Integrating a warehouse management system

A feasibility study

Bachelor Thesis
Industrial Engineering and Management

Ruben Wienk

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Preface

In front of you lies my bachelor thesis “Integrating a Warehouse Management System”, which is a feasibility study I performed at the company Schmits Chemical Solutions. With the completion of this research, I am graduating my bachelor study Industrial Engineering and Management at the University of Twente.

First, I want to thank the employees of Schmits for giving me the opportunity to perform my bachelor thesis at their company. Above all Miechel Zweers for supervising my research at the company and his involvement in my project. Also, the other employees for helping me with my questions and making me feel welcome at the company.

Second, I want to thank Devrim Yazan, my supervisor from the University of Twente. Despite his busy schedule, he was able to find time for me to discuss my approach and progress of the thesis. I also want to thank Guido van Capelleveen for being the second reader for this thesis.

Finally, I want to thank my family for their full support during my bachelor study. And my fellow student Wilco Nieuwenhuis, for providing me useful feedback on my thesis and being always open for discussions regarding the bachelor thesis.

I hope you will enjoy reading my report!

Ruben Wienk

September, 2019

Management summary

Background

Schmits is a company active in the chemical industry that provides chemical solutions to its customers. Currently, inventory is managed in the ERP system of the company by processing written reports on inbound, outbound and production flows of materials in the warehouse. It can concluded that this procedure is inefficient and prone to human errors. There is need for a system that can support warehouse management with a more automated approach for inventory control and tracking and tracing, so the company is thinking about investing in a warehouse management system. In this way, Schmits can automate more of their management processes in the factory and improve their inventory management. However, the company does not have enough insights yet on the properties of these system, how to incorporate such a system in the organization and its effect on the relevant management processes. In this research I gave the company advice on this matter, so they are better prepared when meeting with potential suppliers of these system in the future and a well-informed investment can be made.

Research approach

In the first step of my research, I performed a literature study to assess what the functionalities are of warehouse management systems and what the possibilities are for the company in this field. Also, I attended two meetings with potential suppliers of these systems. With this information as input, I conducted interviews with the involved parties about the possible functionalities to set priorities and formulate requirements for the system using the MoSCoW method.

After the requirements for the system were set, I used business process modelling to illustrate the current and the proposed new situation in the factory. The processes in the factory are separated in two diagrams. The first starts at an incoming order and ends when all required raw materials for the order are procured and stocked in the warehouse. The second diagram follows the production steps where the raw materials are transformed in the end product until the product is picked up and distributed to the customer. With these diagrams, the differences in the process flow and data flow between the current and new situation can be depicted, so that the impact of a warehouse management system on the process in the factory can be analyzed and conclusions can be drawn.

Based on this analysis, an end advice is formulated that gives insights in important considerations for the company when a future investment in a warehouse management system is made. The advice is divided in system specific considerations and management considerations.

Advice

System considerations

- From observations at the company, it came forward that the warehouse operations at Schmits are various and differ a lot per order. In order to adopt a warehouse management systems that guides the workers through each warehouse management operation step, a degree of flexibility is needed from the system. Also, the WMS must be properly communicating with the company's ERP system to synchronize

information. If these systems complement each other well, administration can be further automated. In order to establish flexibility and communication with the ERP system in the WMS, the system must be partly customized and configured to the specific procedures at the company. This results in additional development costs for the supplier, so a good balance have to be found in this, where the system is flexible and falls within the budget of Schmits.

- There are two aspects where practical experience of experts in this field of work is required and theoretical research is not sufficient to give the company clear advice. First, there is the consideration about the hardware implementation of the system: it must be possible to scan materials while on a forklift as well as with hand scanners. Which solution is the most practical here can better be determined by suppliers of these systems in cooperation with Schmits. Second, it must be considered which objects to include in the inventory control. It is obvious that the inventory levels raw materials and finished products will be monitored by the system, but it might also be possible to include the various packaging materials of the finished products. The practical feasibility of this possibility may be determined by the suppliers.
- During the interviews at the company, it came forward that there were some practical difficulties expected during the execution of a slotting method, which allocates the materials over the warehouse systematically. A warehouse management system can function properly without such a functionality and it could always be added after the rest of the system is established in the company.

Management considerations

- When a warehouse management system is implemented in the company, the manual administration of paper documents will be replaced by direct administration in the system. This will result in a shift of work for the factory managers, a new task for them is to monitor the execution of the WMS during processes in the factory. This monitoring is important, because the factory workers get much more responsibility in this situation, since they can directly change data in the system. Especially in the early phase of the implementation of the system, when workers are not yet acquainted with the new methods, monitoring is crucial.
- A second importation management consideration is how make everyone involved committed to adopt the system in their way of working. New technologies can face some resistance in company's sometimes, when employees are used to a certain way of working. Therefore training of personnel is essential to get acquaintance with the system. An additional way of creating commitment to the WMS is with 'theme weeks'. Schmits works with this method to pay extra attention to a certain subject for a couple of weeks based on KPI's. It may be a good idea to designate theme weeks to the execution of the warehouse management system. In this way, everybody is involved in the process and disagreements can be settled during weekly evaluations.
- A good cooperation with suppliers of materials can support the utilization of the warehouse management system. During the business model analysis, it came forward that a confirmation of receiving goods is convenient for the WMS to already generate barcodes and location slots. But also, if data sharing is possible between the companies, Schmits can possibly use the barcodes of the supplier, which is more efficient and saves work.
- When the warehouse management system is integrated in the company, there will be much more data collected in the factory. It must be considered how to use this data and what KPI to formulate to measure warehouse and production performance.

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Definitions of terms

- **ERP system**: Abbreviation for enterprise resource planning. A software system used by companies to manage and integrate all important parts of their businesses. It can integrate for instance planning, sales, finance and inventory purchase.

- **WMS**: Abbreviation for warehouse management system. It is a more specific software system in comparison with an ERP and is mainly focused on controlling and managing warehouse operations from the time materials enter the warehouse until they move out.

- **IBC** is short for intermediate bulk container. IBC's are used to store liquids and have a volume of one thousand liters. At Schmits, IBC's are the most used storage units for chemicals.

1. Introduction

1.1 About Schmits

Schmits Chemical Solutions is a business to business company located in Almelo that is active in the textile and cleaning industry as a partner for custom-made solutions. For the textile and non-woven industry, the company produces mostly self-developed coatings that can add extra characteristics to the fabric, like flame retardant or water-repellent coatings. For the cleaning industry they supply industrial cleaning products. Schmits is very flexible for their customers in terms of lead times and their product packaging volumes, which can vary between small flacons and whole tank trucks.

Schmits has a factory, consisting of a warehouse, a production facility and a loading dock. The chemical products are produced in large production kettles according to mostly self-developed product recipes. Schmits also has their own bottling lines for filling their product in flacons. The warehouse halls store a wide range of raw materials for these productions, but there is also a hall where the finished products are stored. In these halls, there must be dealt with chemical safety restrictions that come with, for instance, explosive and corrosive materials.

Figure 1.1: The factory of Schmits Chemical Solutions

1.2 Problem identification

The company's turnover has grown significantly over the last couple of years and the production and logistics departments are striving to keep their processes under control. At the moment, the warehouse management operations of Schmits are not running optimal. There are multiple problems that arise when the management processes are observed.

Firstly, the allocation of raw materials over the places in the warehouses are done manually. The chemicals are assigned a place in the warehouse by using standard places for each material. The question is if this way of working is the most practical and efficient, because there might be systems that can allocate the materials in a more optimal way.

The second problem is that the allocated raw materials are not linked to their assigned places in the warehouse with a track and trace barcode system. The location code must be written down on the delivery receipt and can be manually put into the ERP system, but only one location code can be linked to a material. So, if a material has multiple locations in the warehouse, there is only one location code of the material in the system. This leads to a poor traceability and a relatively big margin of error.

What also came forward is that currently the exact amount of chemicals used in production processes are written on the production report during production and the inventory level is updated manually in the ERP system by one of the production managers afterwards. Sometimes there is confusion about the way the factory workers note the used amounts on the report, which can lead to misinterpretations and human errors. Also, some time passes before these production reports are processed in the system, so the inventory levels are not up to date.

Due to the poor traceability and the margins of error, it can happen that production processes are delayed because chemicals cannot be found quickly or are not even in stock. This can have big impacts on relations with the customer, if delayed production results in delayed delivery to customers. It can be concluded that the procedure in the warehouse is inefficient and could have a more systematic and automated approach.

The company is thinking about investing in a warehouse management system, where the chemicals can be automatically allocated over the warehouse and linked with a barcode to their assigned location, so that there is better traceability and no faulty placements. With a system like this, it is also possible that the inventory levels of the chemicals used in a production process are directly updated during production. In this way, Schmits can automate more of their management processes in the factory and improve their inventory management. However, the company does not have insights yet on how to incorporate such a system in the organization and its effect on the relevant management processes.

1.3 Core problem and problem cluster

From the problem identification, a problem cluster can be derived, which is a helpful tool for identifying the core problem. It is mapped on causality and the eventual core problem is directly or indirectly the cause of all problems in the cluster. (Heerkens & Winden, 2012) The core problem is marked with red.

From the problem cluster and problem identification can be concluded that the core problem of the company is: There is no all-embracing warehouse management system. The goal of this research is not going to be to solve this problem, because the company must make an investment in such a system themselves. However in this assignment, an underlying aspect of the core problem will be solved: there are not enough insights on how to integrate a warehouse management system in the company and what the properties of these systems can be. I will give the company advice on this matter, so they are better prepared when meeting with potential suppliers of these system in the future and a well-informed investment can be made.

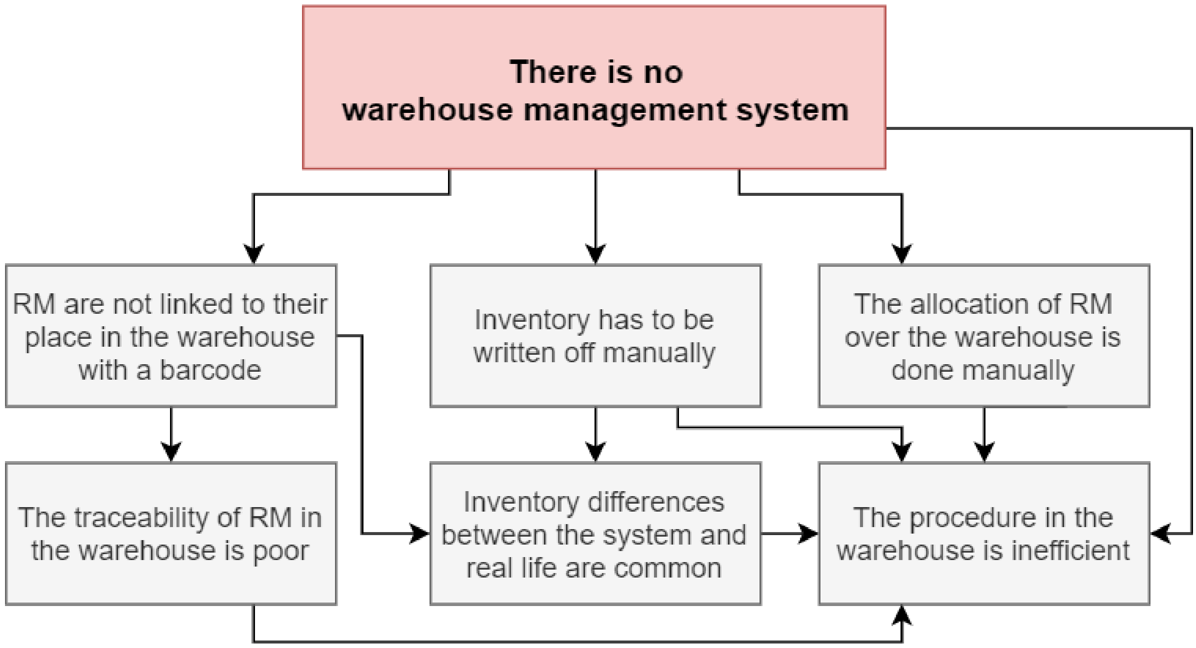


Figure 1.2: The problem cluster

1.4 Norm and reality

Currently, the procedure in the warehouse is inefficient, which is explained thoroughly at the problem identification. It is believed that this can be improved by incorporating a warehouse management system with a barcode system, so that a lot of management processes can be performed systematically. However, the reality is that Schmits does not have many insights yet on how to implement such a system. While the norm should be that there are sufficient insights on this subject, so that a well-considered investment can be made. This gap between norm and reality can hopefully be covered by my advice based on the research.

Besides the gap of insights in a WMS, more gaps between norm and reality can be observed from specific warehouse management processes. These gaps will not be resolved by my research, but hopefully by the functionalities of a WMS. See the table below.

Reality	Norm
Not many insights on WMS	Enough understanding of WMS in specific situation for a well-considered investment
Raw materials allocated manually	Raw material allocated automatically by software
Raw materials not linked to their location in the warehouse	Raw materials linked to their location with a barcode
Raw materials manually written off after production	Inventory level of raw materials directly updated during production
Poor traceability	Good traceability
Inventory differences between system and real life are common	Inventory differences between system and real life are rare

Table 1.1: Gap between norm and reality

1.5 Stakeholder analysis

For the stakeholder analysis, the factory managers and all departments in the organization that have anything to do with the research must be considered. The technical director is my supervisor from the company and the person responsible if it comes to an integration of a warehouse management system in the future. The factory manager and assistant factory manager are the employees that are dealing with most of warehouse management processes at the moment. Currently these tasks are mostly manual, with help from the ERP system. When a warehouse management system gets implemented however, many of their administrative tasks, like processing delivery receipts and production reports in the system, will not be necessary anymore.

The two foremost departments of importance for the research are the logistics and production department. The logistics department takes care of all inbound and outbound logistics from the company. The production department allocates the inflowing raw materials over the warehouse, picks it up when it is needed for production and notes the amount of material used, so that the inventory level in the ERP system can be updated. These activities involve many warehouse management processes, so the departments will be dealing quite a lot with the WMS, will it be integrated. The most important stakeholders in these two departments are the logistics coordinator and the production coordinators. But also the regular workers in these departments must be taken into account, because they could give insights in difficulties and experiences during a working day.

Besides the employees of the company, the suppliers of warehouse management systems must also be considered. Suppliers can make systems that are tailored to the company, so they have quite some knowledge about possible functionalities of the system and the effect on management processes in the warehouse. During the bachelor thesis, I could join two exploratory meetings with potential suppliers of the system and the technical director of Schmits. These meetings and the resulting quotations for Schmits were very helpful input for my thesis and gave me more practical insights, in addition to the theoretical literature. The report on these meetings can be found in appendix B.

1.6 Scope of the research

As already described at the research approach and the analysis of the core problem, the focus of this thesis is to provide advice to the company for implementing a warehouse management system in the future. In order to deliver well-considered advice in a 10-week-timeframe, which is the indicated length of the thesis, boundaries for the research must be set. Therefore, some aspects are treated below that will not be included in this research.

In the first place, quantitative data collection and data analysis to measure warehouse performance are not part of this thesis. This is because there is currently no hardware, like handheld barcode scanners, used in the warehouse to document information. Therefore, the ERP system of the company cannot provide useful data to formulate KPIs that measure warehouse performance. The identified problems cannot be quantified and are based on interviews and observations at the company. So, the advice for the company will be qualitative and not quantitative by nature.

Secondly, the research is focused only on the supply chain within the walls of the company, the warehouse processes. So, the procurement process and the demand forecasting of the company, that might also contribute to warehouse performance, are not addressed in detail in this thesis. This is because these functions are more the responsibility of the company’s ERP system, and not that of the eventual warehouse management system.

1.7 Assessment of validity

In the micro lectures of Hans Heerkens (2015), validity is classified in three different types: internal validity, construct validity and external validity. Firstly, internal validity must be considered, for this type of validity the biggest threats are deprivation and unrepresentative sampling. Because the functionalities a warehouse management system adds to the company might feel as a deprivation of tasks for some employees. For instance, when the system takes over administrative tasks that are usually executed by workers. Unrepresentative sampling might occur during conducted interviews at the company. If it is the case that more talks are done with workers that are easy to talk to, their viewpoint might be taken into account too much. So, it is important that I have talks with everybody involved and consider every viewpoint, without getting biased.

Secondly, construct validity is important for the thesis. Incorrect use of literature might be a threat, because articles about WMS are not timeless, since it is a continuously developed technology. Information cannot be literally adopted from an article that is ten years old, for example. A second construct validity threat is that the operationalization and measuring will be too one dimensional. So, there must be a good balance in information retrieved from literature, interviews and meetings.

Finally, external validity must be taken into account. The threat here is that the research on the company and its situation are too unique to apply to other studies. Especially the environmental circumstances and the time are unique, because the company has a production facility next to their warehouse where the emphasis is on specific processes. This also has effects on the choice of a WMS, since the company needs specific requirements for their system.

1.8 Research approach and deliverables

In order to give the company well-considered advice on integrating a warehouse management system for their particular situation, requirements for the design of the system will be formulated. This starts by doing a literature study, where similar cases or articles on the functionalities of warehouse management systems will be examined. From this, a list of potential functionalities is defined that could be suitable for the company's production warehouse. This list is used as input for interviews with employees of the company to find out what their opinions are on how each functionality fits their way of working and if some functions must be prioritized. From the results of the interviews, requirements can be formulated for the warehouse management system, ranked on priority. A method that helps with formulating prioritized requirements is discussed in chapter 2.2.

After the requirements are drawn up, the current situation of management processes in the warehouse and the proposed new situation with a WMS will be modelled and analyzed. This will be done by using business process modelling, which illustrates the business processes of a company graphically. The theoretical framework for this is discussed in chapter 2.3. First, the current situation in the warehouse will be modelled and with the help of the formulate requirements of the system the new situation will be sketched also. In this way, the current and new situation can be compared and the change in process flows can be depicted graphically. To map these processes accurately, it is important that there is a clear understanding of the warehouse management processes of the company. So, talks must be held with different people in the organization. The meetings with suppliers of warehouse management system could also give clear insights on how the management processes in the warehouse will change when a warehouse management system is implemented, since they have experience with automated information systems.

Finally, qualitative advice is given to the company, based on the main takeaways of the research. This advice gives the company insights in important considerations when a future investment in a warehouse management system is made.

The research approach described above can be best classified as a qualitative case study, because all the information for the research will be derived from literature and interviews at the company, which are examples of qualitative research methods.

So, to summarize the deliverables in bullet points:

- Formulation of WMS requirements with priorities
- Business process modelling of the current situation and proposed new situation
- Analysis of business process models
- Qualitative advice for the company

1.9 Research questions

Main research question:

What should be the main characteristics of a warehouse management system and its related processes integrated into the organization of Schmits?

By answering this main research question, I can give the company suitable advice, so that they are better prepared when their investment process starts in the future. The question is quite broad, because it answers the question how the system will be shaped as well as how the system will affect the management processes in the warehouse and production facility. In order to answer this broad main research question well, these two aspects are divided in two sub questions that will be answered first.

Sub questions:

1. *Which functionalities of a warehouse management system are applicable to the particular situation of Schmits?*

This sub question will be answered by using literature study, which can be found in chapter 3. It should provide a list of possible functionalities for the WMS that can help solving the identified problems in the warehouse. The literature study is already partly done in the systematic literature review, the more general research question answered there was: *Which functionalities can be implemented in a warehouse management system?* This review can be found in appendix A. Besides the literature as input, the meetings with suppliers of WMSs also gives me useful information about the possibilities with these systems, a report on these meetings can be found in appendix B.

2. *How will a warehouse management system affect the flow of management processes in the warehouse?*

As already described at the research approach, interviews at the company and meetings with suppliers will form the input for business process models. But first, literature study is done on a business process modelling technique. With this technique, the current and proposed new situation will be depicted graphically. It will give a clear overview on the alterations of management processes in the warehouse and production facility, which will answer the sub question in detail. These steps can be found in chapter 4.

2. Theoretical framework

2.1 Warehouse Management Systems

A warehouse management system (WMS) is an information system that supports stock management and administration in the warehouse. It is used to increase the performance of the warehouse by supporting the management processes systematically. Because of the higher degree of automation in the warehouse, manual administrative tasks are reduced, resulting in less chance of human errors and accurate inventory levels. (Apak, Tozan, & Vayvay, 2016)

WMS covers functionalities for managing and controlling the flow of goods within the warehouse only and therefore it operates always in combination with an Enterprise Resource Planning (ERP system), which takes. The basic configuration is that an order is handed over from the ERP system to the WMS, where in turn the necessary warehouse operations for the order are executed. (Van Den Elsen, 2017) After these operations are performed, the output data collected by the WMS is then shared with the ERP, so that the systems are synchronized. Schmits already works with an ERP system called Blending from the company Infor, which is a specialized system for companies in the chemical industry. So, it is of importance that the WMS can connect with this system and can work alongside it.

One of the main findings in the literature was that the applications of warehouse management systems are becoming more various. The traditional scope of the systems is expanding, and more and more new functionalities are being developed. Therefore, it is interesting to investigate the various possibilities in a WMS. For a deeper analysis about the functionalities of these systems and the suitability for the specific warehouse of Schmits, see chapter 3.1.

2.2 Requirement selection method

For selecting the requirements of the Warehouse Management System, a literature study and meetings with system suppliers will be used as input for a list of possible functionalities. Then interviews will be held with stakeholders in the organization to assess their viewpoints on how each possible functionality fits to the warehouse of Schmits.

To formulate possible functionalities into requirements for the system, the MoSCoW method is a helpful tool that sets priorities. (Mulder, 2017) It originates from software development projects where it is used as a prioritization framework for timebox projects. In these timebox projects, the deadline is fixed, so the focus must be on the most important requirements of the software. By giving ranked priorities to each requirement of the software, there is more clearness between the developers and the management of the company about the intention of the project.

Nowadays, the method is more broadly used for projects with constraints regarding time or money where the goal is to realize the most added value for the company within the boundaries of the constraints. MoSCoW is an acronym for ‘Must haves’, ‘Should haves’, ‘Could haves’ and ‘Won’t haves’.

- ‘Must haves’ are the requirements that the end-result has to satisfy. These are not negotiable and are essential for the system.
- ‘Should haves’ are much desired requirements with high priority. However, they are not critical to launch and the end product can be usable without them.
- ‘Could haves’ requirements can be considered when it falls within the time or budget constraints. They are desirable but not necessary and are also known as ‘Nice to haves’, so they are more a wish than a requirement for the system.
- ‘Won’t haves’ are functionalities that are out of scope of the current project but may be included in a future project.

So after the interviews, the list of possible functionalities will be ranked as requirements according to this method. In this way, Schmits can give a potential supplier of the warehouse management system in the future a clear indication on what the priorities for the system are, see chapter 3.3 for the results.

2.3 Business process modelling

For mapping the current and proposed new situation with a warehouse management system, business process modelling will be used. Business process modeling is a general term for capturing the business processes of an enterprise graphically in diagrams.

Aguilar-Savén (2004) defines that *‘a business process is the combination of a set of activities within an enterprise with a structure describing their logical order and dependence whose objective is to produce a desired result. Business process modelling enables a common understanding and analysis of a business process.’* In other words, business process modelling can provide helpful insights in sets of activities in a company, by graphically capturing these sets. In this way, improvement points can be recognized and processes can be improved.

According to Atieh et al (2016), Business Process Model and Notation (BPMN) is a fitting tool for modelling the situations with and without a WMS, because it provides accessible diagrams that are easily to understand for everyone involved in the organization. The BPMN has established itself as the standard method for depicting business processes in diagrams. The first version was developed about fifteen years ago and it is a revision of previous used methods for business process modelling. (Zur Muehlen & Recker, 2008) The method contains a great variety of modelling elements, so it can be applied in all sorts of businesses.

The elements that can be used in the BPMN diagrams are divided into four basic categories: flow objects, artefacts, connecting objects and swimlanes. (Weske, 2012)

- Flow objects are the basic units that are used to build the business processes and give them shape; they are separated in activities, events and gateways. Activities represent the tasks performed during the business process. Triggers and
- Artefacts show additional information about the business processes and serve for information purposes only; examples are data objects and groups. Data objects depict paper documents or electronic information that is input or output from a process activity. For electronic data, an information system is providing or storing the data objects most of the times. Group objects are artefacts that are used to group elements of a process together, they serve for documentation purposes.

- Connecting objects connect the building blocks of the diagram with each other. There are three types of connection flows: sequence flows, message flows and associations. Sequence flows are used to model the flow objects direction from one activity to the other, while message flows represent the information stream between different departments, or swimlanes. Associations connects artefacts with other elements in the business process and is most of the time used for illustrating the data flow of the process.
- Swimlanes represent organizational entities like departments or specific functions. By modelling flow objects in a lane, it can be graphically depicted which organizational entity is responsible for performing the task.

In appendix D, an overview can be found of all BPMN elements that are used in the business process diagrams of this thesis.

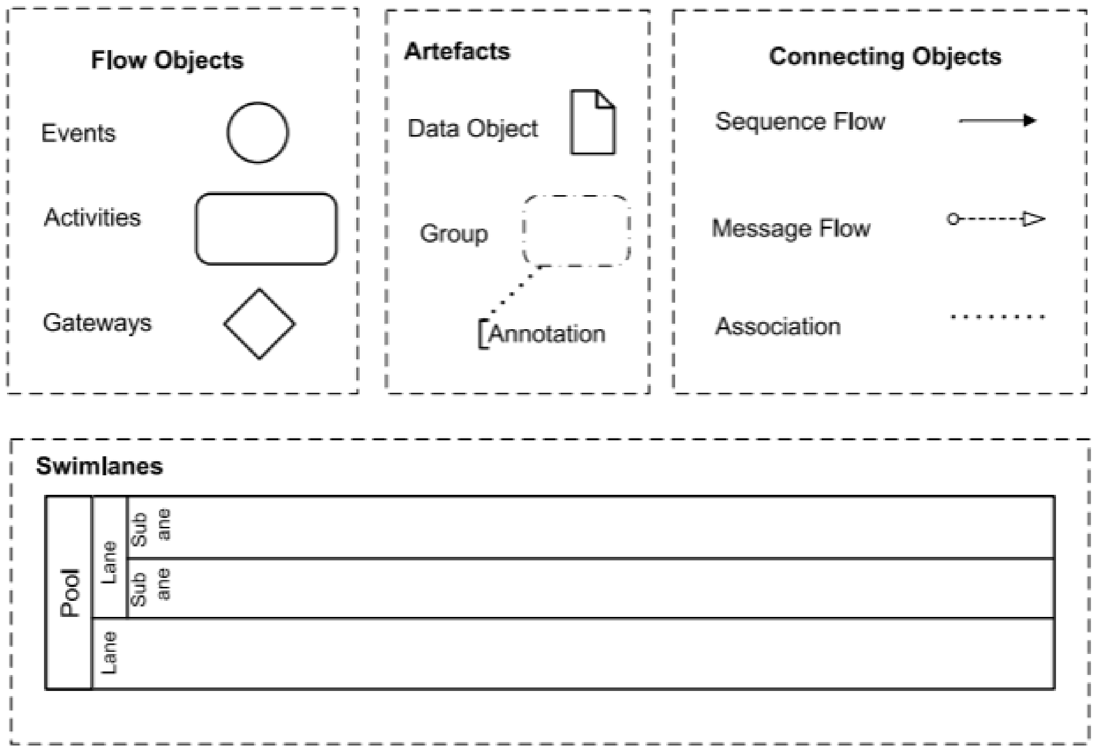


Figure 2.1: All elements of the BPMN

The figure below is an example of business processes mapped with the use of BPMN method. Here it can be seen that the swimlanes are used to separate organizational departments in the process flow, which makes the responsibilities for each department clear.

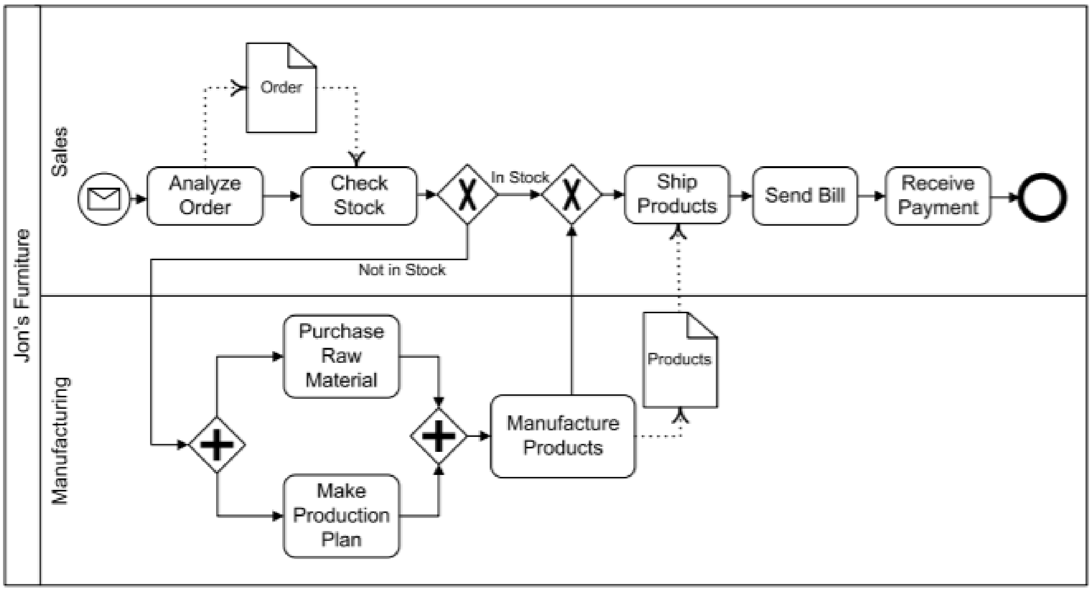


Figure 2.2: Example of a business process represented with BPMN

In 2011, the revised version 2.0 of BPMN was released and the name was changed to Business Process Model and Notation. Various new characteristics were added and some existing elements were altered. One of the main changes was the greater emphasis on data processes, by creating a separate element category for data activities and introducing a new data element, data storage. (Chinosi & Trombetta, 2012) Data will be an important aspect for my models of business processes, because with data activities the differences between the current and new situation in the warehouse can be better illustrated. Since the new situation with the warehouse management system will involve a lot more data flows than the current situation.

3. Formulation of requirements of the warehouse management system

3.1 Literature study

In this section, literature study will be performed on the functionalities of warehouse management systems (WMS). After studying literature about the properties of warehouse management systems, potential functionalities can be defined that could fit the specific case of Schmits. Also, exploratory meetings with two potential suppliers of a WMS gave many insights on the properties of these system, so these will also be included in this study. With this literature study the first sub question can be answered: *Which functionalities of a warehouse management system are applicable to the particular situation of Schmits?*

With this literature study as input, interviews can be conducted under the stakeholders to get their opinions on how each functionality fits in the organization and where the priorities lay. Based on these results, a decision can be made on what the priorities are for the requirements of the warehouse management system.

3.1.1 Possible functionalities of the system

To place the functionalities of warehouse management systems in perspective, it is important to understand the different applications of the system. According to Van Den Elsen (2017), a WMS adds value to three types of organizations: stockholding warehouses, warehouses with crossdocking operations and warehouses with value-added operations. The last type fits the warehouse of Schmits, because they create value by transforming raw materials into products in their production tanks. The first two types are however warehouses that are only storing and distributing goods, so it is important to keep in mind that many functionalities are focused on these types of warehouses and are therefore not interesting for the production warehouse of Schmits.

Most of the modern literature about warehouse management systems, still use the classification of Dusseldorp (1996) to make a distinction between WMSs. (Ramaa, Subramanya, & Rangaswamy, 2012) (Faber, 2015) It makes a distinction between three groups of WMSs: basic, advanced and controlled WMS.

- A basic WMS supports stock and location control only, so the support is primarily on inventory management and track and tracing. The generated warehouse management information is simple and focuses on throughput of products.
- An advanced WMS can process activities and resources to assess the flow of goods through the warehouse. It focuses mainly on throughput, stock and capacity analysis
- A controlled or complex WMS can further optimize a warehouse, or a group of warehouses and it also takes processes outside the walls of a warehouse into account. It can determine the destination of all materials and in this way, it can offer additional functionalities, like transportation planning and value-added logistics planning, which optimizes the entire warehouse operation.

It is the question if the additional functionalities of a complex WMS really add value to the warehouse of Schmits, because these functions are more associated with stockholding or crossdocking operations, where the emphasis is more on logistical flows and no production takes place.

Rogers (2011) elaborates further on basic and advanced WMSs and has a lot of similarities with the classification of Dusseldorp (1996). It states that a basic WMS supports the everyday functions that are the basis for warehousing: receiving, directed put away, order fulfillment planning, picking and packing, and shipping the order. While an advanced WMS may also support:

- **Inventory management:** the WMS can constantly update inventory based on the planning and it can adjust the inventory of materials when an amount is used in a production process. In this way, the inventory level is real time and if a material is running out of stock, it can give a signal to reorder the material. This can potentially fix one of the problems in the problem cluster, because inventory is currently updated manually in the system after production and this functionality might result in less administrative work and less chance of human errors. Besides inventory of chemicals, the inventory of packaging materials, like drums or flacons, can be monitored.
- **Cycle counting:** instead of drawing up all inventory once or twice a year, cycle counting makes a distinction between materials with high and low use rates and scrap factors, and assesses the frequency it should be counted. So for instance, a material with a high use rate and scrap factor, should be counted much more than a slow-moving material. Resulting in an effective continuous count program. (Piasecki, 2017)
- **Slotting:** Slotting software makes an optimal allocation of materials over the warehouse, basically by assigning the most frequently used materials to the most easy accessible places. This tool can be used for raw materials as well as finished products. Schmits currently uses standard places for most of their materials and the workers can pick these materials very fast based on experience. So for them, it might not be fitting if the location of materials over the warehouse is changing all the time. A potential supplier of a WMS for Schmits explained during a meeting that a slotting method with more standard places suits small production warehouses like Schmits better, see appendix B. This method is executed by assigning ranked preference locations to all materials. It works as follows: a raw material needs to be stored in the warehouse and the system checks if the first preference location is occupied. If it is unoccupied, the system checks if the safety restriction regarding the material and the surrounding chemicals that are explosive, corrosive or toxic are not exceeded. If not, the material is assigned to the location. If the first location is occupied it checks the second location and follows the same procedure. This policy goes on until the system finds the first preference location that is unoccupied and where the safety restrictions are met, see the flowchart below in figure 3.1. However, the system works best if the preference locations are updated frequently and are calculated again based on routing data. Because in time, a high use rate material could be become a low use rate material, or the other way around.

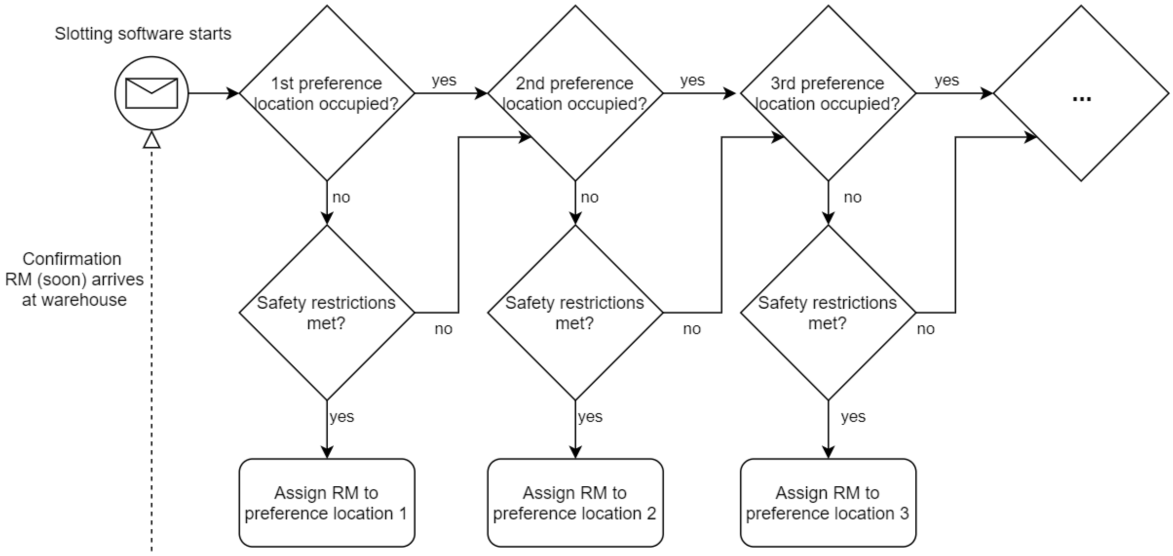


Figure 3.1: Flowchart of slotting software that works with preference locations

- **Automatic data collection:** because of the handheld devices that are used for the implementation of a WMS, a variety of data can be automatically collected and it is important to determine on beforehand how to make the most of this data. For instance, it is possible to measure productivity of individuals and the user responsible when a faulty product is reported. It is important however to remember that all workers must have their own user account in order to trace data back to individuals. The data could also give technical insights from the warehouse, like the percentage of pallet utilization and production tank occupation.

3.1.2 Automatic identification and data capture

Besides the additional functionalities, the foundation of the warehouse management system, the track and trace functionality and its different applications must be researched. For tracking and tracing, different kinds of automatic identification and data capture (AIDC) technology are used. AIDC is important to consider, because it is the infrastructure for most of the functions of the WMS, like data collection and inventory management. Barcodes and QR codes are examples of this technology that are well-known, but also radio frequency identification (RFID) is a possible tool for data capture. RFID is a technology that uses radio frequency waves to provide data transmission between a label and a reader. Instead of the other technologies, RFID labels can be read simultaneously and without being in the line of sight of the reader, however the technology is much more costly and complex than standard barcode technology, so the question is whether the advantages outweigh the disadvantages of the system.

When the application areas of RFID and barcodes are compared, it seems that RFID technology is more applied in distribution warehouses with stockholding and crossdocking operations, where the focus is more on the complex logistics flows, while barcodes are much more common in manufacturing facilities and production warehouses. (Erkan & Can, 2014) Also, the warehouse of the company primarily works with bulk products and is not that complex, so the functionalities of RFID seems to be excessive and too expensive to have an edge over a barcode system. (Campbell, 2018) So, a barcode track and trace system is the most fitting AIDC technology for the situation of Schmits, it has a cost-advantage over RFID and the complexity of RFID is not necessary in the company's compact production warehouse.

There are also different barcodes to consider: a distinction can be made between 1D or 2D barcodes. The main difference between the traditional barcode and 2D barcodes is that the latter can store much more information than the former. However, during a meeting with a supplier of a track and trace system came forward that 1D barcodes are sufficient for the situation of Schmits, see appendix B. This is because the barcodes are used to link a place in the warehouse to a certain material that is placed there, where a small set of numbers or letters is enough to capture the required data in the system. 2D barcodes can also capture this data, but these codes are accompanied with more complex barcode scanners and printers, which are obviously more expensive. Also, 2D barcodes can be scanned from all angles, which is a drawback while working in a crowded warehouse with many barcodes, because it can happen that adjacent barcodes are accidentally scanned. Concludingly, it is not necessary to make use of a more expensive 2D barcode method and a 1D barcode method will suffice for the amount of data storage needed.

Figure 3.2: Examples of a 1D and a 2D barcode

3.2 Evaluation of possible functionalities by management team

In order to measure the support of the possible functionalities of a warehouse management system by the management team, an interview will be held with each of the subjects to formulate and classify the requirements of the system. The subjects can explain their viewpoint on how each functionality will fit to the situation of Schmits and priorities can be given by using the MoSCoW method, see section 2.2 for a description of this method.

The subjects will consist of four employees that are managing and controlling most of the operations in the production facility and in the warehouse of Schmits: the coordinator of production, the factory manager and assistant factory manager and the technical director. If a WMS gets implemented at Schmits, these people will work on a day-to-day basis with the system, so it is interesting to take their viewpoints about the requirements and functionalities into account. Other factory workers will also be working with the system a lot, but they are less concerned with the management and administrative side of the warehouse and therefore not subjects for this interview.

During the interviews, each possible functionality will be explained so that the aspects are all clear for the subjects. Then the MoSCoW method is defined, where the functionality must be classified in ‘Must haves’, ‘Should haves’, ‘Could haves’ and ‘Won’t haves’. In this way, the subjects can classify their priorities for the system, based on the fit to the situation of Schmits and the expected advantage the functionality could give. Besides this prioritization method, the subjects will get room to explain their viewpoints, which can be input for the argumentation of the requirements. The functionalities that will be measured are:

- Inventory management: for this functionality, the focus will particularly be on the ability to adjust the inventory level of a chemical systematically during production. According to a meeting with a supplier of WMSs, see appendix B, it was possible to link the weight system of a forklift truck to the system. In this way, the difference in weight on the fork of the truck can be adopted by the system to update the inventory of the material. Inventory replenishment functionalities will not be discussed in the interview, because this is already adopted in the company’s ERP system.
- The track and trace functionality with a barcode system will also be discussed in these interviews. In earlier exploratory interviews, it already came forward that this is a ‘Must have’ for the system. But it is nevertheless important to discuss because there might be ideas on application of barcodes in the warehouse. For instance, the production tanks can be labeled with a barcode, so that it is registered which tank is used for which production batch. It is also interesting to consider the method for labelling the materials and products. Most likely, a barcode printer is necessary at the logistic department for labelling the incoming goods.
- Cycle counting will be explained as a systematic way of continuous counting of materials. It may be a very fitting tool for Schmits, because there is a lot of diversity in the chemicals in terms of use rates and scrap factors. Also, quite a lot of materials for third parties are stored in the warehouse, for which keeping track of the inventory regularly is obligatory. And Schmits stores dual use goods for which strict regulations are set in terms of inventory reporting. Dual use goods are chemicals that can also be used in the military industry, for instance for chemical weapons. The cycle counting tool relies on the track and trace system, because it provides the input for the locations to check when doing cycle counting.
- Slotting software that is based on preference locations is the most applicable to the situation of Schmits, so this interpretation will be used in the interviews. See figure 3.1 and the explanation at 3.1.1, for an interpretation of this method.
- Automatic data collection is an additional benefit when integrating a WMSs, but it is important for the management team to consider what to use and how to make the most of it. For instance, labor tracking of individuals and production data are measurements that can be used. Data collection will be an open question in my interview: for what purposes should the management team collect data of processes in the warehouse? It will not be classified with a priority term.

3.3 Results of interviews and formulation of requirements

The report of the interviews and an extensive explanation on how the MoSCoW priorities of the requirements are established can be found in appendix C.

Real time inventory management

An improved inventory control with reliable inventory levels is one of the main incentives to possibly invest in a warehouse management system for Schmits. At the moment, inventory is updated in the system based on handwritten notes of the production workers. It came forward during the interviews that this leads to misunderstandings and human errors. Also, processing the inventory updates is not done directly after production, resulting in inventory levels that are not up to date. Resolving these misunderstandings and establishing a real time inventory is a main priority for the warehouse management system. So, this requirement is a must have for the WMS according to the subjects.

Track and trace system in the warehouse

Together with real time inventory management, a track and trace functionality is regarded as the most important requirement of the warehouse management system. When it is executed properly, Schmits will not have issues with its traceability in the warehouse anymore. Also, many other functionalities of a WMS will rely on the location codes of the track and trace system, like cycle counting and the slotting tool. Therefore, it is a crucial part of a WMS and a must have for the system.

Slotting function

A slotting function that allocates the incoming raw materials systematically over the warehouse, is regarded as an interesting functionality that could further professionalize the operations in the warehouse. Because currently, the allocation is done manually and it lacks a systematic approach. There are however some doubts about the practical implementation of this function; the goods in the warehouse are stored in different packaging sizes and the pallet locations also differ in size. So, some practical difficulties with optimally utilizing the warehouse space are expected. Formulating proper slotting software for this requires an extensive preparation and it is suggested that this functionality could be added after the implementation of a warehouse management system. The functionality is conceived as a requirement of high importance, but the system can properly work without it, so a slotting tool is a should have requirement for the system.

Cycle counting

It came forward during the interviews that stocktaking is an activity that is easily neglected when the company is facing a busy production schedule. Therefore, it is agreed that a cycle counting tool, with calculated counting frequencies for each chemical, is an interesting functionality for the system. It is however not regarded as a priority for the company and not as a core functionality of the system. So, cycle counting can be classified as a ‘could have’ requirement for the system.

Automatic data collection

Many interesting applications of data came forward during the interviews and the more extensive explanation of this can be found in appendix C. Firstly, labor tracking of individuals is useful to trace back a person’s responsibility and to measure productivity. Secondly, data can be used to estimate production times for the production planning, based on past experiences. Also, KPI's can be formulated that can give technical insights on the warehouse performance, for instance percentages of pallet utilization and production kettle occupation can be deduced from data.

Requirement	MoSCoW priority
Real time inventory management	Must have
Track and trace system in the warehouse	Must have
Slotting function with preference locations	Should have
Cycle counting tool	Could have

Table 3.1: Prioritized requirements for the system using the MoSCoW method

For modelling the process flow in the new situation, the must have and should have requirement are taken into account. So, the new situation will be mapped with a slotting tool, a track and trace system and real time inventory management included in the warehouse management system. A cycle counting tool, will not influence the warehouse management processes on a daily basis, so the presence of this functionality in the system will not be included or excluded in the process analysis.

4. Analysis of current and new situation

4.1. Current situation

In this section the current situation is sketched of relevant management processes in the warehouse. To map these processes accurately and make a good comparison with a sketched situation with a warehouse management system, models are made by using the Business Process Model and Notation, which is discussed in the theoretical perspective section. A free online modelling tool is used for this called draw.io, which has a special BPMN template. For an explanation of all symbols used in the BPMN language, see appendix D. For a list of all abbreviations used in the models, see table 4.1 on page 21.

It is difficult to create a model that applies for all production orders of Schmits, because they make many different products for which the management processes in the factory can differ. For example, Schmits stores chemicals for third parties where they only deliver the service of transforming these chemicals into an end product. In a process like that, the company is not responsible for the procurement of chemicals and the administration of inventory is done differently. Therefore, the diagrams are created with the most standard process flow in mind, where Schmits is a traditional supplier of products.

The current situation in the factory is separated in two BPMN diagrams: the raw material receipt process and the production and outbound process. The first process flow starts with an incoming order and ends where all raw materials are stored in the warehouse and awaiting for production. The second process flow starts from the beginning of production and ends when the finished product is transported, and the order is finished. The two diagrams are extensively explained below.

1. **The raw material receipt process**

This trigger for the start of this model is an incoming product order of a customer. When the order arrives, the managing administration of the factory and warehouse checks the stock availability of the raw materials that are required for the product order in the company's ERP system, Blending. If the stock is sufficient for production, the production can be put in the production planning and this process is ended. If the stock is not sufficient, raw material procurement activities are executed, this set of activities is external to the relevant model and is therefore not described in detail. However, the procurement can retrieve information about the raw material lead times, this can be used to plan a production activity in the production planning. From this, it can be concluded that the used production strategy is Make to Order: production starts after the order is received.

The process continues at the logistics department when the supply of raw materials arrives. The goods are unloaded and the delivery quantity is checked on the delivery receipt, then they are temporary stored at the loading bay. After that, the coordinators of the production department are responsible for allocating the materials over the warehouse. Since they will be the ones working with the material, it is best they put it away so that they can find it easier. This allocation over the warehouse is based on standard places for most of the chemicals and a large warehouse for additional bulk storage, but they must also satisfy the safety constraints of corrosive, explosive and toxic chemicals. When the raw materials are assigned to their locations, the locations of the chemicals are noted on the delivery receipt if there is no existing stock of the chemical in the warehouse. This is because the ERP system can store only one location code for each chemical, so if there is existing stock the chemical is already linked to a location in the system.

After the storage of the materials in the warehouse, the completed delivery receipt will be brought to the administration to be processed. The delivered quantity and the location code are added in Blending and subsequently the process is ended.

2. Production and outbound process

This process flow starts when the production is started, in accordance with the production planning. The production report is taken from the planning board and the materials are picked up in the warehouse with a forklift truck. The material locations may have to be checked in the system by the managing administration, if there are location codes linked to the products. The batch number of the materials are noted on the production report, so that it is traceable which batch of raw material went in which production. Then the production process starts, which differs a lot between products. During the production, the exact amount of used materials and the production kettle are noted down on the production report for administration. When the production process is finished, a test sample must be tapped off the tank and brought to the test lab. Here takes a quality inspection of the production batch place, where the sample must satisfy certain margins of, for instance pH level and dry matter content. When the sample is not approved by the lab, certain alterations must be made on the production batch and another sample must be tested.

When it is approved, the chemical can be filled in the prescriptive packaging, which can vary between small bottles and IBC's. After filling, the amount of end product can be assessed and noted down on the production report. Also, the packaging materials have an inventory level in the system, so this must be noted down also after the filling process. When the filling is done, the production report will be sent to the administration for processing and the product is delivered to logistics where it is stored in the finished goods warehouse until the transportation arrives.

Meanwhile, the filled-out production report is processed at the managing administration, where the exact quantities of used raw materials and end product are adjusted in the ERP system's inventory. Also, the packing list is printed out and sent to logistics, so that everything is ready for transportation.

When the truck arrives at the loading bay, the products are loaded into the truck and the transportation papers are filled in. The only thing left in this process is the handling of the transportation papers by the managing administration, after that the order can be regarded as completed and the process ends.

Abbreviation	Written in full	Meaning
RM	Raw material	All incoming chemicals and materials for production.
DR	Delivery receipt	A document signed by the company to indicate that they have received the inbound goods
WH	Warehouse	
PR	Production report “Productieverslag”	A document with the recipe and all prescriptive steps of a certain production for production workers.
TD	Transport documents	Contains transport information for outbound products accepted by carrier.

Table 4.1: list of all abbreviations from BPMN diagrams with explanation

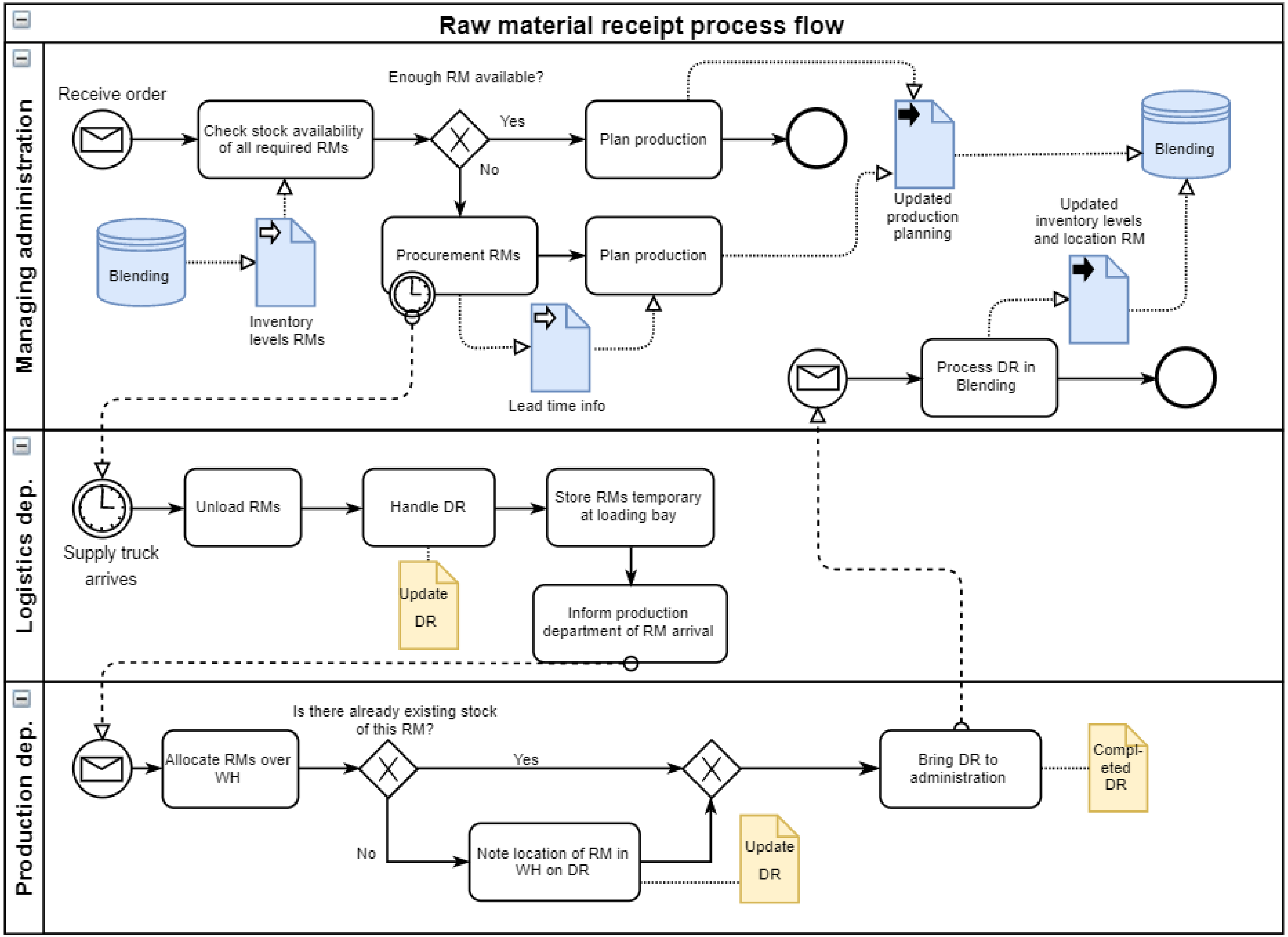


Figure 4.1: The current raw material receipt process

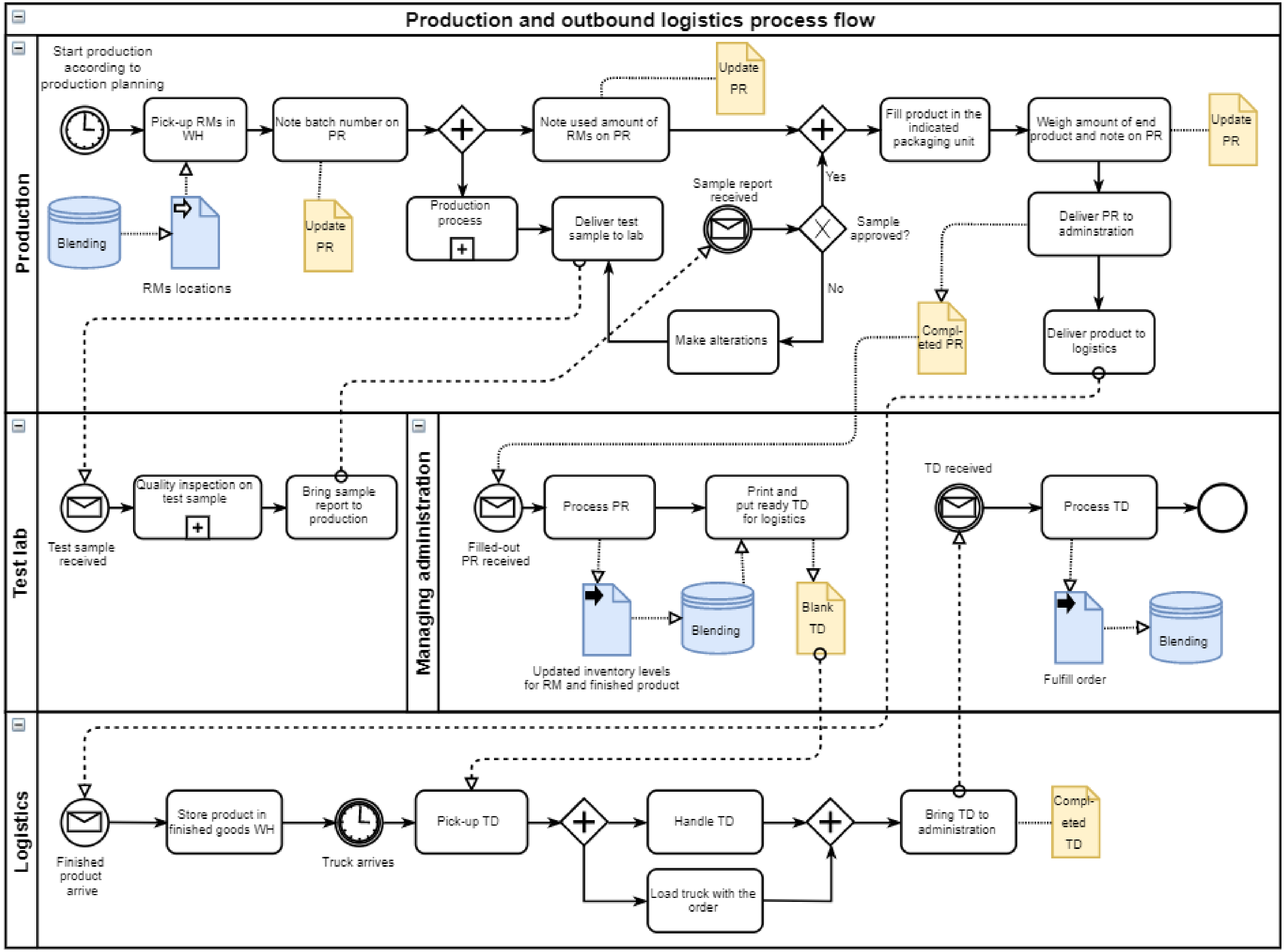


Figure 4.2: The current production and outbound logistics process

4.2. Proposed new situation

In this section, two BPMN diagrams are made of the management process flow in the new situation, with a warehouse management system, to compare it with the existing situation. Conclusions can be drawn on what the biggest changes are in the warehouse management process and what the implications for Schmits are. In this way, the second research question can be answered: *How will a warehouse management system affect the flow of management processes in the warehouse?*

In the new situation with a WMS, the same separated processes are used as the current situation: the Raw material receipt process and the Production and outbound logistics process. The new processes are explained below, with emphasis on changes in the diagrams in comparison with the current situation. For both processes, the WMS has a separate lane, this gives convenience in recognizing the function of the system in each activity.

1. **Raw material receipt process**

The first part of the new process is identical to the current situation: an incoming product order of a customer arrives, and the stock availability is checked of the required raw materials. If the stock is not sufficient, procurement must be done before the production can take place and the process continues.

In the new situation, the warehouse management system has to know which materials will soon be delivered on beforehand. Therefore, a confirmation from the supplier is required about the materials what they will deliver. With this information, which is also called an advanced shipment notification, the warehouse management system can generate unique barcodes and assign location slots in the warehouse for the goods, so that the receipt of the goods is well-prepared and structured. This sub process is called the WMS receiving goods process and is depicted below.

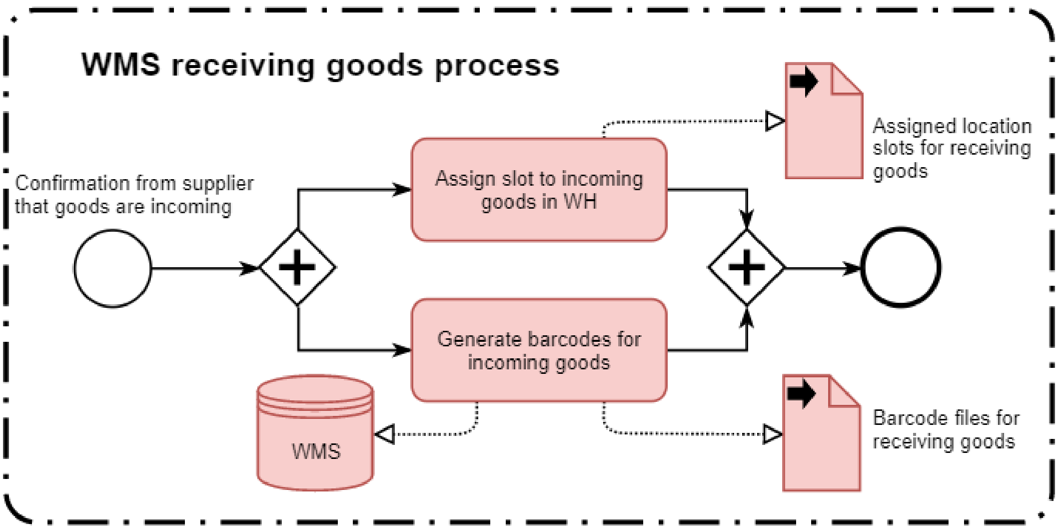


Figure 4.3: the sub process of receiving goods by the WMS in detail

The process continues when the supply truck arrives at the logistic department. The raw materials are unloaded and the delivery receipt is signed. The delivery receipt is not significant anymore for the process, so it is left out of the model. Meanwhile, the labels are printed by the barcode printer and are put on the packaging of the goods. Then the goods can be stored on and linked to their assigned place in the warehouse. When the material is stored on the right place, it is confirmed by the WMS and the inventory and location is updated in the system. The updated amount of inventory also has to be communicated with the ERP system, so the WMS exchange this information in turn with the ERP, which is also the last event of this process.

2. **Production and outbound logistics process**

Just like the current situation, the production process flow starts according to the production planning. The warehouse management system receives the production details and required materials from the ERP system. The WMS then knows where to picks these materials up and the worker is guided by the hand terminal to the respective locations. When a material is picked up from the warehouse with the forklift, it will be scanned with the hand terminal to confirm that the right material is collected. Also, its weight will be checked with the forks of the truck, so that the start weight is known.

When all materials are collected the production process can start. This is represented as a sub process which can be seen below. First the used production kettle is scanned. Then the steps of the production report are followed precisely. During these steps the exact amounts of materials used can be registered with the hand terminal by taking the difference between the start weight and the end weight of the material. After all chemicals are added to the kettle in accordance with the production report, the leftover materials will be placed back at their original spot in the warehouse. The leftovers are linked to their location again and their quantities will be updated in the system. If a material is not placed back in this process, the system can assume the whole packaging is used and the location slot is released as unoccupied again.

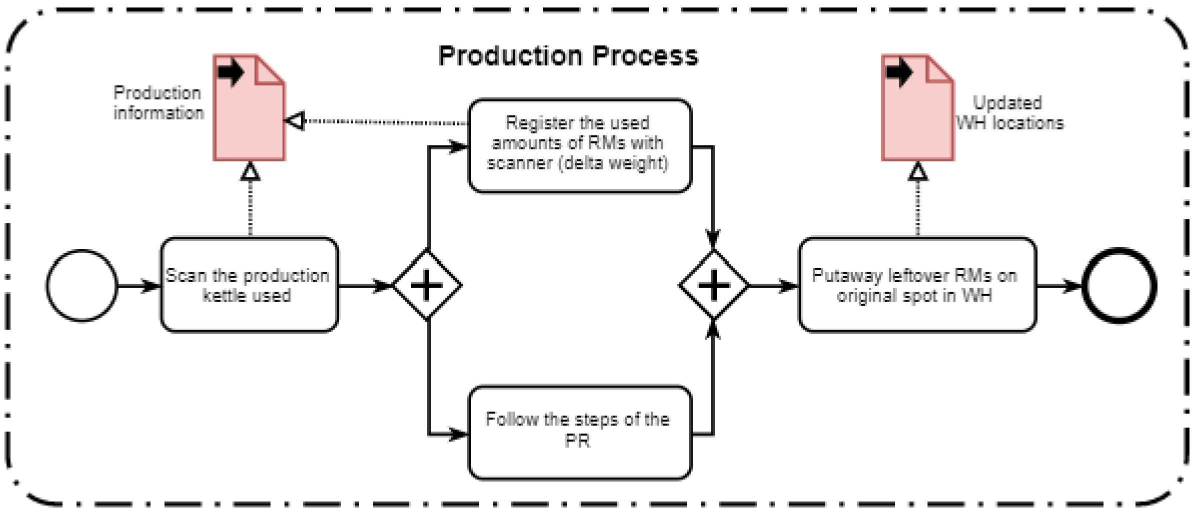


Figure 4.4: the sub process of production in detail

After all production activities are completed, a test sample will be tapped off, which will be brought to the lab for quality control. This process is already treated in the current process description and the procedure remains the same, so it is modelled globally as a sub process in this diagram to keep it comprehensive. If the test sample satisfies the quality requirements, the production batch can be filled in the ordered packaging units. After the filling, the quantity of finished product can be added to and the used packaging units removed from the inventory in the system with the hand terminal. The remaining task for the production workers is to deliver the finished products to the logistics department for the outbound procedure.

When the finished products arrive at the logistics department, they are labeled with a barcode. Then the products are stored and linked to a place in the finished goods warehouse with the barcode. The warehouse for finished goods is not so big as the warehouses of raw materials, because most of the products are manufactured with the Make-to-Order production strategy where products are not stored for a long time. Since this warehouse is relatively small and no difference can be made between products with high and low use rate, it is probably not necessary to use slotting software here for assigning locations to the products. But the workers can just link the pallets to a free spot with the hand terminal.

When the truck arrives to pick up the order, the products are collected from the warehouse. All outgoing products are scanned again to register their outbound distribution and are loaded in the truck. When the outbound distribution is registered and completed, the order is fulfilled in the system and the inventory of the finished products is updated.

All output data retrieved from the process is stored in the WMS, which can be seen in the model. The WMS synchronizes this data with the ERP system, so that both systems are up to date. This data storage is done throughout the process, so that the systems are working with real time data.

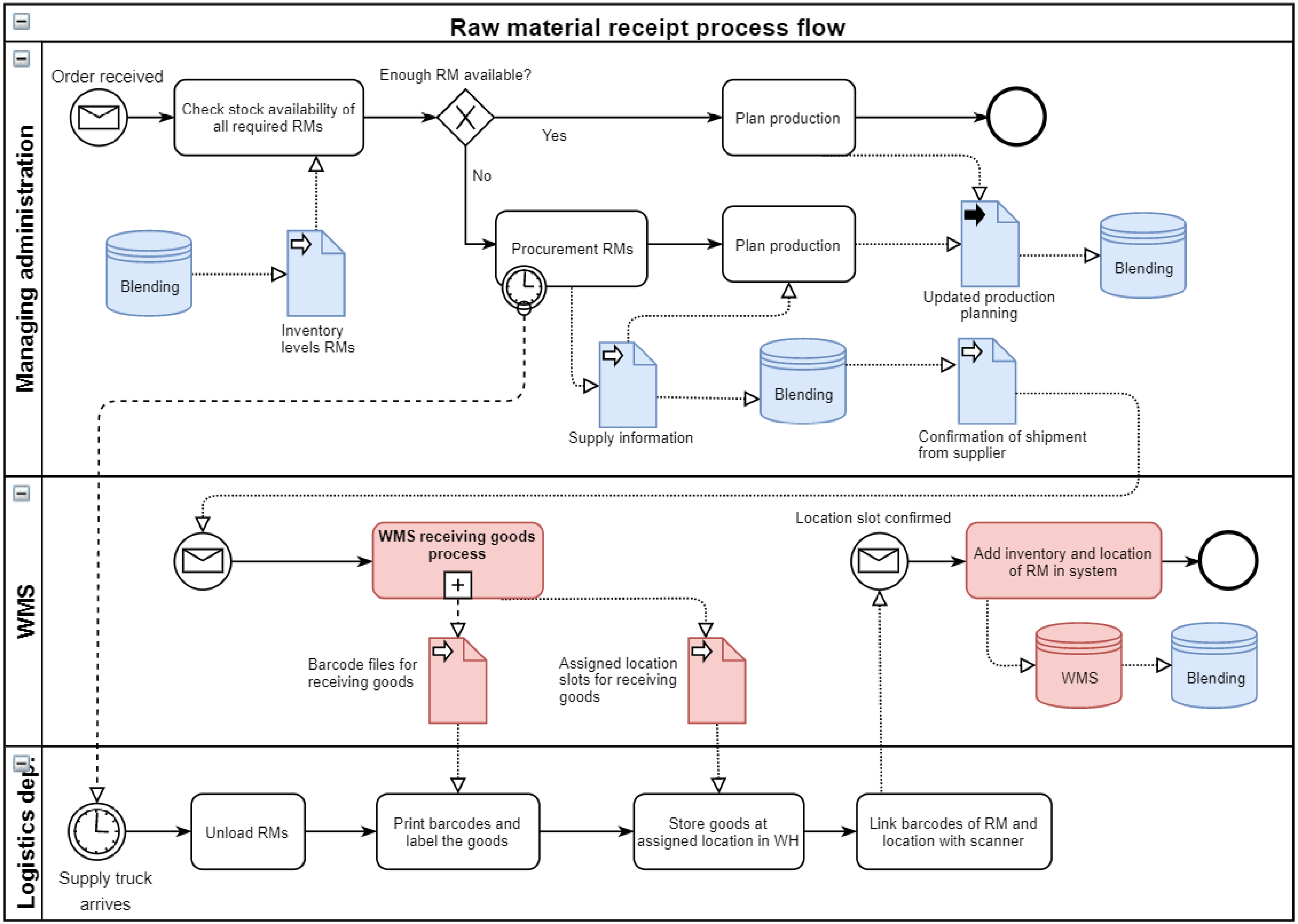


Figure 4.5: sketched new situation of the raw material receipt process

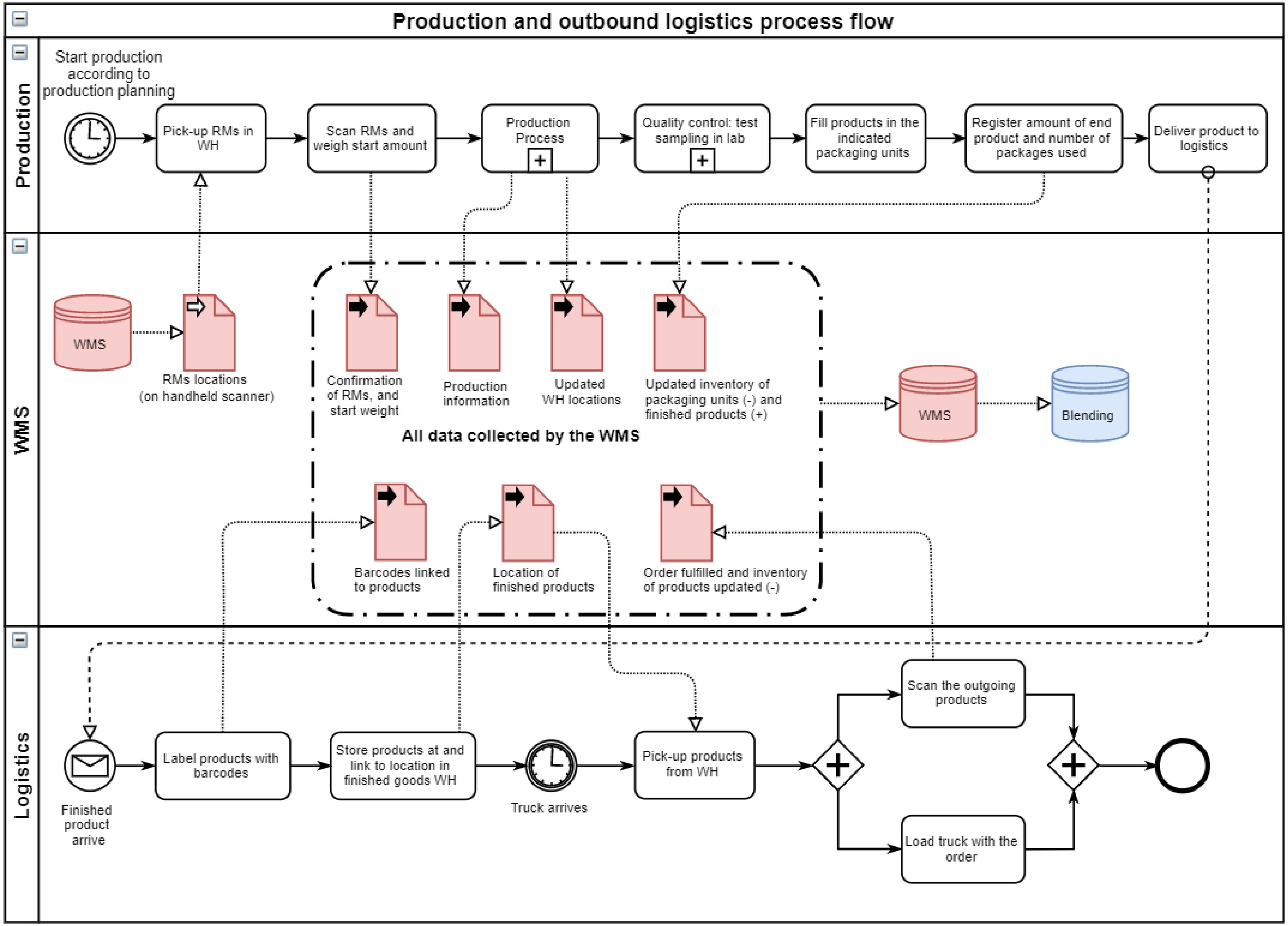


Figure 4.6: sketched new situation of the production and outbound logistics process

4.3. Comparison of current and new situation

Raw Material receipt process

The proposed new process starts identical to the current situation, but it changes a lot when the goods arrive at the warehouse. The first change is the need of confirmation of shipment from the supplier. This is needed because at the moment it occurs sometimes that suppliers only deliver a part of the ordered materials and that the remaining part is backordered. If there is no insight in the exact delivered number of pallets, the WMS receiving goods process, see figure 4.4, will not be performed accurately. Because when a supplier only delivers a part of the order, the WMS will assign too much location slots to the delivery and will generate too many barcode files.

There are multiple changes at the logistic department for this process. The first step after unloading the goods is labeling all pallets or other entities with a barcode. In between these tasks, handling the delivery receipt may still be a task for the logistics department to confirm right delivery for all parties involved. But it will not be needed for the administration of the delivered goods, since the WMS takes care of this.

The storing of goods in the warehouse also changes a lot in the new situation. The most obvious change is that the system assigns location slots for every arriving pallet, so the workers are guided by the instructions of the system. Also, the goods are not temporarily stored at the loading bay anymore and the responsibility of storing the goods is shifted from the production to the logistics department. It is currently done by production workers, because they can trace the ingredients of a production recipe better if they store all materials themselves. In the new situation, however, all materials are linked to their place with a location code and the production workers are guided to their place by the hand terminal. So, the traceability is much better and it is no longer beneficiary for production workers to store the materials themselves. It seems more logical to assign this task to the logistic workers than to the production workers, so that logistics is in charge for the storage and distribution of the goods, while production is responsible for the value-added activities.

The last main change is the output data from this process. When a pallet is linked to the right spot at the warehouse, a confirmation is sent to the WMS and the inventory level and location of the material gets updated in the system automatically. Then there should be a connection between the WMS and the ERP system to synchronize this updated information. This differs from the current situation where administration of the delivery receipt takes place afterwards by the factory managers, directly into the ERP system.

Production and outbound logistic process

In the production department, the processes surrounding the actual production change a lot. It starts with the picking of the required materials from the warehouse. In the current situation the materials are picked from the warehouse based on experience from the workers. Only if the material cannot be found, they turn to the factory managers to ask up the location code of the material. When the materials are found, the batch numbers are noted on the production report. The production workers are in the proposed new situation guided by a hand terminal that directs them to the places in the warehouse. The materials are confirmed by scanning the label, the start amount is registered and production is ready to start. Noting the batch number is not necessary anymore, because the materials can be traced back by the WMS with the barcode.

The differences in the production process can be seen in figure 4.5: instead of writing the used amounts and production kettle down on the production report, they are directly registered with the scanner and updated in the system. Also, when the leftover materials of production are placed back, the location slots are updated. If a material is not placed back, it is assumed it is fully used and the slot will be marked as unoccupied again.

After the quality control is passed, the products will be filled in the right packaging. Where in the current situation the end product and used packaging is noted on the production report, it is in the new situation directly registered with the hand terminal.

In the new situation at the logistic department, the pallets or entities of finished product are labeled with a barcode upon arrival and are linked to a location in the finished goods warehouse. When the truck arrives, the products are picked up with help from the hand terminal. So, it is basically the track and trace procedure that distinguishes the new from the current situation here. But another difference is that the outgoing products are scanned during the loading of the truck, so that the order is regarded as fulfilled and the inventory of the products is reduced. In the current situation, this part is done by the factory managers based on the transport documents.

4.4. Conclusion

In this section, conclusion will be drawn up based on the comparison of the two situations. Which will answer the second sub question: *How will a warehouse management system affect the flow of management processes in the warehouse?* Also, it will be assessed if the gap between norm and reality that should be filled by the warehouse management system, is resolved in the proposed new situation.

It can be concluded, when comparing the current process flow with the new process flow, that especially the administrative and management activities in the warehouse change a lot. These activities are in the new situation directed by the WMS instead of handwritten paperwork. The activities are for instance the arrival, storage, pick up, production and shipping processes. By handling these activities, the WMS provides a clear procedure for a more systematic approach of handling incoming and outflowing goods in the warehouse.

But besides providing and generating information, it collects a lot of information throughout the process flow. This is in the current situation mostly done by written documents: the delivery receipt, production report and transport documents. But in the new situation, these documents are not used anymore for administration in the system, because of the direct access to the system for workers. This will likely result in a reduction of time spent on administrative work by the factory managers. Besides this, the automatic collection of data gives useful insights in the performance of the warehouse and production facility if KPI’s are formulated. In appendix C, more possible applications of data collection are discussed that came forward during the interviews at the company.

Furthermore, it can be seen that the information stream between the ERP system and the WMS flows both ways, in the form of data files. The WMS receives information about incoming materials and production details from the ERP system, so that it can initiate the required operations in the warehouse and production facility. The ERP system in turn receives all data collected during processes in the factory, particularly the inventory levels of materials and products and the receiving and shipping information are of importance for the ERP system.

The roles of the departments in the warehouse will also change when a WMS is integrated. In the sketched situation, the task of allocating the incoming goods over the warehouse is shifted from the production to the logistics department. Besides, the workers in the factory will get much more responsibility. Since the hand terminals enables them to directly change things in the system, like inventory levels, where normally a factory manager is involved. Perhaps it is wise to assign a supervisor in the factory that has the task to monitor the application of the WMS by the workers.

The sketched situation with a warehouse management system reaches the norm of all warehouse management processes that are described in table 1.1:

- Raw material allocated automatically by software.
- Raw materials linked to their location with a barcode.
- Inventory level of raw materials directly updated during production.
- Good traceability in the warehouse.
- Inventory differences between system and real life are rare.

So theoretically, a WMS that functions like depicted in the model, is able to fill the gap between reality and the desired norm of the company.

5. Advice

In this end advice, the main takeaways of the research are used to give the company insights in important considerations when a future investment in a warehouse management system is made. These takeaways are mostly acquired from the analysis of the business process models of the current and new situation. But also the literature study and the formulation of requirements gave helpful information for the company. The advice will be separated into system specific and management considerations. The first should be discussed and decided with close cooperation with the supplier, the latter is more for Schmits to decide. After this, the restrictions of the research are discussed to define what could be investigated further on this topic.

5.1. System considerations

Firstly, the system must give a certain degree of flexibility to execute all various operations in the factory. So that all operations can be carried out as usual without being restricted by the system. In order to set up a warehouse management system that can function flexible, it is most likely that the system has to be partly customized to the procedures of Schmits. This customization requires more development time of the software supplier, which results in more costs. Therefore, it is important that a good balance is found in this, where the system is flexible and falls within the budget of Schmits.

One of these company-specific configurations is the connection with the ERP system of the company, Blending. It is key for a proper functioning warehouse management system, because the systems must communicate both ways to synchronize information, which is most of the times accomplished by sharing data files between the system. When this is done correctly, the systems complement each other and the warehouse administration is further automated.

Another point of attention, when specifying the way of working with the system, is the scan method. In some cases, workers are driving on the forklift when a barcode scan confirmation is required, so it must be analyzed what type of equipment can be installed on the forklifts and how this is combined with the application of hand scanners. Suppliers can judge this technical specification better because of their practical experience and they can make a decision based on this.

A particular outcome of the interviews was that a slotting method is a good way to further professionalize the warehouse, but it will likely create some practical difficulties and challenges if it is not implemented correctly. That is why the question rises if the slotting method will be added to the system directly or in the long run. As described in the interviews, the system can function without slotting software and it can be added after the rest of the system is established in the organization. In this way, the challenges can be dealt with in a less hectic environment.

The last system consideration is the width of the system in terms of controlling inventory levels. While this research is mainly focused on inventory control of raw materials and finished products, the inventory of packaging materials could also be monitored by the warehouse management system. In the proposed process flow of the new situation, the used packages are registered during the filling process. But this might not be appropriate for all productions and production sizes. This might also be a consideration where suppliers of warehouse management systems can provide additional empirical advice.

5.2 Management considerations

Before the WMS is integrated, it must be thought out how to use the automatic data collection possibilities in the factory optimally. As a result of the WMS and the scan terminals in the factory, information can be documented and formulated into KPI's for warehouse and production performance. Schmits already works with a KPI list that is updated every month, but because of little data documentation in factory this part of the company is underexposed in the list. During the interviews at the company, the subjects already came forward with some technical KPI's for the factory, this can be found in appendix C. Besides KPI's, labor and production information can be retrieved from the generated data. With this information about finished products can be traced back to the responsible persons and the used raw materials.

The place of paper documents in the process must be considered, like production reports and transport documents. The production report can still be used to follow all steps of the production process by the workers, but it will not be used to note batch numbers and used amounts for administration. The transport documents will probably still be used to confirm the transfer of goods with signatures.

Because almost no administration of paper documents takes place in the situation with a WMS, a shift of work may arise. Factory managers will likely spent less time on administration, but a new task for them is supervising the execution of the processes where the WMS is involved. Besides this new task for the factory managers, it was concluded from the business processes models that the factory workers get much more responsibility when a WMS is integrated, since they can directly change the data in the system. In order to make this go well, it may be necessary that the work in the system is monitored and double checked by the factory managers or the coordinators. Especially in the early phase of the system's implementation, when workers are not yet acquainted with the system, monitoring is crucial.

It is important that when the warehouse management system is implemented in the factory, everybody involved is committed to adopt it in their daily working routine. When a new system or technology is introduced in a company, it can face some resistance. Because people are used to a certain working method and must acclimatize to a new method. Therefore, training of personnel is essential for acquaintance with the system.

Schmits currently uses so called 'theme weeks' to draw extra attention to a certain subject. In these weeks, multiple goals or KPI's are set for all departments and weekly evaluation takes place about the obtained scores. It is a good idea to designate 'theme weeks' to the subject WMS, if the system is implemented in the factory. This can support the two points mentioned above: commitment to the system and monitoring of the system, because the weekly evaluation and emphasize on the WMS can result in a framework of the WMS that everyone is content with and involved in.

A good cooperation with suppliers of materials can support the utilization of the warehouse management system. In the business model analysis, it came forward that a confirmation of receiving goods is convenient to already generate barcodes for the products and reserve a location slot in the warehouse. But the barcodes of the supplier could also be adopted, if they are working with a barcode system. This is efficient and saves work, but a close cooperation is essential, because the product and barcode information must be communicated to the WMS and ERP system. For some key suppliers data sharing might be a possibility, but for some low volume suppliers not. So in that case, generating barcodes for incoming products is still necessary.

Finally, the detail study of supplier might be shortened, because of this research that can give a head start in the orientation phase for the supplier. They probably spent less time on defining the user requirement specifications, because the prioritized requirements are already formulated and the intention of Schmits are made clear. Also, analyzing the current situation and drafting up the new process flows is already treated in this research.

5.3 Restrictions and suggestions for further research

There are some restrictions in this research that could be further investigated when the investment procedure is started by Schmits in the future. This extra research can possibly help with making a well-considered decision on the investment.

Firstly, there is no data available to quantify the benefits of a warehouse with an operating WMS. There is not much data collected in the warehouse at the moment, so no cost-benefit analysis of the system can be conducted. If there is more data available of the current situation, the possible suppliers of WMS may indicate how much the situation can be improved when their system is adopted.

Finally, the results of this thesis are based on a combination of literature and research at the company. This theoretical approach is however not sufficient to define definite characteristics of the warehouse management system. There is also need of practical experience from professionals in this field, like the suppliers of these systems. They can assess the practical feasibility of this proposed plan for Schmits and if it falls within the constraints, in terms of budget and complexity.

References

Aguilar-Savén, R. S. (2004). Business process modelling: Review and framework. *Int. J. Production Economics*, *90*, 129–149. https://doi.org/10.1016/S0925-5273(03)00102-6

Apak, S., Tozan, H., & Vayvay, O. (2016). A new systematic approach for warehouse management system evaluation. *Tehnicki Vjesnik - Technical Gazette*, *23*(5), 1439–1446. https://doi.org/10.17559/TV-20141029094700

Atieh, A. M., Kaylani, H., Al-abdallat, Y., Qaderi, A., Ghoul, L., Jaradat, L., & Hdairis, I. (2016). Performance Improvement of Inventory Management System Processes by an Automated Warehouse Management System. *Procedia CIRP*, *41*, 568–572. https://doi.org/10.1016/j.procir.2015.12.122

Campbell, A. (2018). RFID or Barcodes: Which Are Better for Small Businesses? Retrieved May 16, 2019, from https://smallbiztrends.com/2010/10/rfid-or-barcodes-which-are-better-for-small-businesses.html

Chen, C., Mao, J., & Gan, X. (2018). Design of Automated Warehouse Management System. https://doi.org/10.1051/matecconf/201823203049

Chinosi, M., & Trombetta, A. (2012). BPMN: An introduction to the standard. *Computer Standards & Interfaces*, *34*, 124–134. https://doi.org/10.1016/j.csi.2011.06.002

Dusseldorp, T. (1996). Inventarisatie van warehouse-managementsystemen en cross-dockingsystemen.

Erkan, T. E., & Can, G. F. (2014). SELECTING THE BEST WAREHOUSE DATA COLLECTING SYSTEM BY USING AHP AND FAHP METHODS. *Technical Gazette*, *21*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1022.9538&rep=rep1&type=pdf

Faber, N. (2015). *Structuring warehouse management*. Retrieved from https://www.narcis.nl/publication/RecordID/oai:repub.eur.nl:78603

Heerkens, H. (2015). Microlecture on validity. Retrieved April 25, 2019, from https://vimeo.com/album/2938606/video/117885780

Heerkens, H., & Winden, A. van. (2012). *Geen probleem, een aanpak voor alle bedrijfskundige vragen en mysteries*. Van Winden Communicatie.

Mulder, P. (2017). MoSCoW Method. Retrieved June 11, 2019, from https://www.toolshero.com/project-management/moscow-method/

Piasecki, D. (2017). Warehouse Management Systems. Retrieved May 2, 2019, from https://www.inventoryops.com/warehouse_management_systems.htm

Ramaa, A., Subramanya, K. N., & Rangaswamy, T. M. (2012). *Impact of Warehouse Management System in a Supply Chain*. *International Journal of Computer Applications* (Vol. 54). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.258.6734&rep=rep1&type=pdf

Rogers, L. K. (2011). Supply chain software basics: Supply chain execution. Retrieved May 21, 2019, from https://www.mmh.com/article/supply_chain_software_basics_supply_chain_execution

Van Den Elsen, R. (2017). Wat is een WMS? Retrieved April 17, 2019, from https://www.logistiek.nl/warehousing/artikel/2017/03/2-wat-is-wms-10121690

Warehouse Management Software. (n.d.). Retrieved April 17, 2019, from http://www.warehousemanagementsoftware.org/processChange-Warehouse-Management-Software.htm

Weske, M. (2012). *Business Process Management*. https://doi.org/10.1007/978-3-642-28616-2

Zur Muehlen, M., & Recker, J. (2008). *How Much Language Is Enough? Theoretical and Practical Use of the Business Process Modeling Notation*. *LNCS* (Vol. 5074). Retrieved from https://link.springer.com/content/pdf/10.1007/978-3-642-36926-1_35.pdf

Appendix

Appendix A: Systematic literature review

1. Definition of the research question

My research question is going to be:
Which functionalities can be implemented in a warehouse management system?

One of the research questions for my bachelor assignment is what requirements the warehouse management system (WMS) should have for Schmits. When the company is going to invest in such a system in the future, it is most likely going to be customized to their needs. So, it is important that they are well informed on the possible functionalities these systems can have. With this research question, I can determine the breadth of these systems and discover possible functionalities that might be applicable in the case of my company.

2. Defining the inclusion and exclusion criteria

Inclusion criteria:

- Articles about warehouse management systems or synonyms of it
- Article is published in the last 10 years
- Functionalities of WMS are mentioned

Exclusion criteria:

- Articles more than 10 years old: not representative anymore
- Article is written in a language other than English or Dutch
- Article is about ERP systems and not about WMS

I want to include Dutch articles as well, because the Dutch warehouses are one of the frontrunners of implementing these systems, so there are possibly some useful articles in Dutch about functionalities of WMS.

3. Defining the databases used

I will use Google Scholar as my database, because I have the most experience with this search engine. If I am not able to retrieve enough information from Scholar, I can make use of other databases, like Scopus or Business Source Elite.

Also, I found a helpful article via Google on logistiek.nl, which is a Dutch site with news and articles regarding logistic processes, like warehouse management.

4. Describing the search terms and the used strategy

Custom range: between 2009 and 2019
Settings: search English and Dutch papers

Search terms:

- “warehouse management system” functionalities

- “warehouse management systeem” functionaliteiten
- allintitle: "warehouse management system"

Besides scrolling through the results of my search terms, I found some useful articles by using ‘snowballing’. I scanned some articles that were related to, but not helpful for my research. However, in the references some helpful articles were mentioned. This also worked reverse, I found some articles by using the ‘cited by’ function. This gave me a list of articles were the current article was referenced in.

5. Listing the final set of articles

1. Impact of Warehouse Management System in a supply chain

   http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.258.6734&rep=rep1&type=pdf

2. Warehouse management software

   http://www.warehousemanagementsoftware.org/processChange-Warehouse-Management-Software.htm

3. Wat is een WMS?

   https://www.logistiek.nl/warehousing/artikel/2017/03/2-wat-is-wms-10121690

4. Design of Automated Warehouse Management System

   https://www.matec-conferences.org/articles/matecconf/pdf/2018/91/matecconf_eitce2018_03049.pdf

6. **Conceptual matrix/summary of findings**

Article 1: Impact of Warehouse Management System in a supply chain (Ramaa et al., 2012)

This article states that the aim of a WMS is primarily controlling the movement and storage of materials in a warehouse and processing the related transactions, like receiving and picking. A WMS is a computer application that is driven by a database, which optimizes processes in the warehouse and writes off inventory according to the warehouse transactions based on real-time information. The article distinguishes three groups of WMS: basic, advanced and controlled WMS. A basic WMS supports stock and location control only, so the support is primarily on inventory management. On top of that, an advanced WMS can process activities and resources to assess the flow of goods through the warehouse and it can make a capacity analysis. A controlled WMS also takes the destination of all materials into account, in this way it can analyze processes like transportation and a value-added logistics planning can be made, which optimizes the entire warehouse operation.

Article 2: Warehouse management software (“Warehouse Management Software,” n.d.)

The original role of WMS in the early stages, controlling movement of inventory within a warehouse, is rapidly changing. WMS can contain accounting systems and order and transportation management systems nowadays. Next to this, WMS works best together with data collection systems, which can be facilitated by tools like barcode scanners. When a new system is put into practice, it is important to choose the most fitting automated data collection system.

Article 3: Wat is een WMS? (Van Den Elsen, 2017)

The definition of a WMS that is given in this article is practically the same as the other articles, a WMS comprises functionalities to manage and control material flows in the warehouse. This informative article has a whole section on the possible functionalities of a WMS. It states that almost every WMS comprises five core tasks: order processing, order release, inventory management, stocktaking and management information. Besides these core tasks, there are various additional functionalities that can be included in the WMS depending on the surroundings of the system. Example of this are material flow control, storage of hazardous substances, capacity planning and storage optimization with slotting. It is also mentioned that there is a trend of stretching the scope of WMS. Traditionally, WMS are concentrated on the flows within the boundaries of the warehouse, but supply chain management can also be embedded in the systems. Outbound and inbound logistics can be managed and functionalities like vendor managed inventory arise.

Article 4: Design of Automated Warehouse Management System (Chen, Mao, & Gan, 2018)

This scientific article reports the system design process of a WMS. It is pretty technical, but I can extract some technical specifications of a WMS out of it. This designed system platform is divided into different modules, where the main modules are system management, data management, warehouse management and communication

7. **integration of the theory**

In almost all articles it is mentioned that the scope of WMS is becoming broader. In the last years, more and more functionalities are developed that can be integrated in the system. Three of the four articles were predominantly focused on the technical architecture and modules of a WMS and not so much on the specific functionalities. However, this is also useful for answering my research question.

The core tasks of a WMS are described differently in the four articles, but by combining the articles I have drafted up two core functionalities that almost all WMS contain, warehouse/inventory management and order/transaction processing. For more advanced WMS there are extra functionalities like process flow management and capacity analysis.

Article 3 also gives an extensive sum-up of specific functionalities a WMS can comprise. Some of these functionalities can be considered to be one of the requirements the WMS must include, for example, storage of hazardous substances and storage slotting are very interesting functionalities for my specific company.

Appendix B: Report on meetings with warehouse management system suppliers

During my time at the company, my supervisor at the company met two suppliers of warehouse management systems at business fairs. Because of the interest of Schmits in this subject and my related research at the company, exploratory meetings with the suppliers were held to get a clear practical picture of a possible investment in the near future.

First supplier

The first meeting was with two collaborating businesses, a software and a hardware supplier.

The hardware representative was a salesperson that sold Cognex scanners. These scanners work with 2D barcode and they take a picture instead of scanning a surface. From this picture, the code is recognized and read. Cognex scanners have a patented technology which can read every code, even if it is soiled or torn.

The software company was a more practical business that provided software that supports and drives the hardware in the warehouse. It is predominantly focused on value-added warehouses, like the warehouse of Schmits where production takes place. They also take care of the integration of the warehouse management system with the current ERP system, so that these systems properly communicate with each other. When this company gets the job, they proceed with an orientation phase, called the “pre-engineering”. In this phase, the current situation is analyzed from which the capacities of the WMS are defined and “User requirement specifications” formulated. Also, the desired situation is drafted up by using flowcharts. Based on this, the required technical and IT activities from the company can be determined and a cost implication can be given.

From this meeting, some takeaways are acquired that can be used in my research. First, the software representative proposed a way of updating inventory during production at Schmits. He could link the weight system of a forklift truck to the system to register used amounts in production. In this way, the difference in weight on the fork of the truck can be adopted by the system to update the inventory of the material. Secondly, they knew from experience that labeling arriving goods is the most convenient way of using (2D) barcodes in the warehouse, because Schmits is working with numerous suppliers and there are many intermediaries in this sector. So, it is difficult to influence the way of labeling of the arriving goods. Lastly, an additional argument for working with hand terminals in the warehouse was brought up by the hardware supplier: hand terminals give a professional impression of the production facility. If business partners visit the facility of Schmits, which happens quite often, hand terminals confirm the structured way of working of the production and logistic departments.

Second supplier

The second meeting was with a supplier of both the hardware and software equipment. They offer a standard warehouse management module with functionalities focused on inventory management, where also some additional extensions are possible. The system guides the processes of goods receiving, storage, order picking and shipping. Their standardized system is not only applicable for value-added warehouses, but also for crossdocking and order-pick warehouses, so it might be the case that their module is too general.

This company also makes use of an orientation phase to suggest a fitting solution, they call it a detail study. In this study, interviews with stakeholders and practical experience of the specialist will be used to formulate the functioning of the system. From this, fixed-price quotation will be drawn up for the software as well as the hardware.

The main takeaway of this meeting was the possible use of slotting software at Schmits. The workers at the production facility use standard places for chemicals and can pick most of them up based on experience, so it was the question if slotting software could reduce the order pick time, since chemicals would switch frequently from location in the warehouse. The representative of the company proposed an alternative method, which may be more fitting to a production warehouse like Schmits'. Where ranked preference locations for all materials are used. It works as follows: a raw material needs to be stored in the warehouse and the system checks if the first preference location is occupied. If it is unoccupied, the system checks if the safety restriction regarding the material and the surrounding chemicals that are explosive, corrosive or toxic are not exceeded. If not, the material is assigned to this location. If the first location is occupied it checks the second location and follows the same procedure. This policy goes on until the system finds the first preference location that is unoccupied and where the safety restrictions are met.

A second takeaway was in the field of using 1D or 2D barcodes for the track and trace system. In the first meeting, one of the representatives was a salesman of 2D barcode scanners, so he advocated for them. This supplier explained however, that 1D barcode would be sufficient for Schmits. 2D barcodes can store much more information than 1D barcodes, but this is not necessary for Schmits because the barcode only have to represent a specific location or material, which can be expressed with just a few digits or letters. So, the use of more expensive 2D barcodes and scanners would be unneeded. I tend to agree with him on that point, also because he has a more objective view than the salesman of 2D scanners. He also mentioned that mistakes were more often made with 2D barcodes, since they are easily scannable. This seems as an advantage, but it can be a pitfall in a crammed warehouse with many barcodes when it scans the adjacent barcode instead of the barcode you meant to scan.

Conclusion

It can be concluded from both meetings that the approach of these companies on formulating the right system properties for Schmits are comparable with my research. Both companies use an orientation phase/detail study, where among other things, interviews take place at the company to formulate the requirements of the system. One of the suppliers even uses flowcharts to model the desired situation, which comes very close to my approach with business process models. The difference however is that the companies rely on their practical experience in this process, while I use academic literature to justify my choices and give advice to the company.

Appendix C: Report on interviews

In the introduction of the interviews I explained the goal of my research: giving the company advice on automating more of their management processes in the factory, by utilizing a warehouse management system. Then I described the goal of the interview: measuring the viewpoints of the stakeholders on possible functionalities of the WMS and their fit to the way of working at Schmits. The possible functionalities can subsequently be formulated as requirements of the system by using the prioritization method, MoSCoW.

Real time inventory management

It came forward during the interview that the current way of inventory management is prone to error. Production workers now note the used amount of chemical down on the production report, which is brought to the factory managers for administration after the production is finished. Because of the different ways of noting things down and bad handwriting, misunderstandings arise which are a source of human errors and time consuming. All subjects agreed that updating inventory directly during production with a handheld terminal could be an interesting solution for this problem and it would also result in a real time inventory. It is also mentioned that the desire to improve inventory management is the main reason to explore the possibility of integrating a warehouse management system. All four subjects formulate this requirement as a must have for the system.

Track and trace system in the warehouse

All subjects agree that the warehouse needs a track and trace functionality the most, because of the traceability it gives, which is currently a problem. Also, other functions like cycle counting and slotting rely on the track and trace system. One subject proposed that the production kettles could also be labeled with a barcode, so that it is registered which kettle is used for which production batch. Also, finished products that are awaiting departure in the finished goods warehouse could be labeled and linked to their location to increase traceability. Labelling the goods also enables the system to automatically scan and register outgoing goods upon departure. A track and trace system is key for the system and definitely a must have requirement for all of the subjects.

Cycle counting

According to one of the subjects, the plan of the company was to perform stocktaking twice this year, instead of the usual yearly operation. However, the planned stocktaking activity in May was cancelled, because of the busy production schedule. It is an activity that can be neglected, because it is easy to procrastinate in comparison with production activities. Since, for production activities, customers are waiting. A cycle counting tool which can classify each chemical's counting frequency based on use rate, scrap rate and other factors appeals to the subjects. However, all subjects agree that it is not the most important functionality for the system. One subject classifies it as a 'nice to have', because it is more of a side functionality of a warehouse management system. Someone else thinks that cycle counting will not be necessary when the inventory management in the system works properly, since human errors are almost ruled out. Concluding, the cycle counting functionality can be classified as a 'could have' requirement for the system.

Slotting function with preference locations

Using a slotting functionality to allocate the incoming raw materials over the warehouse is regarded as an interesting functionality that could further professionalize the warehouse. But there are some doubts about the practical implementation of this function. Mainly because of the different sizes of the packaging materials, like drums, IBC's and euro pallets, some practical difficulties are expected. Also, the size of locations can differ a bit in the warehouse. For instance, some shelves cannot store an IBC, because there are water tubes in the back of the place. This all requires an extensive preparation to assess what the storage possibilities are and to formulate this in the slotting software. It is also suggested that the functionality could be added to the warehouse management system after the implementation of the WMS. Concludingly, the functionality is conceived a requirement of high importance for the warehouse management system, however the system can properly function without it and it could be added in a later stage. So, a slotting tool is a should have requirement for the system.

Automatic data collection

Automatic data collection is not treated as a requirement with a certain priority in the interviews, because it is not really a separate functionality of itself but more an additional benefit of a warehouse management system. During the interviews, there were many smart ideas on how to make use of this data in order to reach a more optimal management of the warehouse.

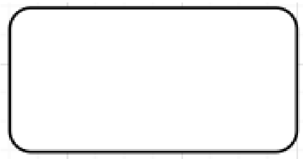
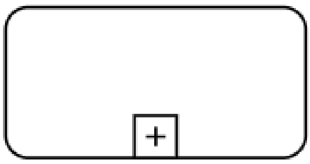
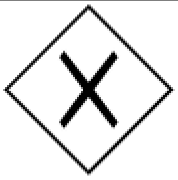
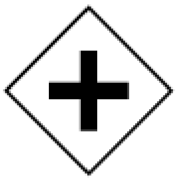
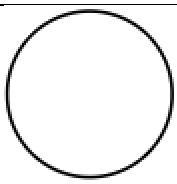
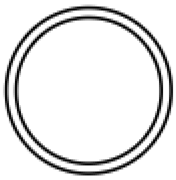
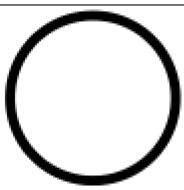
Firstly, labor tracking of individuals was discussed. Labor tracking is useful to trace back the responsible workers when complaints arise about a product. The subjects were moderately enthusiastic about measuring productivity of individuals because there were some doubts if productivity could really be measured, since the production workers are occasionally doing multiple production at the same time or are helping each other with some tasks. So, the measurements should sometimes be taken with a grain of salt. It was also suggested that production information of individuals could be used to define certain specialties of workers. For instance, a worker is significantly faster with completing a specific production process than others, because of experience. This could be considered in the production planning by assigning a production to a particular worker that is specialized in this.

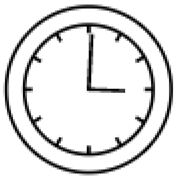
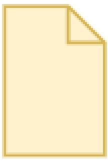
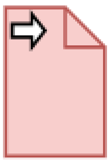
Next to individual labor tracking, the data collected during a specific production process can used for production planning in the long term. When the production is done multiple times, the data can be used to estimate the mean production time precisely, where also the batch size must be taken into account. In this way the production planning can be done more optimally, since production times are easier to estimate.

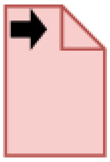
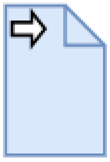
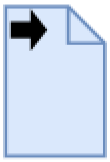
Also, some technical key performance indicators (KPI) for the warehouse were suggested that could be derived from the data. Utilization percentage of pallet locations is a logical one, but it was remarked that the locations must be grouped, because the total number does not say enough. Distinctions must be made for locations where groups of corrosive, acid, base or toxic chemicals could be placed. Locations can also differ in size, so insights into the utilization of location places for euro pallets, IBC's and drums is required. With insights into the utilization of the warehouse, it can be assessed if the warehouse is too crowded or too empty for each of the groups and actions can be taken. Furthermore, occupation percentage of the kettles could be measured when the production kettles are also labeled and linked with a barcode during production.

Lastly, routing data can be used to update the optimal preference locations of the slotting software once in a while. In the software, materials with high use rate will be placed on a more easily accessible and prominent place than materials that are rarely used. Use rates can fluctuate over time, so that is why the preference locations must be updated once in a while.

Appendix D: Overview of BPMN elements

Group	Symbol	Name	Explanation
Participants		Swimlane	Swimlanes indicate the actor responsible for the activities in the lane. These actors can be departments, systems or individuals.
Activities		General task	A task is an activity that has to be performed in the flowchart by the responsible actor of the swimlane.
		Sub process	A sub process is a separate small process flow of its own and can be explained in detail in a separate figure.
Gateways		Exclusive gateway	A split point in the process flow. The process can follow different paths, based on a certain condition. Only one path can be followed.
		Parallel gateway	Splits up the process into two or more simultaneous tasks. After each separate task is executed, the flow will merge again.
Event basics		Start event	An event that triggers the start of a process flow.
		Intermediate event	An event that within a process.
		End event	Event that indicates that the whole process flow is ended.

Group	Symbol	Name	Explanation
Type of events		Message event	An event that is triggered when a message is received. This can be an email or an order, for instance.
		Timer event	These events indicate that time passes before the process starts or continues. For instance, when you are waiting on something or an activity is planned.
Connecting objects		Sequence flow	Connects flow objects with each other: events, activities and gateways. Shows direction of the activities.
		Message flow	Indicates the flow of information, like messages and documents between actors. Mostly used with message events.
		Association	Indicates the flow of data between the process and systems. Mostly used with activities and artifacts.
Artifacts		Group	Used to group elements to attach one connecting object or to indicate a subprocess.
		Paper document	Paper sheets used during processes mostly for administration, like transport documents.
		Data input from WMS	Data extracted from the WMS used as input in the process.

Group	Symbol	Name	Explanation
Artifacts		Data output into WMS	Information output from the process, which is shared with the WMS.
		Data input from Blending	Data extracted from the ERP system, Blending, and input for the process.
		Data output into Blending	Information output from the process, which is registered in the ERP system.
		Data store in WMS	Used to depict storage of data in WMS or extraction of data from WMS.
		Data store in Blending	Used to depict storage of data in ERP or extraction of data from ERP.