reference and picking request numbers. After two hours

Table 4.1: Standstill time in Alpha- and Rohtex-Section

	Days	**Hours**
Average	3.79	90:85
Median	2.77	66:30
Quantile 0.6	3	72:00
Maximum	20.72	497:21
Minimum	0.19	4:30

Table 4.2: Standstill time in Gamma-Section

	Days	**Hours**
Average	3.63	87:00
Median	3.47	83:20
Quantile 0.6	4.34	104:12
Maximum	6.46	155:00
Minimum	0.23	5:30

carriages are controlled and checked, if they have been taken for assembly or if they are still waiting for use. Enlarging the database, after two weeks the marking of carriages stopped and the controlling of use was continued until the last transport medium was used in assembly. Due to the plant being closed during weekends, these days are not included in the analysed standing-still time. We know, that this statistic is giving us only a short insight and does not take into consideration the whole outside influences but it offers a measurable access point for improvements of the process. Gamma is organized in an different way. Therefore the analysis is separated from the other production lines demonstrating the results in table 4.2. Comparing the two medians and the two extreme values from the different lines, it can be seen, that at Gamma the picked median waiting time is approximately one day longer due to less outliers. This is a sign for a better planned and more stable process by taking into consideration a longer waiting-time. Taking a closer look at

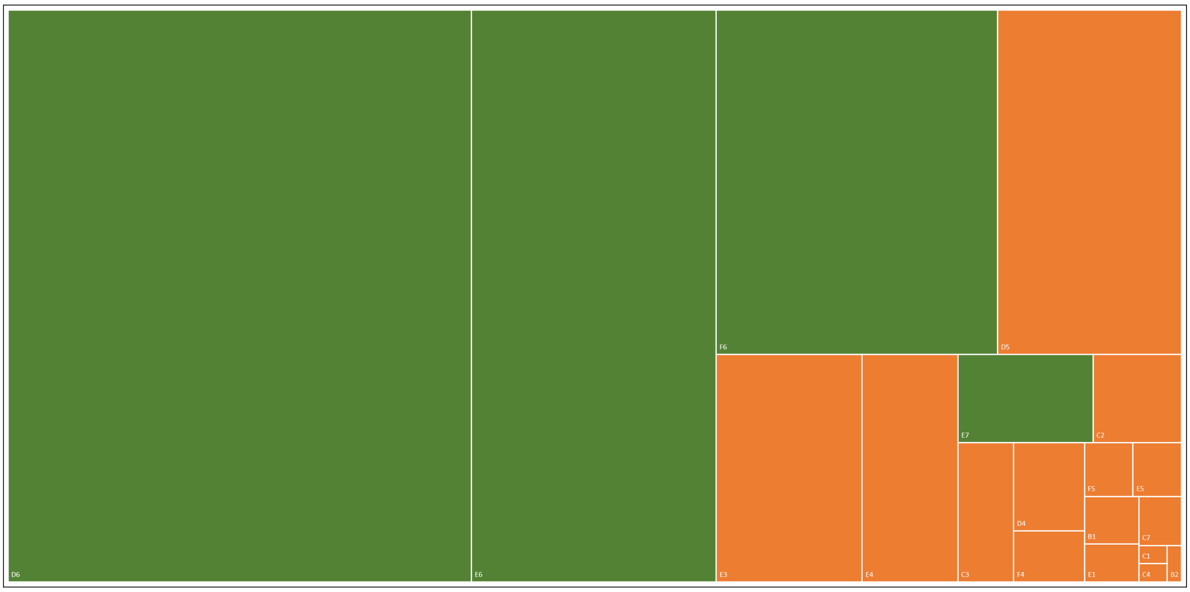

Figure 4.15: Picking distribution: Places for task fulfilling[a=]

[a=] Green are areas in the main storage, orange are areas in the assembly - see figure 4.9

the picking request numbers gathered in the standing-still analysis and referencing to the parts, we identified a pick rate of 22%. Obviously there are not all possible modules listed. Therefore we decided to take a closer look at the bills of material by eliminating multiple parts, bulk material and old material not used anymore. The result showed a picking rate of 27,19% which demonstrates a failure rate of 16%, due to the reason of determined short time horizons. Improving this rate helps speeding up production due to more needed parts already available at the assembly point eliminating unproductive picking all over the plant.

Another problem occurs with the actual retrograde acknowledgement. Due to no confirmation of moving 'recently picked' parts, they may appear as stile available in the data system even though none is in stock. This is slowing the picker down switching between fixed placed electronical inventory overview and picking spot, if required parts are missing in shelves and due to analysis time to understand the actual situation. As already claimed, not all parts are picked and brought to the fitter. The technician is responsible to get all the not yet committed parts from the different stations. Taking into consideration the hall layout, a fitter has to accept long ways in order to get the needed parts. Thereby it is not guaranteed to find required material at the postponed place, due to the fact that storage management is done on the overall quantity and not on the quantity on the spot level. One main storage place is assigned to the part and subcamp places are administrated in text boxes making it impossible to actual know where the required material can be found. This un-transparent data management is slowing down the process significantly. As soon as a part could not be found on the main place, the picker has to go to a fixed place terminal looking for the required information. Both processes can not be supervised and influenced by the management because it is impossible to shape it transparent by the actual working mode. A starting point would be the digitalization of the actual processes getting measurable and proved data. Furthermore, carts are standing in average 90 hours before actual usage around, blocking shelves. This is a sign that picking starts too early and responsible stuff do not really know when they have to provide the required material. The reason could be found in too long lead times of paper-based processes and too slow communication between different departments. The problem of the retrograde booking goes hand in hand with the long standing-still time by worsening the accuracy of actuals whereabouts. The Systems, Applications and Products in data processing[5] (SAP) estimates that the parts would be still available even if they are already picked and storage spots are empty. This could lead to wrong quantity corrections or long times seeking for parts trying to correct the data. In order to solve this problem digitalization, the introduction of an acknowledgement right after the picking process and the change of quantity of material to quantity on spot would help.

Information System Problems Summary

Described problems in actual information system are summarized for better understanding and easier requirements establishment like follows:

- No knowledge of the process start due to no properly defined actuator.
- Preparing staff is relying on experience and therefore workers are not replaceable in case of illness or vacation.
- Sorting algorithms are based on bytes not setting the list in right order.

[5] `https://www.sap.com/index.html` (visited on 06/09/2017)

- Time wasting by checking resources on fixed terminals.
- Storage management is based on material and not on spot level and therefore knowledge of the exact quantity at each place missing.
- No notifications when missing parts are arriving.
- Long stand still time of loaded carriages
- Low picking rate slows production down, because the fitter has to pick parts on his own.
- Paper-based processes have too long lead times compared to digitalized ones.
- Independent work scheduling of the pickers can lead to increased standing-still times (graded workload).
- The retrograde acknowledgement of used parts

Informations Requirements and Functions

The described processes, research and requirement elicitation helped to establish figure 4.16 as one basis for the system requirements analysis in the information development phase. Chosen is a simple data model where the circled main lane represents tasks of the working mode. The established information system triggers the process, which was already one of the stakeholders requirements, followed by the creation of picking orders, a guiding for pickers, the product information of what has to be picked on which quantity is displayed the viewing of data what is to pick and how much, followed by the picking process itself, which we already have analysed in section 4.4.2, and last but not least the acknowledgement, fundamental for fulfilling stakeholders requirement of avoiding retrograde booking. The circles above are boxes showing actual systems operators or connections to humans. In this case the fitter is chosen as trigger element starting the following processes and the picker as dependent working 'gadget'. Below there are electronical system elements as data storages or analysis tool providing the required information or showing how to generate them. Arrows are signing the direction of the information flow and

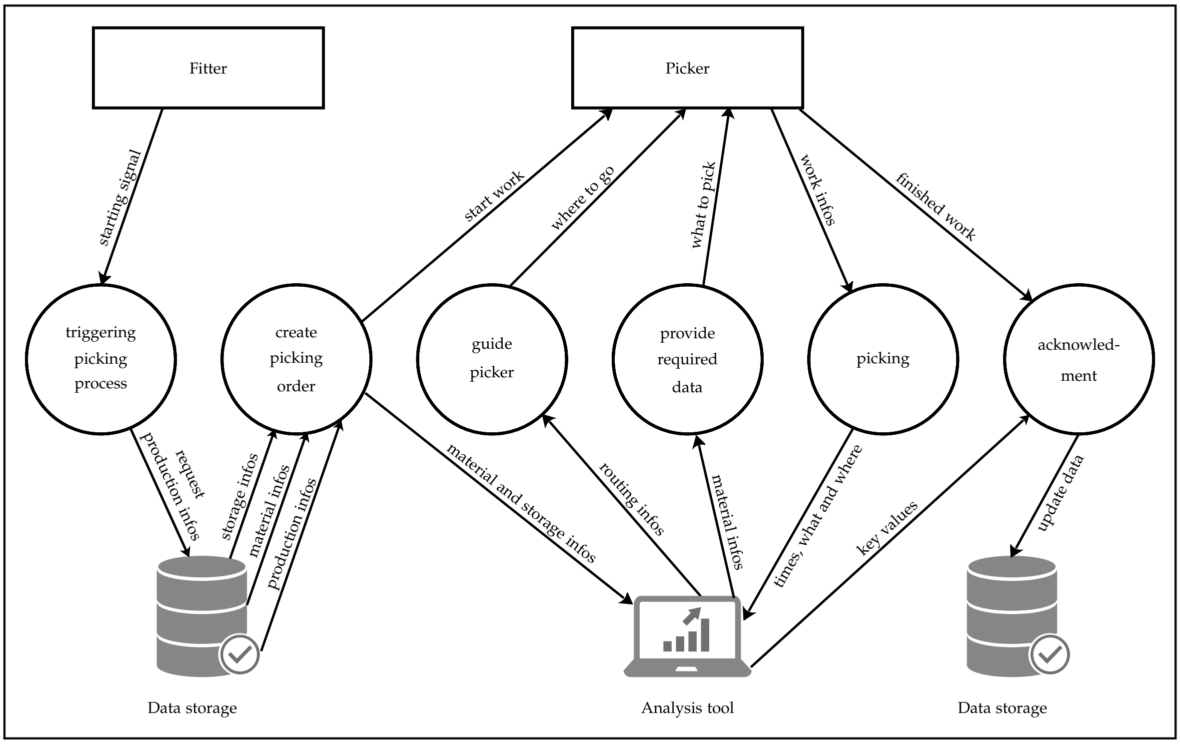

Figure 4.16: Data model as basis for requirements engineering's main information study

where the source is located. With this model some *'must requirements'* can be detected including even different kind of data like storage, material and production infos. They contains data like what material is needed, where it can be found and how much of it is required. For a guiding systems in order to avoid long roads, a storage map can be used, addressing requirements for the picking system.
Presented conditions give rise to some functional requirements:

- Actuation: starts the process and in the previously designed model the fitter is chosen randomly not knowing, if he is the best actuation mode. Basically, this can be seen as a signal transmitter.
- Preparation: is called the procedure of preparing information for the picker. In figure 4.16 it is represented as one main task connected to different information sources. Actually this assignment is fulfilled by the assembly supervisor, requiring up to 30 minutes for a single actioned data maintenance for new machines and up to ten minutes for a paper-based order.

- Transfer: all the arrows require same kind of data transfer as part of a communication network. Therefore this action is fundamental for any working system.
- Routing: represents the supply with directions for finding spots while picking. Section 2.2.2.4 shows already some simple heuristics to perform this task.
- Acknowledgement: in order to get rid of retrograde booking.

Taking into consideration the problems of the actual information system, following requirements can be established:

- Lead times have to be shorter than two days as currently time frames are not transparent.
- 100% picking rate in order to get rid of fitter picking operations.
- Change sorting algorithms in the preparation phase from comparing bytes to detecting numbers.
- Transfer data to the operator paperless (stakeholders requirement).
- Proportional scalability to the personnel deployment (stakeholders requirement)
- Capability of virtual routing
- Descriptions in German and Italian
- Maximum order stand still time of one day
- Preparation time less than 10 minutes
- Availability of at least three following picking positions in order to achieve mental preparation time
- Reducing picking time to 0:28 minutes per article enabling 100% picking

Prioritization

Taking all requirements into account, it is advisable to prioritize them, fulfilling most important ones first. Section 3.2.4 shows some weighting methods able to deal with that task. We have chosen a combination of MoSCoW and numerical analysis, transferring MoSCoW settings into values. This combination of methods is particularly useful for unifying varying statements like in simple surveys. In our case different people were assigned a catalogue and evaluated it. MoSCoW is an abbreviation for categorising furthers according to Must have (M), Should have (S), Could have (Co) and Won't have (W). Therefore requirements have been weighted by customers regarding importance and substantiated by mathematically usable values. So must is replaced by number 50, should by number 30, could by number 10 and won't by number -10. The negative value is chosen in order to not add weight to unnecessary options, but giving at same time measurable influence to the person's saying. As soon as this is done, a weighted prioritization average is to calculate. All stakeholders had different influence power on certain demands and taken it into account, the stakeholders influence power is rated by numbers between one and three. In order to get the average weighting, the sum of the product between MoSCoW weighting and weighting factor is calculated and divided by the sum of weithing factors.

$$Average\,Weighting = \frac{\sum(MoSCoW\,Weighting * Weighting\,Factor)}{\sum Weighting\,Factor} \tag{4.4}$$

Implementation Options

In the actual picking system the person has to know what to do and how to do it supported by a minimum of information including material number, main location and quantity. Looking at a standard ERP system, a lot of information is already stored, but the knowledge of what exactly is needed at which time is not transparent for the operators. Therefore the assembly supervisor has to start the previously described process. As already done before, it is set up a morphological scheme for the information flow. In this context the process is triggered by an actuator and in

Table 4.3: Evaluation of requirements: main study

	Stakeholder 1		Stakeholder 2		Stakeholder 3		Average Weighting
Requirements	**Moscow**	**Weighting**	**Moscow**	**Weighting**	**Moscow**	**Weighting**	
descriptions in German and Italian	Co 10	1	S 30	2	M 50	3	36.6
accurate trigger for error free process starting	M 50	3	M 50	3	M 50	3	50
capability of virtual routing and guiding	S 30	2	Co 10	3	Co 10	1	16.7
preparation time less than 10 minutes	Co 10	1	S 30	3	Co 10	1	22
paperless processes avoiding printed media	S 30	3	Co 10	3	Co 10	1	18.6
maximum order stand still time of one day	M 50	3	M 50	3	Co 10	1	44.3
Reducing picking time to 0:28 minutes per article enabling 100% picking	S 30	2	S 30	3	W -10	2	18.6
elimination of the retrograde acknowledgement	M 50	2	M 50	3	Co 10	1	43.3
proportional scalability to the personnel deployment	Co 10	1	Co 10	1	Co 10	1	10
at least following three picking positions have to be available	Co 10	1	M 50	3	S 30	1	38

our case this element can either be static or dynamic. First option represents a fixed actuation element not changeable and always the same, meanwhile in the second case it is changeable and adaptable to environmental influences like high working loads and short capacities. Triggering the action we found four main possible ways of doing it. Firstly a planning advice which should give information to the operators at the assembly line of what they have to do and what the requirements are. As the information of what, where and when are already available within the so called 'Feinplanungstool', they could be taken from there, starting data-driven processes. Another plan-driven method is the use of a reference part, which triggers the order for the next picking unit during installation. Next way is starting the order process by an experienced operator or the assembly supervisor, ordering material based on experience. Finally it is also possible using as actuator the delivery date of the machine, counting back from it and starting the picking processes one day earlier the material is required similar to the material requirements planning (MRP). This option represents a push system offering new material in certain planned time sequences. Another main function for transferring right information is the preparation. Therefore it is has to be decided, if single, batched or partial orders should be prepared depending significantly on the in-house production mode. In this context batching means putting orders together and preparing them for one commissioning round or splitting them up and assembling them to new orders. In assembly, bundled pick orders have to fulfil certain characteristics such as assembly at the same location and the need in same time horizons to create a flexible assembly area. Further the question of how to prepare them is raised and answered by the three solution options of manual, semi-automated or disordered lists. The automatic mode has a big advantage that no human working power is required but if special changes are needed a trained operator has to adapt it. A manual process on the other hand tends to be slow and takes a lot of time, is cost intensive due to the need of man power and error-prone because human have to interfere in a non standardised process. As soon as the picking list is assembled, it has to be transferred to someone / something performing the process. Therefore there are two ways: the first one is a paper-based action using supporting documents and the second one is a paper less process without supporting documents. It is even possible to determine the quantity of transmitted data distinguish between a single and multi positions action. As already announced, it is important to keep distances short during order picking which can be achieved by using routing methods. We are not presenting mathematical strategies of solving such problems because at this point we are not focusing on such detailed factors, but on technical options for realization. So routing can be done by using papers or voucherless. Received informations can be made human-readable by picking lists, fixed terminals, pick by light, mobile terminals or pick by voice. Last possibility we led aside because Durst's headquarters is based in South Tyrol a bilingual part of Italy and implementing such a system would require the use of two languages raising implementation costs. In figure 4.17 we implemented only two options to identify if such a system is really required in first place. Up to this point, only the information flow from the system to the picker was examined and therefore the picker itself cannot feed any information into the system, which means that the requirement for transparent process control cannot be fulfilled. Therefore we implemented the option of acknowledgement (not obligatory): this can be done after each part, after a certain sequence of parts or at the process end. It is even possible doing it manually, semi-automated or automatically using sensors which are detecting if the carriages is loaded, what parts are on it and when it is leaving the picking zone. Markets are offering also many other possibilities, but this would go beyond the scope of this thesis.

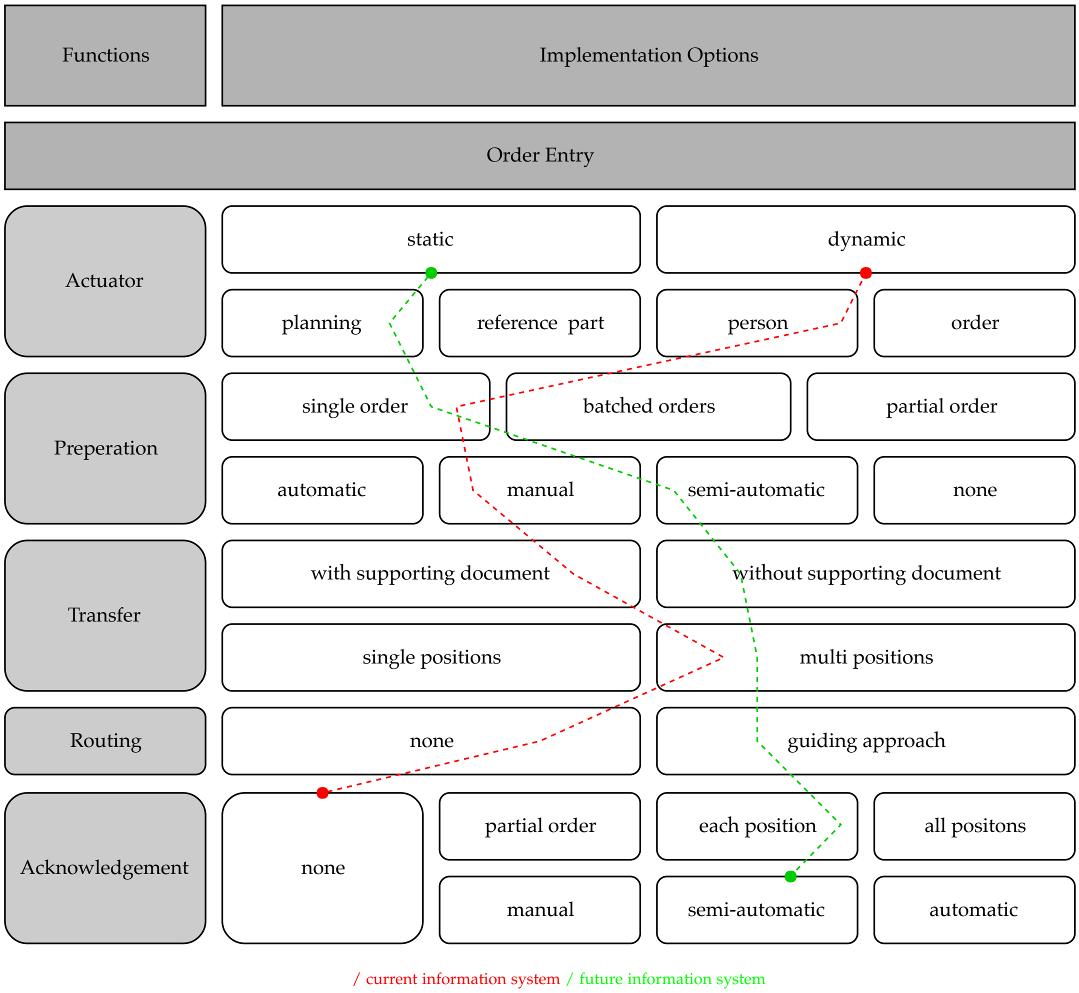

Figure 4.17: Morphological Scheme for the Information Flow*=
*= In compliance with ten Hompel, Beck, et al. (2011)'s table 3.4 at page 28

Figure 4.17 shows possible design variants resulting into 12.288 possible process main designs for an information flow. The morphological schema is an advice supporting the creation of suitable variants able to fulfil functional requirements and can become quite complex. So we decided to take the five most promising ones fitting to our demands. Table 4.4 shows the five solution options.

Until here only some of the possible solution options are presented, not answering the question which one suits most to Durst's requirements. As Hall and BWI's problem solving cycle shows, the best way is to evaluate and weight them against each other. For weighted and prioritized requirements by the customer, it is decided to use an evaluation matrix as presented in section 3.3. Therefore is set up a target catalogue

Table 4.4: Possible implementation options: main study

Functions	Variant 1	Variant 2	Variant 3	Variant 4	Variant 5
Actuator	static	static	dynamic	static	static
	planning	reference part	person	person	order
Preparation	single order	batched orders	partial orders	single order	batched order
	semi-automated	manual	automatic	manual	semi-automated
Transfer	without supporting documents	with supporting documents	without supporting documents	with supporting documents	without supporting documents
	multi positions	multi positions	multi positions	multi positions	single position
Routing	guiding approach	guiding approach	none	none	guiding approach
Acknowledgement	per position	all positions	all positions	none	per position
	semi automated	manual	semi automated		semi-automated

comparing solution potential of established variants to desired requirements, represented in table 4.5. The weighting values [g] are taken from table 4.3. Then the degree of requirement fulfillment of the individual variants was determined and graded with numbers between one and ten. Thereby one is a bad and ten a perfect suiting. Multiplying the corresponding grades and weights and summing them up yields the solution with the highest customer satisfaction.

$$Satisfication\,Factor = \sum n * g \tag{4.5}$$

Table 4.5 shows the results of this evaluation. Different grades are given for rating the requirements fulfilment level. First requirement of actuating the process on the right time is fulfilled the best by variation one because system information is automatically starting the process. A static starting with reference part, person and order are less accurate, due to the fact that assembling speed is varying between operators, employees can start it within desired time frames and delivery dates are changing constantly, postponing the start of assembly. The dynamic process is, as described, changeable as well as the person starting the actuation is varying. Next requirement is facing the need of a guiding through the storage. Due to no further specification of different guiding possibilities and no guiding is an option (sourcing the task to the operator), we have decided to award the grade eight for the guided system and the unguided four. The required preparation time of less than ten minutes can not be evaluated right in this project phase and therefore automated systems are graded highest followed by semi-automated and manual solutions. The retrograde acknowledgement can be eliminated using different strategies. The quotation after each position sets shorter time frames of not knowing the actual part status than doing it after picking all and none does not fulfil this requirement. The use of paper-based picking lists can be evaluated by determining if the transfer mode is supported by documents or not. Similarly the grading of the availability of the next three pick points is done by looking at the quantity of transfer positions. The last requirement is evaluated by comparing the picking speed. A guided process is seen as being faster than a not guided one because ways should be shorter. A further possibility of influencing this factor is the type of acknowledgement, since automatic systems do not require human interaction and for the confirmation at the end of the entire

Table 4.5: Valuation of the different systems: main study

goals	weight	variants									
		variant 1		variant 2		variant 3		variant 4		variant 5	
		n	n*g	n	n*g	n	n*g	n	n*g	n	n*g
accurate trigger for error free process starting	50	9	450	8	400	5	250	8	400	5	250
capability of virtual routing and guiding	16.7	8	133.6	8	133.6	4	66.8	4	66.8	8	133.6
preparation time less than 10 minutes	22	7.5	165	5	110	10	220	5	110	7.5	165
elimination of the retrograde acknowledgement	43.3	10	433	5	216.5	6	259.8	1	43.3	10	433
paperless processes avoiding printed media	18.6	10	186	1	18.6	10	186	1	18.6	8	148.8
at least following three picking positions informations have to be available	38	10	380	10	380	10	380	10	380	1	38
reducing picking time per article enabling 100% picking	44.3	7	265.8	7	310.1	4	177.2	1	44.3	7	310.1
	overall fulfilment										
variant 1	2057.7										
variant 2	1568.8										
variant 3	1539.8										
variant 4	1063										
variant 5	1478.5										

process only once the processing time occurs, these options can be seen as faster than the others. No routing and no acknowledgement are Durst's current working mode and therefore graded as not raising the speed.
The result of this evaluation identified version 1 as the most promising one. Therefore the following in-depth study is based on that particular variant.

4.5 In-Depth Study

In our main study we detected version 1 as our most promising option improving the information flow for the current level of automation at Durst by supported digitalization. For a lot of problems there already exist different, possible solution strategies on the market and in order to get some hints we decided to screen the market for information technology supporting warehouse functions and processes.

Market Study on Warehouse Management Systems

Screening the market, we detected already existing warehouse management systems (WMS). These applications are available and approved for a bidirectional data exchange fulfilling requirements and conceptual data flow, offering even additional functions solving also problems that here are not mentioned and possessing the possibility of netting approaches presented in section 4.4. Netting helps avoiding errors, speeding up processes because data is exchanged automatically while gathering process knowledge due to constant data collection, making work steps transparent. Further information on the advantages of netting offers Pawellek (2014).

Warehouse management means leading a storage or distribution location efficiently. But this is a hard task if information is not evident in the system and decisions like choosing the right storage spot or which transport advice is to use human made. With increasing automation, it is necessary to deposit relevant system information. The amount of needed data depends on used warehouse technology. Certain systems require more information like storage spot dimension, storage spot carrying capacity and coordinates. We can assume that with increasing automation and the requirement of more accurate predictability, parts information must also increase, or what is the storage spot carrying capacity used for, if the component wait is not known? Other tasks of the inventory management are the control of environmental conditions and flexible grouping of tasks avoiding a work intensive editing of single elements with similar properties. All these duties are used for optimizing the warehouse productivity, supporting management decisions by edited and visualized data. WMS is an electrical and software technical automation gadget in the field of intra logistics. Besides its core competence of managing quantity, location, disposition and the relationship between functions, it has the task to optimize, steer and control even complex storages. Figure 4.18 gives an overview of basic system functions. Since the system has a modular structure, it is divided into core systems and expansion modules. The first category represents the standard purchase package and can be adapted to special requirements with the help of the second one making these applications customizable. All these information systems support the material flow from source to valley by enabling a transparent data exchange between all stakeholders. Additional functions can be implemented if the customer needs them. Even interfaces to third-party providers for special applications are available but most functions are supplied by the WMS provider. These interfaces to third-party providers are representing dock in station for stand-alone expansion modules like pick by light. A market study shows, that alone in the German speaking countries more than 150 provider with a turnover over 1,25 billion Euro are available. Comparing the revenue from 2015 to that from 2012 it is discernible that there is a 6% increase in turnover. A market study from the "Frauenhofer IML" shows that most provider are active for more than ten years and nearly 20% even more than 30 years. Table 7.1 gives a short overview of different WMS providers and categorize them as described in section 2.3.1 (IML, 2017a). Table 7.2 gives an overview of these systems showing certain function fulfilments. A main requirement of Durst is, that used third party providers are certified by there ERP-provider. Therefore many of the analysed systems have already to be excluded and cannot be implemented. Next requirement is, that the system has to be capable to provide informations in German and Italian as the company is located in a bilingual part of Italy. The only remaining system in table 7.2 is the SAP Extended Warehouse Management (SAP EWM) offered by different providers. SAP EWM requires higher investment cost than similar products

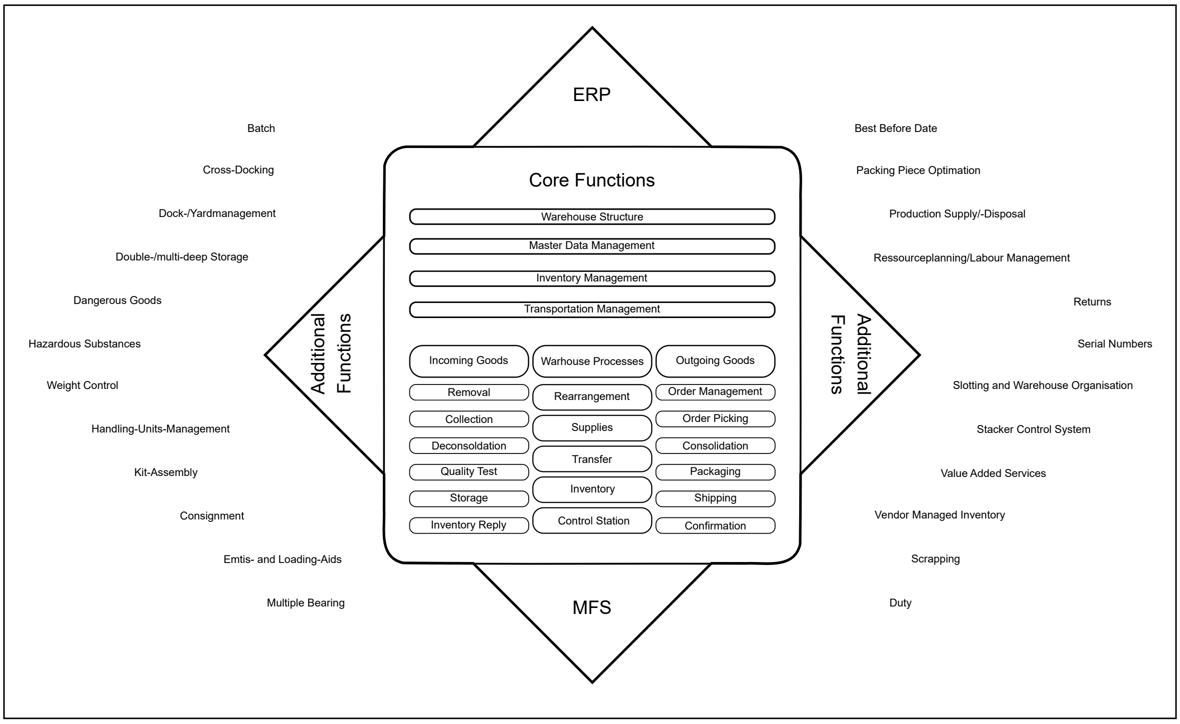

Figure 4.18: Functions of a Warehouse Management System*=

*= In compliance with IML (2017)'s figure 2.13 at page 92

due to more specific system requirements and the necessity of high customization. Another possibility would be to change working processes, adapting them to the WMS standard, which would even lead to adaptations in the storage, raising costs and thus violating customer requirements of using simple technology and set target costs. Summing up, it is advised to develop first an own simple system, gathering data and to find out if related projects are also considered, if a standard WMS is a proper solution for Durst's workflow visions.

Target Definition

Due to the fact that WMS provider are not offering suiting products for our needs, we decided to develop further the system represented in section 4.4.3. Figure 4.19 shows a possible work flow for a data management system. SAP is providing required information for needed parts waiting to be picked. The process has to be actuated or triggered from detailed planning system or from the fitter depending on the work stage. The detailed planning tool is not yet implemented but currently under development. The aim of this system is to plan upcoming work and to visualize it to the fitter at the individual assembly points on fixed placed terminals. As soon as a new assembly is scheduled, the foreman sends the worker to the designated assembly station, where he can call up his tasks. In order to be able to start the work more flexibly, the required material must already be available and has to be called up earlier by a suitable trigger. This avoids long standing-still times for montage and increases fitter's productivity. In order to raise flexibility and agility it is recommended to use already existing data like which product is produced at which time on which work place. In order to minimize standing-still time for loaded carriages during assembly, following material orders should be done by the operator. Summing the points up, the trigger is a combination out of planning, which is representing a push system, and ordering by the fitter, which represents a material pull. As soon as the process is actuated, availability of material is checked. If it is not completely available yet, the picking order has to be postponed or, if the delivery is urgent, material has to be picked while keeping track of missing parts and delivering them as soon as they are in stock again and informing at the same time the fitter of which material is delivered. For incoming material requisitions, the system should check whether a combination with other picking orders is possible. For this purpose, various criteria must be checked, such as the compilation at the same location within a determined time horizon. One possible batching[6] option is reducing ways by using some storage heuristics represented in section 2.2.2.4 or similar improvement strategies as announced in section 4.4.2. After gathering additional data and optimizing ways with mathematical applications, information is transmitted to a mobile advice. This package contains data like required articles, quantity, storage place where to pick and how this storage spot can be found. After successful picking, the operation is acknowledged by scanning an EAN on the storage front. If not all required material is available, demand has to be pent up and held evident for additional subsequent deliveries. If there are some inconsistencies in stock, a type of inventory can be carried out, which checks various options and specifies further procedures (see figure 4.19).

[6]Further informatinon about batching is provided by Koch (2014)

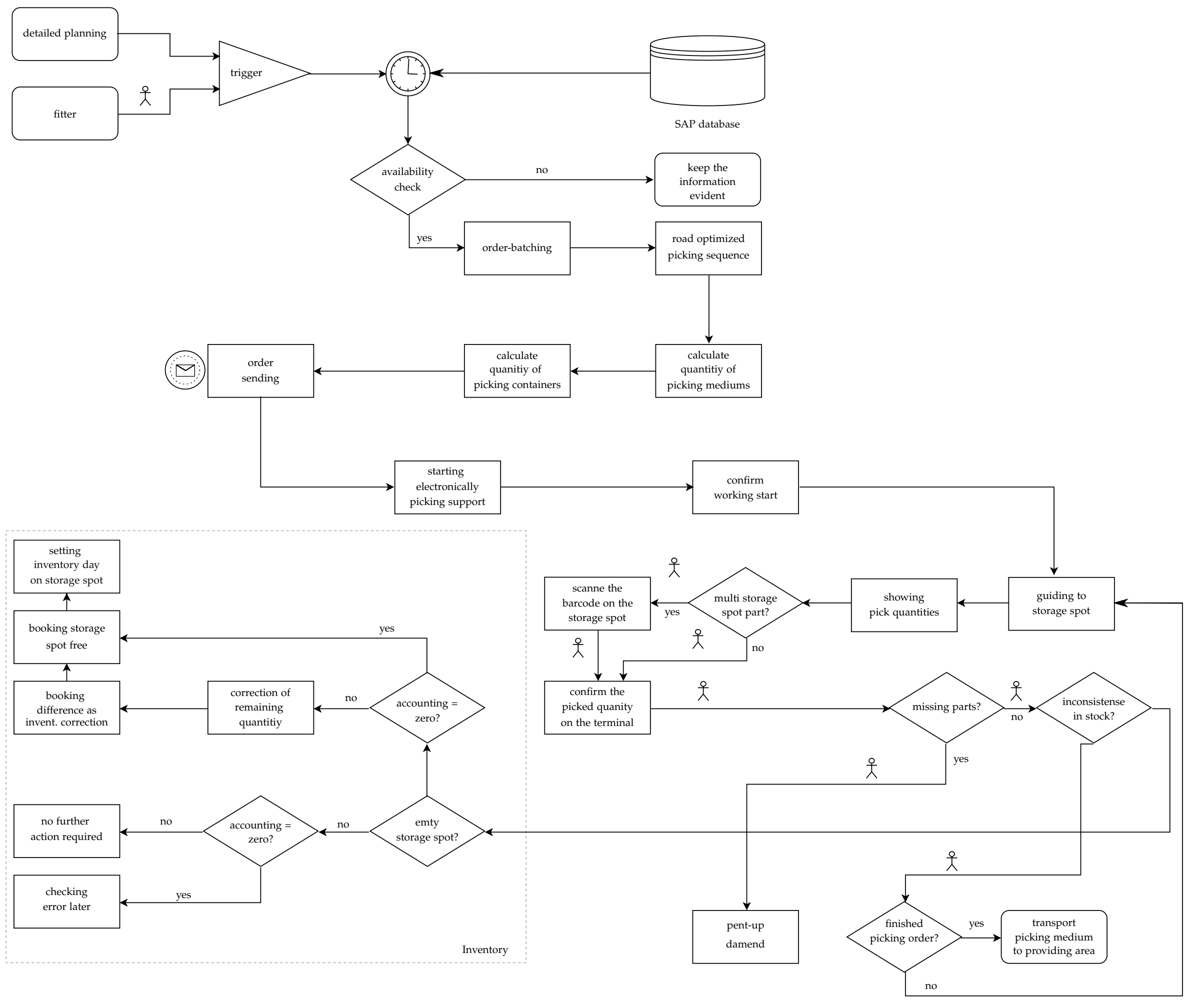

Figure 4.19: Digitalised system for the information flow

The system presented in figure 4.19 is the starting point for the further in-depth studies requirements analysis. Thereby additional functions can be detected and requirements established by discussing this possible model with stakeholders. As already discussed several times, the actuator also plays a key role in this development phase. The main study already proved that a combination of ordering by person and planning is to prefer. Stakeholders claimed that due to the fact of nearly daily changing production begins, the time slot between actuation element and process start should be as short as possible avoiding long standing-still times of parts and people should be able to manually interact with the system when changes need to be made. Further elicitations showed, that several orders should be transmitted simultaneously and that already existing technologies or networks should be used in order to keep costs low. COOs vision is that 'everyone' is able to do the job and therefore the learning time of how the system works has to be as small as possible, leading us to the already established system of a routing advice supported by virtual task explanation. This in-depth study shows that pick informations have to be visualised for the picker, claiming a functional requirement of using a data monitoring advice. During the investigation of the current processes in the warehouse, a plastic plate was discovered that keeps analogous data of missing parts transparent for subsequent deliveries. Eliciting further requirements with model-figure 4.19 it is claimed to implement a holding evident system raising flexibility, if needed stuff is send out earlier and to replace the plastic plate. Furthermore following requirements should be fulfilled:

- Log transactions in order to trace errors and making processes transparent.
- Ensure the integrity of the information.
- Information has to be accessible all the time.
- Developments have to guarantee smooth data speed for a good work experience.
- Third party providers have to be SAP-certified.
- The system has to contain interfaces to used applications like the new planning tool.
- Hands free for picking fulfilment.

Prioritization in Detail

These elicited requirements have to be structured and weighted in next process step. As already in the information's main study, we have chosen the MoSCoW analysis combined with the numerical approach for weighting and prioritizing requirements. As structure a simple list of statements is chosen which is than weighted. Table 4.6 shows the results and shows as well the stakeholders influence power on requirements. This power is multiplied with the new MoSCoW values and summed up. By

Table 4.6: Evaluation of requirements: in-depth study

	Stakeholder 1		**Stakeholder 2**		**Stakeholder 3**		**Average Weighting**
Requirements	**Moscow**	**Weighting**	**Moscow**	**Weighting**	**Moscow**	**Weighting**	
log transactions in order to trace errors and making processes transparent	Co 10	3	S 30	3	Co 10	18.6	**50**
third party providers have to be SAP-certified	M 50	3	M 50	3	W -10	1	**41.4**
hands free for picking fulfilment	S 30	1	M 50	3	Co 10	1	**38**
using already integrated products at Durst	S 30	2	Co 10	3	W -10	1	**13.3**
guarantee smooth data speed for good work experience	M 50	3	M 50	3	M 10	1	**44.3**
connectable to applications as the new planning tool	M 50	3	S 30	3	Co 10	1	**35.7**
informations have to be accessible all times	S 30	2	S 30	3	Co 10	1	**26.7**
time slot between actuation element and process start should as short as possible	M 50	1	S 30	2	M 50	1	**40**
learning time of less than one hour for being capable to use the product	M 50	3	S 30	3	W -10	1	**35.7**
pick informations have to be made visual for the picker	S 30	1	S 30	1	S 30	1	**38**
holding data evident	Co 10	1	S 30	2	Co 10	1	**20**

building the quotient of that sum and the summed up influence powers, a single weighting value is established. Functional requirements are not weighted, as they are all necessary for the recommended workflow with the exception of the inventory capability, representing only an optional function, avoiding an actually time consuming process at Durst.

4.5.1 Alternatives Options and Additional Functions

New requirements and more detailed already existing functions are setting up new boundaries for possible implementation options. Summing them up, a new morphological schema can be developed represented in figure 4.20. We are focusing more on technical details fulfilling the overall functions. The actuation of our system can be started by planning or by person with various possible implementation options: a start by planning can be actuated by:

- Detailed planning is the usage of already existing information from the previously named detail planning tool with data of where the machine should be assembled and when the assembling should start.
- Forecasting as in using historic data in order to determine the directions of future trends (Investopedia, 2018). Therefore it is possible to use different techniques like shown by Chambers et al. (1971) in his article. This would help to solve problems with uncertain order intakes and deliveries blocking assembling places.
- The approved delivery date would allow to choose the starting day for assembly. For this system the detail planning tool is not necessary reducing downtimes by system breakdowns or interface problems.
- Data driven planning is similar to the forecasting method, with an additional use of internet of things (IoT) and big data aspects. This would have the big advantage of constant live data but would require a better customer loyalty because using data is required. Further information on IoT advantages for the inter-logistic provides Günthner et al. (2010).

Now different approaches of triggering actuation by person are presented:

- One possible option would be the assembly manger. This is already the case but but without digital support and too little knowledge of processes and key indicators of the intra logistics department. Therefore he is not capable of starting that process with zero lead time and is responsible for big fluctuations and for the costly standing-still times.
- Another possibility would be to shift that work to the work preparation capable to using forecasting techniques and supporting systems in order to trigger the process.
- The third possibility would be that the fitter himself is ordering parts and material. Starting an assembly he is not capable of doing so as he earlier is working on another assembly stations and work tasks are assigned to working stations and not directly to fitters. Truly, it would be possible to do it by making person- and not work-related work assignments. Durst's new job monitor is build for fix terminals on workstations and not mobile gadgets. This completely eliminates the option to assign workers to a certain task and therefore raising flexibility in personal usage.
- Next the product specialist could trigger the actuation. He is already on the production line and sees live work advances. It is always necessary to have more persons capable of fulfilling the job when the responsible one is absent.
- Last but not least the production planning and control team would be capable of triggering picking as they know when assembly starts.

As soon as the process is triggered and informations for the operator prepared, multi-positions (transmission of several orders) have to be transmitted to the operator. Therefore following solutions are possible:

- Storage media: these are devices on which data can be stored, transported and retrieved. A classical example is the USB stick. Picking requests can be exchanged without requiring any infrastructure.

- Wires: it offers the possibility of transporting data within cooper or optical wires enabling high transfer rates. A disadvantage is the necessity of being connected to a cable reducing flexibility and therefore reducing their usage to fixed terminals.
- Wireless communication: theses approaches allow to communicate devices wirelessly with each other. Some technologies are presented in the following:
  - WiMax: is the abbreviation for Worldwide Interoperability for Microwave Access capable of transferring up to 40 Mbps. This technology can either be used indoor or outdoor (Ray, 2015).
  - WiFi: is one of the most used systems transmitting data by radio waves between Ian internet router and different devices (Ray, 2015) with an transfer rate up to 20 Mbps and more (Nagarajan et al., 2013).
  - ZigBee: is a standard for low data rate wireless networks providing low cost and low power consumption system solutions. Depending on the used bandwidth between 20 to 250 Kbps are available (Nagarajan et al., 2013).
  - Bluetooth: is a wireless transfer technology used for short distances normally up to 10 meters with a data exchange rate of 720 Kbps (Nagarajan et al., 2013).

Wireless and wire communication use different protocols as TCP/IP[7] or FTP[8] for data transmission. Thereby sending and receiving is based on three main possibilities (Nevase, 2016):

- Unicast: this is a one-to-one transmission method exchanging data between a single sender and a receiver.
- Multicast: this is a one-to-many method sending data from one sender to several chosen receiver.

[7] https://www.ibm.com/support/knowledgecenter/en/ssw_aix_71/com.ibm.aix.networkcomm/tcpip_protocols.htm (visited on 15/12/2017)

[8] https://www.ibm.com/support/knowledgecenter/en/ssw_ibm_i_71/rzaiq/rzaiqreference.htm (visited on 15/12/2017)

- Broadcast: this is a one-to-all method sending data from one single starting point to all possible endpoints.

After the operator got the picking informations, he has to be guided through the storage as our main study shows in section 4.4.3:

- Operating with arranged paper based picking lists is Durst actual working mode. In the new system lists should used digitalized, offering all necessary information's for a manual picking system.
- Navigation systems are an overall term for different possible guiding methods in a storage. The name of the first method corresponds to that of the navigation system class and guides the worker through the warehouse based on a map. A further guidance option is voice guidance, which is often used in addition to other approaches. Last system in this category is the guiding by light marking the picking way with light symbols.

Presented rooting strategies can be supported by different possible way optimization algorithms like isolated routing[9]. Thereby we have taken into consideration adaptive algorithms as Durst's storage is changing every day and does prevents static approaches[10]. Simpler routing strategies are represented in the following points:

- Using heuristics (see chapter 2) supported by picking list helps to fulfil a way optimized picking using less technology. In chapter 2 we already have spoken of different approaches of such routing systems.
- Line sequence optimization is the act of sorting material in picking lists according to the lines of their respective storage location number taking into consideration warehouse layouts (Moeller, 2011).

Using these strategies efficiently requires knowledge of how many parts are on each storage spot and not how many parts are available in total. We already have seen that seeking the corresponding part in the storage is very time consuming. The preferable

[9] https://en.wikibooks.org/wiki/Routing_protocols_and_architectures/Routing_algorithms (visited on 17/12/2017)

[10] Further information provides Hausladen (2016) with examples of the classical milk run.

version isolated in section 4.4 relies on data transfer without supporting documents. Visualizing transferred data requires technical devices including:

- Mobile terminals: mobile terminals are gadgets like smart phones, tablets, computers or similar advices which can be used online or offline. The advantage of using an online network is that data is updated continuously due to live synchronization.
- Fixed placed terminals: are similar to the first category while not being portable.
- Pick by light: such systems are guiding the operator to his picking place, where on the rack face of the needed item a display is showing picking quantity. With radio-frequency identification (RFID) sensors or similar options, the pick can be acknowledged and the way to next item visualized.
- Voice: this options provides all needed informations on a headphone including part quantity and required articles.

Sometimes not all parts are yet available in assembly and to be requested, because they would take up too much place in assembly area. Therefore we implemented the function 'delivering in addition'. We detected two main implementation options: the operator gets a pop up message as soon as the parts are being delivered or instant needed or he gets such a message with collected information once a day. Next question that has to be answered, how he implements this additional work without losing time in his daily business. Therefore he has the three main options of single subsequent deliveries, subsequent deliveries batched and using new picking orders for the subsequent deliveries. First option introduces a break into the actual working cycle in order to deliver needed parts while second option is less flexible because there is no direct reaction on urgent requirements possible and the last option is that such an order is implemented directly in the actual or next picking order and delivered within that bundle even if an alternative delivery station is previewed.

We even require some kind of acknowledgement per position in our solution as our main study proves. Therefore we identified the options of scanning barcodes, noting the operation on the picking list, using a data terminal connected to RFID sensors linked to a single storage spot or to each part. Last is an optional function if the inventory should be done during the picking process or during low operation periods. This offers the option of doing it within that process by setting the inventory date as soon as a storage spot is empty and counting other parts during low work load times or last but not least not doing it within the picking process.

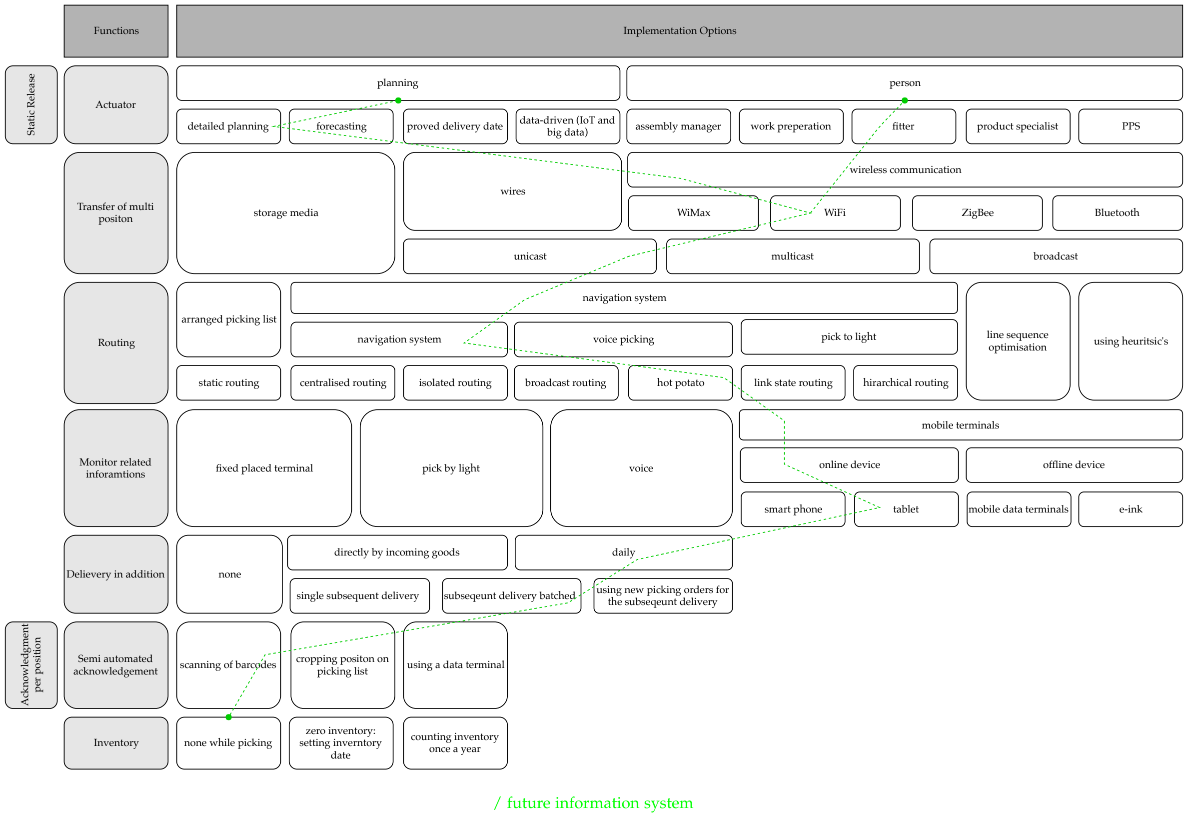

Figure 4.20: Morphological Scheme for the in-depth study

The next step is to find the best solution. Therefore we are using the same approach as in the main study: by combining solution options from row to row we get several potential solutions. In our system we used only the two most promising ones which can be seen in table 4.7.

Evaluation and Decision

For combining requirements with designed systems and for evaluating them, we have chosen the evaluation matrix. As previously done, this is divided in a weighting part for each requirement and in a grading part representing the level of fulfilling

Table 4.7: Possible implementation options: in-depth study

Functions	**Variant 1**	**Variant 2**
Actuator	planning	person
	detail planning	PPS
Transfer of multi positions	wireless communication	by wire
	WIFI	
	unicast	multicast
Routing	navigation system	arranged picking list
	navigation system	
	hot potato	static routing
Monitor related informations	mobile terminals	fixed placed terminals
	online device	
	tablet	
Delivering in addition	daily	none
	subsequent delivery batched	
Semi automated acknowledgement	scanning of bar codes	cropping positions on picking lists
Inventory	none while picking	counting inventory once a years

Table 4.8: Valuation of the different systems: in-depth study

goals	weighting	variants			
		variant 1		variant 2	
		n	n*g	n	n*g
hands free for picking fulfilment	38	5	190	10	380
using already integrated products at Durst	13.3	8	106.4	3	39.9
guarantee smooth data speed for good work experience	44.3	8	354.4	9	398.7
informations have to be accessible all times	26.7	10	267	2	53.4
time slot between actuation element and process start should as short as possible	40	8	320	5	200
pick informations have to be made visual for the picker	38	8	304	6	228
holding data evident	20	10	200	8	160
overall fulfilment					
variant 1	1741.8				
variant 2	1460				

established requirements. By multiplying both factors and summing them up for one solution option, a value is generated and the highest one represents the one fulfilling customer requirements the most and should be used for further development steps.

The grading for table 4.8 is done as following: First requirement of having hands free during the picking process is fulfilled best by no additional gadget or device in hand and therefore a fixed terminal is to preferred. Next requirement is focusing on low budget solution keeping costs low by using already available technology as the exiting WiFi. These networks have a high data change capacity and modern solutions can be faster than copper cables but not than optical once and therefore we graded it similar to the cable usage. A cable solution is not as good as a mobile solution using wireless technology, if data has always to be accessible and be monitored by operators. For avoiding long stand still times for the carriages - as already required in the main study - an accurate trigger is required which holds the time slot between assembly start and picking as short as possible and therefore the detailed planning tool is fitting best. Therefore the option that should be preferred is the variant 1 which is summed up in section 4.6.

4.6 Results

With the help of SE we have been able to establish a information system fulfilling the customer requirements. Figure 4.19 shows already the needed work flow established in our main study. This in depth-study is the transition between concept and component development (Hall and BWI calls it system construction). We defined already some used technologies like the transmission technology or the used monitoring device. Completing the solution with needed data, figure 4.21 is established. On the bottom different data sources are defined. The middle line shows functions and tasks to fulfil. The top layer shows acting stakeholders. Source and sink are connected by arcs showing the data flows and where the origin is located. Summing the system up shortly, the process is actuated by the fitter or detailed planning depending on the work phase. After it, data like part ID, quantity or location has to be provided preparing the picking lists. These lists and required routing information are transmitted over the already existing WiFi network to mobile gadgets visualizing informations as quantity, part ID, storage place and fastest route to it. As soon as the operator reach the picking place, he fulfils the task and acknowledges the action by scanning barcodes. The system then books parts at related picking medium automatically eliminating the retrograde booking. Simultaneously information of ways (routing provides informations) and times are provided to an analysis tool which calculates key factors as the picking performance, adapting it to the system of picking orders. The operator should get the chance to book time wasting reasons or problems which are delivering informations for further improvements including indicators for storage adaptations. In order to get this system running some further steps are necessary.

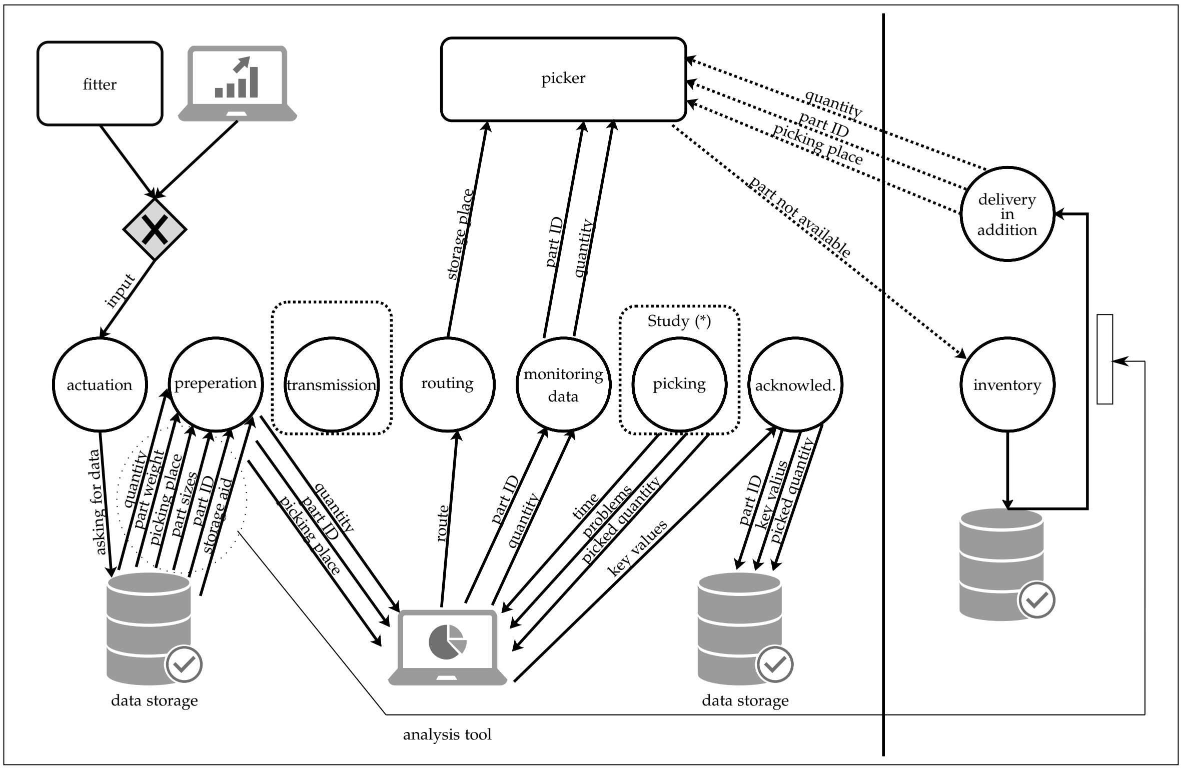

Figure 4.21: Needed data structure*=

*= This element can be improved by adapting the system represented in section 4.4.2

4.7 Proposed System and Recommendation for further Action

We developed a system capable of fulfilling needed requirements on a conceptual base. In order to realize it (concept of section 4.6), some further steps are required based on the classical V-model. Similar to the VDI 2026 software and hardware development is to be split up. Starting with the software approach, different functions are represented in our main and detail study. Now these functions can be seen as components which have to be developed. Starting this process, components requirements have to be set up. Before coding is started, each component has to be modelled with related requirements. Even interfaces to systems like the detail planning tool or SAP system have to be previewed. Based on the software development, components requirements for the hardware have to be established and, based on a short market study, hardware should be chosen.

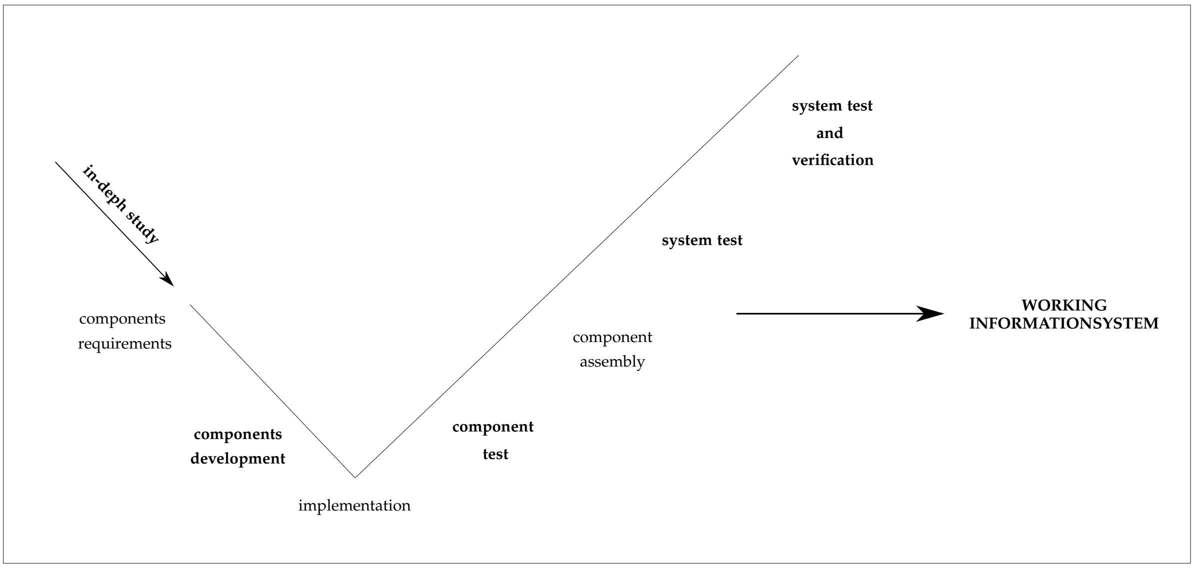

Figure 4.22: Recommendation for further steps[b=]

[b=] Green are areas in the main storage, orange are areas in the assembly - see figure

Following the V-model of figure 4.22 both developments have to be combined, tested and verified by evaluating requirements fulfilment in test phases. Detailed steps are represented in the following points:

- Split development up in a hardware and a software process
- Software development:
  - Creating of component system - it is advised to use different functions for one component
  - Build the components requirements for each component.
  - Program the components and test requirements fulfilment.
  - Combining the code and test if it is able to fulfil requirements on in depth-study.
- Hardware development:
  - Establish hardware requirements on the component level
  - Look which devices are already identified.

  - Specify the component requirements.
  - Screen the market for technology to use.
  - Evaluate detected technology.
  - Decide which technology should be used.
- Implement software in hardware device.
- Test functionality and cooperation of hardware and software in asystem test.
- Iterate steps if this is not working
- Test the hole system and verify it by looking at the stakeholders requirements

As soon as these steps are fulfilled, a working system is established capable of addressing stakeholders requirements and improving the actual process. With the support of the new transparent working mode and by gathering key values and problem lists, further improvements are possible by adapting the picking process represented in section 4.4.2 and making the risk of higher investments better assessable.

5 Proposals for further Projects

Many agile companies work simultaneously on different projects which often also depend on each other. That is also why other current projects at Durst depend on this work, including topics like 'setting the pre-assembly on picking', 'feasibility of driverless transport systems' or 'the job monitor' (in this thesis we called it planning tool). In order to take even a bigger picture into consideration, we decided to give some recommendation for these projects. Due to the fact that detailed descriptions would go beyond the scope of this work, only some short insights are given as follows:
For the actual project of 'setting the pre-assembly on picking' (already in pilot phase), the needed capacity can not be provided by the actual working mode, because, as shown in this thesis, it would require the reduction of the picking time per article from 1:44 minutes down to 0:28 minutes and the established information system improves mostly the actuation and makes the process transparent. As an interim solution, it is recommended to increase the staff in the current process and, based on better data quality, to change the physical procedure at a later point in time, which could save people again.
The project 'feasibility of driverless transportation systems' is facing similar problems. These machines require data, that the actual system and the newly developed one can not provide, forcing an adaptation of actual storage data. The usage of them solves the problems caused by the stationary placed transport media while picking, helps to reduce paths and contributes to achieve the required process time.In this project, the possibility of implementing such transport options was also considered, but due to Durst's requirements, the high investment in this field could not be adequately justified. A good starting point for this further project would be the morphological schema represented in figure 4.13.
Combined with these new projects, warehouse management systems can provide

useful features which should be evaluated again due to additional requirements for the system. Though, first of all, the data quality should be improved for accurate statements and further adjustments.
The 'job monitor' delivers data for the newly designed picking process and has to be finished before the actually development starts as proposed in chapter 4. Durst's IT department already started with the development during the research for this thesis, but as this process was still not finished yet and therefore it was not possible to provide further insights in this system and required connection points.

6 Conclusion

This projects scope was to design a new picking management for Durst and evaluate different implementation options. Thereby the three main improvement possibilities of changing the organisational structures, the physical picking process and the information system could be identified. Due to the fact that Durst is struggling with the data quality and required data quantity for statistical relevant statements, it is decided in consensus with the company to focus on the information system. A morphological schema helped to detect different implementation options for these systems. By evaluating various solutions pairwise against each other, the most promising option could be detected. It is a combination of the already used picking mode and digitally supported guiding fulfilling customer demands. The previously paper based processes are replaced by digital ones in order to make the process transparent and understandable for the management. It could also be shown, that the changing of the information system represents a starting point for adapting the physical picking mode and the organisational structure in the future.

Digitalization and working with data represents an important pillar for industry 4.0 and helps the management to take decisions. Nowadays, also software projects require huge investments and therefore even those have to be assessed precisely and requirements as well as systems engineering are approaches that help to fulfil this task objectively. The work with data requires creative people for analysis in order to be able to make sufficient and precise statements. Further research in the analysis phase is required to avoid wrong decisions and support automation projects.

7 Appendix

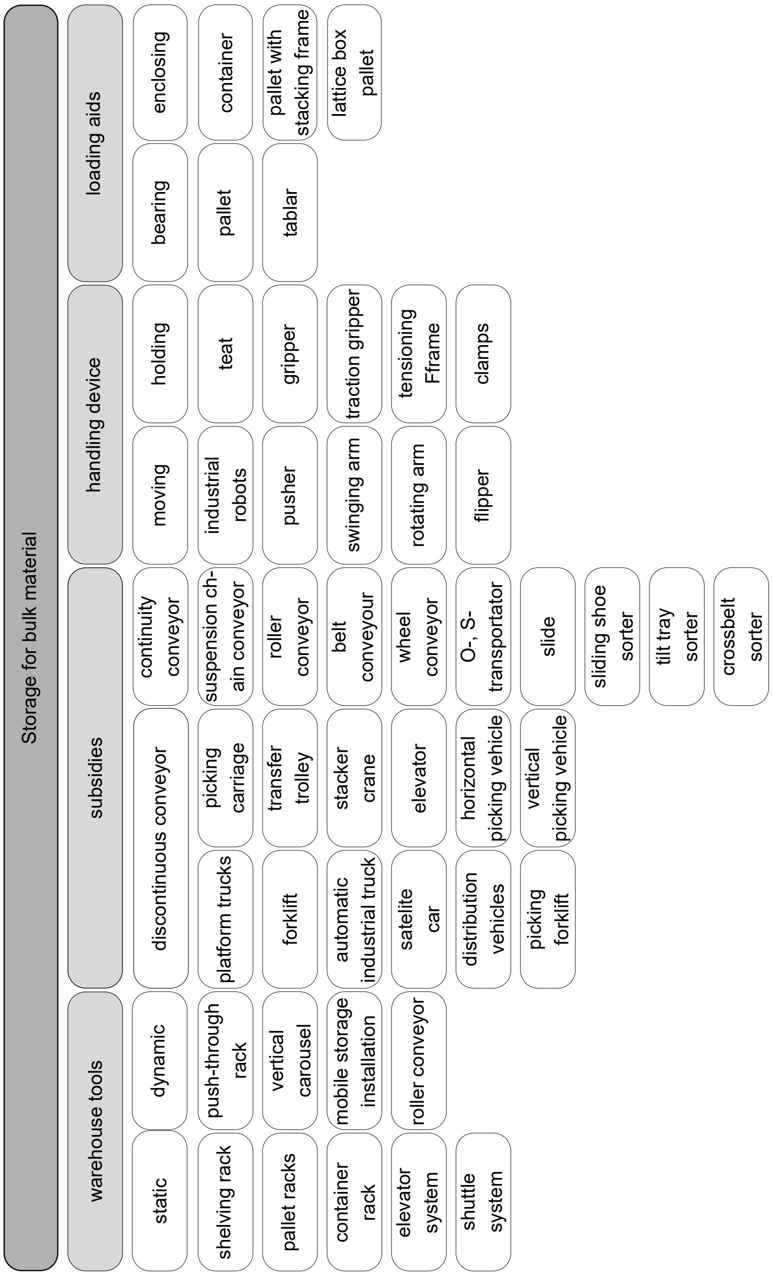

Figure 7.1: Technical function elements in picking systems (ten Hompel and T. Schmidt, 2010)

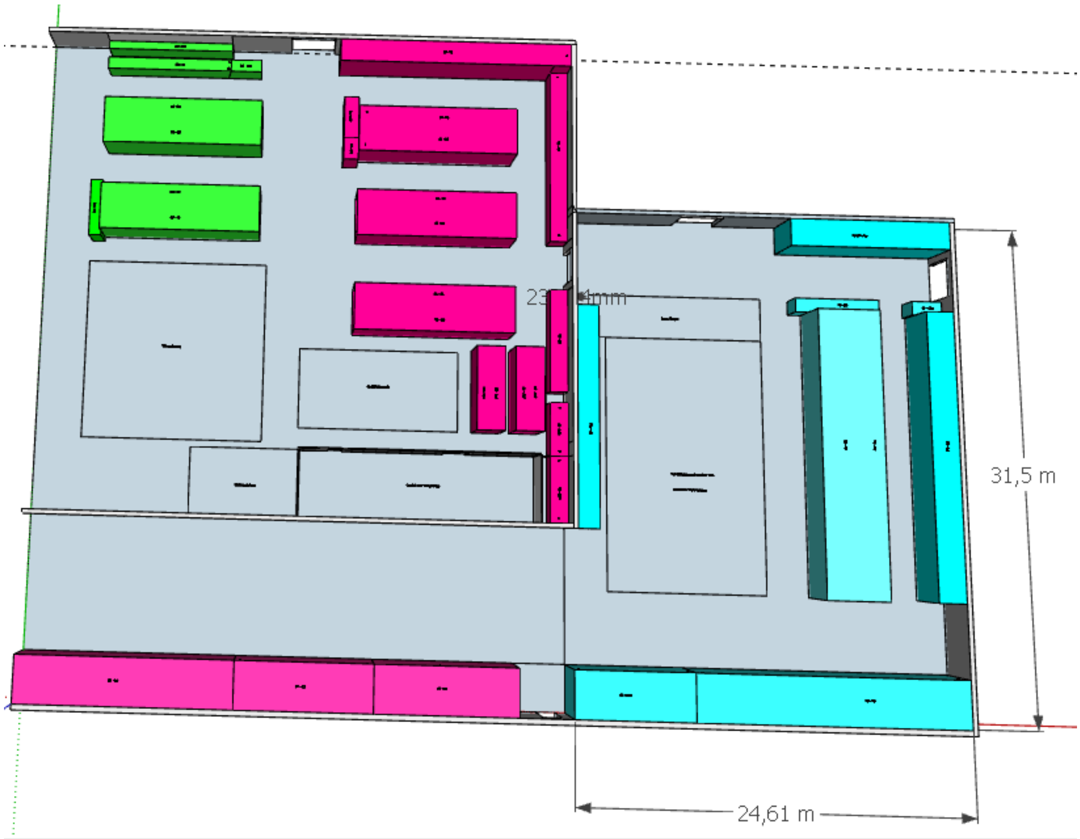

Figure 7.2: Structure of the main warehouse

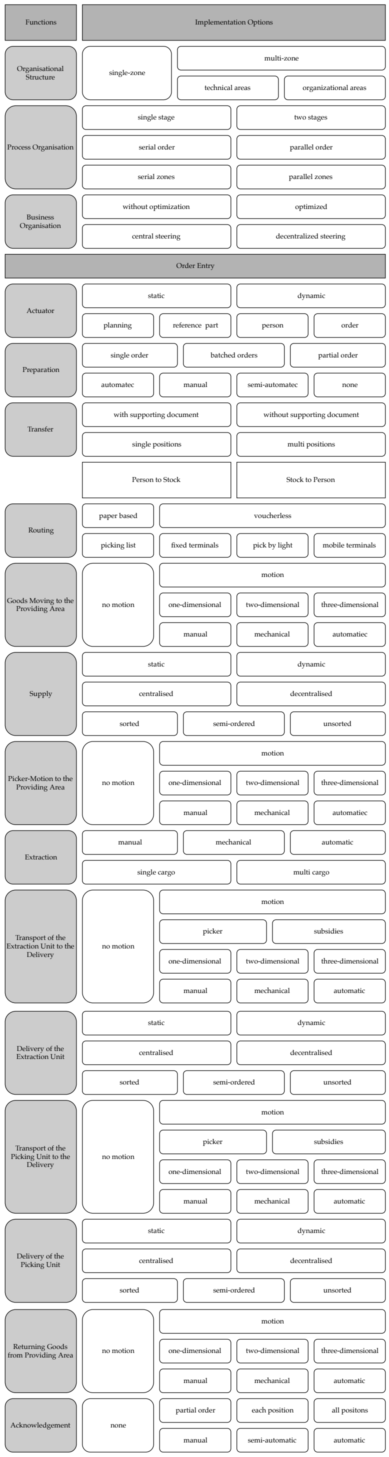

Figure 7.3: Morphological Scheme of the whole process

Figure 7.4: Technical function elements in picking systems (ten Hompel and T. Schmidt, 2010)

Table 7.1: Presentation of various warehouse management providers

Company	Product	Specification
epilog - WMS-WarehouseIT	Atlas WMS	Epilog is a pure system provider supplying warehouse management systems supporting material flows. Therefore it combines the co-ordination of automated transport equipment and the material management from receipt to dispatch. The interface is adaptable for different options as PC-monitors or mobile terminals. It is an modular build up system for different options supporting pick by glass and other features.
		`https://www.epilog.net`
Coglas - Logistic Solution	Coglas 5.x	Coglas is even a pure system provider. It is a modular and standardised gadget for small, mid sized and large companies supporting all possible processes in a warehouse. Focusing on the picking process, it supports all possible common picking options. Master data enables to determine package quantity and optimize the routing.
		`https://www.coglas.com`
Hoermann Logistik GmbH	HiLIS	Hoerman is a technology supplier by offering whole warehouse concepts. Since more than 20 years it is existing on the market. The IT system supports material flow and WMS functions. It is specialised on full automated storages providing an app with actual statistics on the work status.
		`http://www.hoermann-logistik.de`

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Table 7.1 – continued from previous page

Company	Product	Specification
Infor	Infor Supply Chain Execution	Infor is a suite supplier focusing on the optimization of the whole supply chain. Therefore it is a tool for storage-, personal-, tranportation-management and controlling with an single desktop interface. Target groups besides mechanical engineering sector are the pharmacy industry, the automotive industry, logistics provider and many others. It is a scalable solution for all kind of companies addressed to all company sizes.
https://www.infor.com		
Jungheinrich AG	Jungheinrich WMS	Junheinrich is a technology provider supplying companies with whole storage solutions with over 25 years of experience in IT solution for storages. With the supplying of warehouse equipment they started in 1953. So it is obvious, that the focus of there WMS is based on the material flow with the overview and steering of the machinery. But it provides even overview data for management tasks.
http://www.jungheinrich.it		

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Table 7.1 – continued from previous page

Company	Product	Specification
Klinkhammer Group	KlinkWARE	Klinkhammer is even a technology provider supplying companies with everything needed in a warehouse. Focusing on the picking process, their software supports all common picking possibilities such as pick by light and pick to vision. KlinkWARE is a solution for highly automated storages with many possibilities of providing services.
https://www.klinkhammer.com		
Ehrhardt & Partner	LFS.wms	Ehrhardt & Partner is a pure provider including systems for the supply chain for warehouses. Interfaces customized for all possible stakeholders are available. As target groups are defined all the sectors including even the engineering.
https://www.epgroupna.com		
Gigaton	LogoS	Gigaton is a pure supplier for WMS. It is a modular build up system with packages such as LogoS Beleg and LogoS production. It is a tool for planning the whole production with an integrated WMS. Therefore it could be even used as a planning advice and for triggering the need of picking. It is a gadget for big companies and small once - therefore it is scalable.
http://www.gigaton.de		

Continued on next page

Table 7.1 – continued from previous page

Company	Product	Specification
Opus//G	OPUS//WMS	Opus//G is a suite supplier providing software for warehouse management systems, transport control systems - which is closely related to an WMS - and the manufacturing execution systems. It suits from simple manual to high automated warehouses. This gadget makes an automation of the material flow possible with a control centre for overviewing the processes.
		`http://www.opus-g.com`
proLogistik	pL-Store	proLogistik is a pure supplier for intra logistics processes. Therefore it offers different software modules for picking, routing, material flow steering and WMS.
		`http://www.prologistik.com/en/`
CIM - Logistik-Systeme	PROLOG World	CIM - Logistik-Systeme is a provider for suite systems. Since more than 30 years they are producing WMS systems for all kind of companies. With different packages they are focusing on scalability and adaptability on different productions.
		`https://www.cim.de`
TEAM GmbH	ProStore	Based on Oracle-Technologie ProStore is a provider for intra logistics and WMS. Therefore it is a so called pure supplier built up modular. The system can be used in manual and automated storages providing the highest possible transparency for intra logistic material flows.
		`https://www.team-pb.de/en/`

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Table 7.1 – continued from previous page

Company	Product	Specification
PSI Logistics	PSIwms	PSI is a so called suite supplier providing software for a transparent and efficient warehouse processes. As many other tools, it is build up modular with certain standard options and separated packages. PSIlogistik
Aberle Software	SAP Warehouse Management	Aberle Software is a customizer for software such as SAP Warehouse Management. This software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations..
http://www.aberle-software.com/en/home.html		
arvato Systems	SAP Extended Warehouse Management	arvato System is a specialist in the field of digitalisation and uses standard solutions and custom build software to fulfil the digital transformation. The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
https://it.arvato.com/en.html		

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Table 7.1 – continued from previous page

Company	Product	Specification
	Logistics Execution SAP ERP	SAP Logistics Execution offers all the functions necessary for mapping the execution of logistics processes, with no industry-specific bias. The core functions of Logistics Execution are focusing on complex goods receipts and use processes.
		https://it.arvato.com/en.html
io-consultants	SAP Extended Warehouse Management	Is a planning and consulting company operating as suite supplier in the fields fo supply chain management, production, logistics, software architecture and IT projects. The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
		https://en.io-consultants.com

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Table 7.1 – continued from previous page

Company	Product	Specification
prismat	SAP Extended Warehouse Management	Is specialized for SAP applications and customisation with more than 25 years of experience. The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
		`https://www.prismat.de/en/welcome.html`
SAP SE	SAP Extended Warehouse Management	SAP is working in the field of business management and is one of the revenue strongest companies. The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
		`https://www.sap.com/corporate/en.html`

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Table 7.1 – continued from previous page

Company	Product	Specification
SSI Schaefer	SAP Extended Warehouse Management	The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
		https://www.ssi-schaefer.com/it-it
	WAMAS	Schaefer is a technology provider using the software tool WAMAS to control and optimize the warehouse processes as picking, cross docking and many others. It is used for storage automation with many warehouse functions.
		https://www.ssi-schaefer.com/it-it
IBS - Intelligent Business Solution	speedLOGIX	IBS is a supplier for pure software solutions. Build up in a modular way it is supplying complete solutions for usual processes with an just in time evaluation of actual states.
		http://www.ibsgmbh.ch

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Table 7.1 – continued from previous page

Company	Product	Specification
Stoecklin Logistik	Stoecklin Warehouse Management System	Stoecklin is a suite supplier for software and partly a technology supplier as they are delivering industrial trucks. The WMS is used for automated and manual storages with integrated functions such as configurable storage strategies and incoming goods steering. Mostly they are supplied as general contractor working together with other companies in order to become a whole technology supplier.
`https://www.stoecklin.com`		
Dr. Brunthaler - Industrielle Informationstechnik	storagement 4.9	Is a pure supplier for WMS systems build up in a modular way. The basic version is supporting all necessary warehouse processes
`http://www.brunthaler.com`		
S&P Computersysteme	SuPCIS	S&P is a pure supplier for WMS providing the needed hardware and software for their systems. As most of the other systems it is build up in a modular way and used in manual and highly automated storages.
`https://www.sup-logistik.de/Homepage-90841,l-en.html`		
XELOG AG	XELOG WMS	XELOG is a pure software supplier guiding an optimizing all processes in the intra logistics field. It is build for middle sized and big companies in fields of logistic suppliers, assembly industry and commerce. This gadget is even supporting smart picking processes.
`http://www.xelog.com`		

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Table 7.1 – continued from previous page

Company	Product	Specification
active logistics Koblenz	active ilos	active logistics is pure supplier for WMS. Many different gadgets and interfaces make universal usage of the tool possible. A modern software architecture supports using up to dates business frameworks.
https://www.active-logistics.com		
AEB - Advanced Global Trade Solutions	ASSIST4	AEB is a pure supplier for WMS with more than 35 years of market experience in this sector. The software is supporting the main functions of intra logistics warehousing for small, middle and big companies with automated, partly automated and manual systems.
aebadvancedglobaltradesolutions		
BSS Bohnberg	BSS-L	BSS is a technology supplier operating as general contractor and provides the software to connect different systems. There main operation fields are full automated warehouses for midle sized companies.
http://www.bss-materialflussgruppe.de/en/home.html		
inconso AG	WMS eXtednded	Inconso is a suite provider for WMS offering even Addons for warehousing. Build up modular and offering scalability it is a solution for all kinds of warehouses in all sectors.
https://www.inconso.com/en/home/		

Continued on next page

Table 7.1 – continued from previous page

Company	Product	Specification
TGW - Living Logistics	iWACS.WM	TGW is a technology provider. Focusing on the software department, they are offering different suits for logistic tasks. The iWACS system is supporting all core cometences in a warehouse and mainly used in part automated storages.
https://www.tgw-group.com/en/Living-Logistics		
	DI_LOG	Is a interdisciplinary solution for industry and commerce. This gadget is focusing on the steering task within a warehouse and therefore mainly used in full automated facilities
https://www.tgw-group.com/en/Living-Logistics		
KBU-Logistik	KBU-LVS	KBU is a so called suite supplier offering software for WMS. The software is related to middle sized companies build up in a modular way.
http://www.kbu-logistik.de		
Kugler Consulting	KC-WMS	KuglerConsulting is a suite supplier offering customized software for warehousing since more than 30 years. With the modular build up system, they are capable to fit there solution to dynamic warehouses, full automated warehouses, stacker control systems and other solutions.
http://www.kuglerconsulting.com		

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Table 7.1 – continued from previous page

Company	Product	Specification
Knapp	KiSoft WMS	Knapp is a technical provider offering whole logistic solutions. There software is build up in an modular way combining all warehouse tasks. It is a scalable system adaptable to simple solutions as paperless processes for full automated systems. Thereby it is possible to automate only the IT part or the whole process chain. https://www.knapp.com
	SAP Extended Warehouse Management	The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies. https://www.knapp.com
a-SIS	LM	a-Sis is a suite provider supplying warehouse software for company independent and database independent applications. a-Sis is operating mainly in non German speaking countries penetrating the Italian marked. https://www.asisonline.org
Centric Netherlands	Locus Wms	Centric Netherlands is a suite provider for different warehouse tasks. They are offering special software and packages for data exchange between different systems providing stuff in the warehouse and on other places.

Continued on next page

Table 7.1 – continued from previous page

Company	Product	Specification
https://www.centric.eu/EU/Default/About-Centric		
SALT Solutions AG	SAP Extended Warehouse Management	Salt Solution is a provider for SAP customizing having clients as KNAPP for their WMS. The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
https://www.salt-solutions.de/?gclid=CjwKCAjw7tfVBRBOEiwAiSYGM43KVQ jukElAlRFOCeO06CrXjWKLcgxIH2l-zv_num_aNBwnrixcmhoCj6QQAvD_BwE		
Mantis Informatics S.A.	Logistics Vision Suite	Mantis is a suite provider for warehouse systems. There systems are flexible and adaptable to modern requirements. Functions as warehouse automation, warehouse control, logistics customer services and others are available. Therefore it is even an modular build up system.
http://www.mantis.group		
AJE Consulting	LOSSY - Logistik Organisation Steuerung Systeme	AJE is a pure provider offering even gadgets as barcode scanners. It is specialised to all branches and related to all company sizes. Build up in an modular way, it provides particular radio, reducing errors and speeding up lead times.
http://www.aje.de		

Continued on next page

Table 7.1 – continued from previous page

Company	Product	Specification
iFD	LSVSS	iFD is a suite provider for logistic software. Certain standard modules are available and others are customised for the clients requirement.
		`http://www.ifd-gmbh.com`
aqcon	Lxone	aqcon is a provider for pure software solution. As all the other providers, this solution is build up in an modular way and not only the management and storing are part of this solution, but even the steering and controlling. The website is promoting an universal use of there system.
		`http://www.aqcon.com/de/home/home.php`
Manhattan - Associates Europe	MA WM	Manhatten is a provider for suite systems. Therefore they are not only offering WMS systems but whole supply chain solutions usable on all operating systems. There software is related to different system promoters.
		`http://www.manh.com`
Kardex Deutschland	Power Pick	Kardex is a technical provider. Scalability is promoted across the 3 packages of power pick 1000, power pick entry and power pick 5000.
		`https://www.maschinenmarkt.vogel.de/kardex-deutschland-gmbh/firma/173326/`
Wanko - Information-slogistik	PRAMAG 3000	Wanko provides a suite solution. As all the other system it is build up in an modular way with interfaces to own stacker control system. It is a high flexile solution adaptable to changes in the own processes.

Continued on next page

Table 7.1 – continued from previous page

Company	Product	Specification
https://www.wanko.de/index.asp		
gdv Kuhn	PROBAS	Kuhn is a pure supplier with Probas as an overall system. Probas has some sub systems as the flow of material calculator or the storage management.
https://www.gdvkuhn.de		
Proway	Proway Business	Proway is a system house organized in a network. It supports different application and interfaces to various external applications.
http://www.proway.de/en/		
Hardis Group	Reflex	Is a provider for suite systems solution.
https://www.hardis-group.com/en		
FIS Informationssysteme und Consulting	SAP Locistics Execution	Is basically the same system as SAP WMS adding the functions ot task and resource management and transportation. Therefore FIS is a customizer of an standard software.
https://www.fis-gmbh.de/de/		
Cpor Industry Projects & Soltions	SAP Extended Warehouse Management	Copor is a company focusing on SAP and own custom build solutions. The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.

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Table 7.1 – continued from previous page

Company	Product	Specification
		https://www.cpro-ips.de/s4hana/
IGZ - Ingenieurgesellschaft fuer logistische Informationssysteme	SAP Extended Warehouse Management	IGZ is a specialised SAP customization company. The software provides flexible systems supporting the material flow and management. IIt is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
		http://www.igs-logistics.com/en/
viastore Software GmbH	SAP Extended Warehouse Management	Visitatore is a technology provider offering SAP EWM for management tasks. The software provides flexible systems supporting the material flow and management. It is integrable in the standard SAP with the functions of storage place management, material flow control, steering and monitoring operations, database connectivity and decentralized WMS operations. Used to make processes transparent in middle sized and big companies.
		https://www.viastore.com/en/
psb intralogistics	selectroon	psb is a technology provider delivering whole systems. As many others they are focusing on the automation of systems and therefore there software suits more or less to full automated storages. Steering the production and WMS are the core of the individualized applications.

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Table 7.1 – continued from previous page

Company	Product	Specification
https://www.psb-gmbh.com		
Berco	SIC Sone	SicSone is a modular build up system supplied by a pure provider. All the usual gadgets are available.
http://www.bercologistics.co.za/BAW/ecommerce/EN/html/response.asp?qry=Login		
SOG Business-Software	SOG LVS	SOG LVS is s suit supplier offering software for the whole warehousing process. They are promoting their product with modularity and low investment costs.
https://www.sog.de/erp-warenwirtschaft/uebersicht-erp.html		
SOLVO	Solvo.WMS	Solvo is a Russian company providing suite systems for warehousing.
http://www.solvo.ru/en/products/solvo-wms/		
common solutions	sterologix	Is a pure software supplier for complex logistic solutions. It is special used in e commerce businesses and others.
http://www.common-solutions.de		
Unitechnik Systems	UniWare4	Unitechnik is a general contractor for intra logistics systems focusing on the software task as pure supplier. It is possible to supply full automated warehouses on the basis of Siemens s7.
https://www.unitechnik.com		

Continued on next page

Table 7.1 – continued from previous page

Company	Product	Specification
Siemens	VarioLogistics Suite	Siemens is a technology supplier offering many systems and many products in cross-industry networks. It helps to optimize actual processes and grantees an easy connection to storage steering advices.
http://www.logistics-airports-solutions.siemens.com/las/global/en/pages/postal-parcel-airport-logistics.aspx		
Vanderlande Industries	Vision	Vanderlands is a company with more than 60 years of experience in the material flow sectors (technology provider). It is offering a software capable to implement in all kind of warehouses (manual, partly manual and fully automated).
https://www.vanderlande.com		
Optimizer	WM.O	Is a suite supplier focusing on logistic software.
https://www.optimizers.nl/en/		
SITLog	WMC	Sit log is a technology provider. The system is focusing on the material flow and therefore hardware addicted by steering the warehouse applications.
http://www.sitlogistics.it		
ita vero	WMS eXted-nded	itavo vero is a pure supplier for intra logistics software. The software target group are middle sized companies and logistic suppliers. The system is mainly used in high automated solutions but can be adapted to manual systems.
http://www.itavero.de/loesungen/warehouse-management-system		

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Table 7.1 – continued from previous page

Company	Product	Specification
aisys Advanced Information Systems	x Storage	aisys is a provider for suite pure software solutions in the field of warehousing. Process experts and developers are working together in order to build new products with new ideas. It is easy to use and fast to implement.
https://www.mhp-solution-group.com/lagerlogistik.html		

Table 7.2: Analysed warehouse management systems

		Language of the Interface			Additional Abilities			Bearing Technology					Bran.		SAP Systems
		German	Italian	English	Logistics Planning	Warehouse Planning	IT Planning	Small Part Store (stacker crane)	Small Part Store (Shuttle)	Small Part Store (manual)	Shelf Warehouse (manual)	Block Storage	Prodction	Plant Engineering	
Aberle Software	SAP Warehouse Management	+	-	+	+	-	+	+	-	+	+	+	+	+	+
active logistics Koblenz	active ilos	+	-	-	-	-	+	-	-	+	+	+	+	+	-
AEB - Advanced Global Trade Solutions	ASSIST4	+	-	+	-	-	+	+	-	+	+	+	+	+	-
aisys Advanced Information Systems	xStorage	+	-	-	-	-	+	+	+	+	+	+	+	+	-
AJE Consulting	Lossy	+	-	+	+	+	+	+	+	+	+	+	+	+	-
aqcon	Lxone	+	-	+	+	+	+	+	+	+	+	+	+	+	-
arvato Systems	Logistics Execution SAP ERP	+	+	+	+	+	+	+	+	+	+	+	+	+	-

Continued on next page

Table 7.2 – continued from previous page

Company	Product	Evaluation													
arvato Systems	SAP Extended Warehouse Management	+	+	+	+	+	+	-	+	+	+	+	+	+	+
a-SIS	LMxt	+	+	+	+	+	+	+	+	+	+	+	+	-	-
Berco	SICSone	+	-	+	-	+	+	+	-	+	+	+	+	+	-
BSS Bohnberg	BSS-L	+	-	+	+	+	+	+	-	+	+	+	+	+	-
Centric Netherlands	Locus WMS	+	+	+	-	+	+	+	+	+	+	+	+	-	-
CIM - Logistik-Systeme	PROLOG World	+	+	+	+	+	+	+	+	+	+	+	+	+	-
Coglas - Logistic Solution	Coglas 5.x	+	+	+	+	+	+	+	+	+	+	+	+	+	-
common solutions	storelogix	+	-	+	-	-	+	-	-	+	+	+	+	+	-
Cpor Industry Porjects & Soltions	SAP Extended Warehouse Management	+	+	+	-	-	+	+	-	+	+	+	+	+	+
Dr. Brunthaler - Industrielle Informationstechnik	storagement 4.9	+	-	+	+	+	+	+	+	+	+	+	+	+	-
Ehrhardt & Partner	LFS.wms	+	+	+	+	+	+	+	+	+	+	+	+	+	-
epilog - WMS-WarehouseIT	Atlas WMS	+	+	+	+	-	+	+	-	+	+	+	+	+	-

Continued on next page

Table 7.2 – continued from previous page

Company	Product	Evaluation													
FIS Informationssysteme und Consulting	SAP Extended Warehouse Management	+	+	+	+	-	+	-	-	+	-	+	+	+	+
gdv Kuhn	Probas	+	-	-	+	-	+	+	+	+	+	+	+	+	-
Gigaton	LogoS	+	-	+	+	-	+	+	+	+	+	+	+	+	-
Hardis Group	Reflex	+	+	+	-	+	+	+	+	+	+	+	+	-	-
Harmann Logistik GmbH	HiLIS	+	+	+	+	+	+	+	-	+	+	+	+	+	-
IBS - Intelligent Business Solution	speedLOGIX	+	-	+	+	+	+	-	-	+	+	+	+	+	-
iFD	LVSS	+	+	+	-	+	+	+	+	+	+	+	+	+	-
IGZ - Ingenieurgesellschaft f¸r logistische Informationssysteme	SAP Extended Warehouse Management	+	+	+	+	+	+	+	+	+	+	+	+	+	+
inconso AG	WMS eXtednded	+	+	+	+	+	+	+	-	+	+	+	+	+	+
Infor	Infor Supply Chain Execution	+	+	+	+	+	+	+	-	+	+	+	+	+	-
io-consultants	SAP Extended Warehouse Management	+	+	+	+	+	+	+	+	+	+	+	+	+	-
ita vero	WMS.O	+	-	+	+	+	+	+	+	+	+	+	+	+	-

Continued on next page

Table 7.2 – continued from previous page

Company	Product	Evaluation													
JDA Software		+	+	+	+	+	+	+	+	+	+	+	+	+	-
Jungheinrich AG	Jungheinrich WMS	+	+	+	+	+	+	+	+	+	+	+	+	+	-
Kardex Deutschland	Power Pick Global	+	+	+	+	+	+	+	+	+	+	+	+	+	-
KBU-Logistik	KBU-LVS	+	-	+	-	+	+	+	+	+	+	+	+	+	-
Klinkhamme Group	KlinkWARE	+	-	+	+	+	+	+	+	+	+	+	+	+	-
Knapp	KiSoft	+	+	+	+	+	+	+	+	+	+	+	+	+	-
Knapp	SAP Extended Warehouse Management	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Kugler Consulting	KC_WMS	+	+	+	+	+	+	+	-	+	+	+	+	+	-
Manhattan - Asociates Europe	MA WM	+	-	+	+	-	+	+	+	+	+	+	+	-	-
Mantis Informatics S.A.	Logistics Vision Suite	-	-	+	+	+	-	-	+	+	+	+	+	-	-
Optimizer	Warpspeed	-	-	+	-	-	+	-	-	+	-	+	+	-	-
Opus//G	OPUS//WMS	+	+	+	+	-	+	+	-	+	+	+	+	+	-
prismat	SAP Extended Warehouse Management	+	+	+	+	-	+	+	+	+	+	+	+	+	-
proLogistik	pL-Store	+	-	+	+	-	+	+	+	+	+	+	+	+	-
Proway	Proway	+	-	+	-	-	+	+	-	+	+	+	+	+	-

Continued on next page

Table 7.2 – continued from previous page

Company	Product	Evaluation													
psb intralogistics	Selectron WMS	+	+	+	+	+	+	+	+	+	+	+	+	+	-
PSI Logistics	PSIwms	+	-	+	+	+	+	+	+	+	+	+	+	+	-
S&P Computersysteme	SuPCIS	+	+	+	+	+	+	+	+	+	+	+	+	+	-
SALT Solutions AG	LogBase	+	-	+	+	-	+	+	+	+	+	+	+	+	-
SAP SE	SAP Extended Warehouse Management	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Siemens	VarioLogistics Suite	+	-	+	-	+	+	+	-	+	+	+	+	+	-
SITLog	WMC SITLog	+	-	+	-	+	+	+	+	+	+	+	+	+	-
SOG Business-Softwar	SOG LVS	+	-	+	+	+	+	+	-	+	+	+	-	+	-
SOLVO	Solvo.WMS	-	-	+	-	+	-	+	-	+	+	+	+	+	-
SSI Schaefer	SAP Extended Warehouse Management	+	+	+	+	+	+	+	+	+	+	+	+	+	+
SSI Schaefer	WAMAS	+	+	+	+	+	+	+	+	+	+	+	+	+	-
Stuecklin Logistik	Stuecklin Warehouse Management System	+	+	+	+	+	+	+	-	+	+	+	+	+	-
TEAM GmbH	ProStore	+	-	+	+	-	+	+	+	+	+	+	+	+	-
TGW - Living Logistics	iWACS	+	+	+	+	+	+	+	+	+	+	+	+	+	-

Continued on next page

Table 7.2 – continued from previous page

Company	Product	Evaluation													
Unitechnik Systems	UniWare4	+	-	+	+	+	+	+	+	+	+	+	+	+	-
Vanderlande Industries	VISON	+	+	+	+	+	+	+	+	+	+	+	+	+	-
viastore Software GmbH	SAP Extended Warehouse Management	+	-	+	+		+	+	+	+	+	+	+	+	+
viastore Software GmbH	viadat	+	-	+	+	+	+	+	-	+	+	+	+	+	-
Wanko - Informationslogistik	Pramag 3000	+	+	+	+	+	+	+	-	+	+	+	-	+	-
XELOG AG	XELOG WMS	+	+	+	+	-	+	-	-	+	+	+	+	+	-

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