New Integrated Warehouse Design Framework

And its application at ATAG Benelux BV on the redesign of the distribution warehouse

Master Thesis

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Sofie Vreriks

A New Integrated Warehouse Design Framework

A case study at ATAG Benelux BV on the redesign of the distribution warehouse

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Sofie Vreriks

S1095730

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Committee

Dr. P.C. Schuur
Faculty: BMS
Industrial Engineering and Business Information Systems

Dr. Ir. A. Al Hanbali
Faculty: BMS
Industrial Engineering and Business Information Systems

B. Jansen
Manager Purchase Components
ATAG Benelux BV

L. van Ulden
Supply Chain Manager
ATAG Benelux BV

University of Twente
Behavioural, Management & Social Sciences (BMS)
Industrial Engineering and Management

Drienerlolaan 5

7522 NB Enschede

ATAG Benelux BV

Impact 83

6921 RZ Duiven

UNIVERSITY OF TWENTE.

ATAG
ATAG Nederland B.V.

Preface

After seven years, my study time at the University of Twente is coming to an end. To complete my master Industrial Engineering and Management, I started a research project at ATAG Benelux BV in Duiven at the beginning of February 2017. Over the course of the following 20 weeks I analysed the logistic department of the company, dove into the scientific literature, created a warehouse design framework and eventually applied this at the company. All the research methods and all their results are collected and merged into this Master's thesis, which I proudly present. The whole project would have never been possible without the support and the feedback of some people involved, who I would like to thank.

First of all I would like to thank Peter Schuur, who was my first supervisor at the University of Twente throughout the graduation process. Besides his support in finding an interesting and challenging assignment, I learned a lot from his guidance during the discussions and feedback session we had. Not to mention the pleasant off-topic conversations about sports, theatre and music. Furthermore, I would like to thank Ahmad Al Hanbali for his support as second supervisor at the University of Twente. Despite his forthcoming departure, he managed to find time to read my graduation thesis and to give significant feedback. Besides, I want to thank Gino Balistreri for finding the time to help me with crunching the data even though he was busy writing his own thesis.

Secondly, I would like to thank the people at ATAG for their support and their co-operation. In particular, I like to mention Leo van Ulden and Bas Jansen. In their role as my external supervisors I would like to thank them for their trust in me and the opportunities that were given to me. In their role as colleagues, I would like to thank them for their company and many hours of enjoyable conversations during the various excursions we made. In addition, I am grateful to Manuela Walter for her trust in me to walk freely around her department and for always being available for questions.

Finally much love to my family and friends. I am especially blessed for my boyfriend Thijs, who has patience with me and supports and encourages me in all my decisions. Furthermore I want to thank all my family members and friends for their support during the process and in particular their availability to relieve my many hours of travel with long phone calls. Lastly, I cannot forget to thank my (four) amazing parents for always supporting and loving me. You enabled me to have a fantastic study time in which everything was possible and I could do whatever my heart desired. I hope you all know how much you mean to me and how grateful I am for having such warm and wonderful family and friends.

Sofie Vreriks,

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Management Summary

In this report we present a New Integrated Warehouse Design (NIWD) Framework, which is developed to support (re)design of a warehouse. This framework is applied to realize a research project at ATAG Benelux BV aimed to develop (a part of) the design of their new warehouse to improve their logistic performance.

ATAG Benelux BV is producer and supplier of domestic appliances within the Benelux. To maintain their good market position, a more efficient and transparent service for their customers must be pursued. Increased responsiveness and resilience realizes this market position in the fast changing, increasingly competitive, and highly dynamic markets. To be able to meet these requirements, a well-organized transparent supply chain and an adaptive-flexible logistics management is needed. By redesigning the logistic facility, ATAG will be enabled to improve logistic performance and to keep up with the rapid decision pace. However, as most organizations, ATAG lacks a fitting process for designing a new warehouse. A literature study reveals that despite the demand, academic literature also lacks an integrated framework that facilitates the overall redesign process. Consequently, there is a need for a comprehensive framework. This leads us to the following research aim:

"Development of an integrated warehouse design framework, to support the design of a new warehouse that takes into account strategic, tactical and operational aspects on different description detail".

ATAG Benelux BV provided a study object for our case study. They acknowledge that their current warehouse is not fit for further logistic performance improvements and should be completely redesigned and reconstructed.

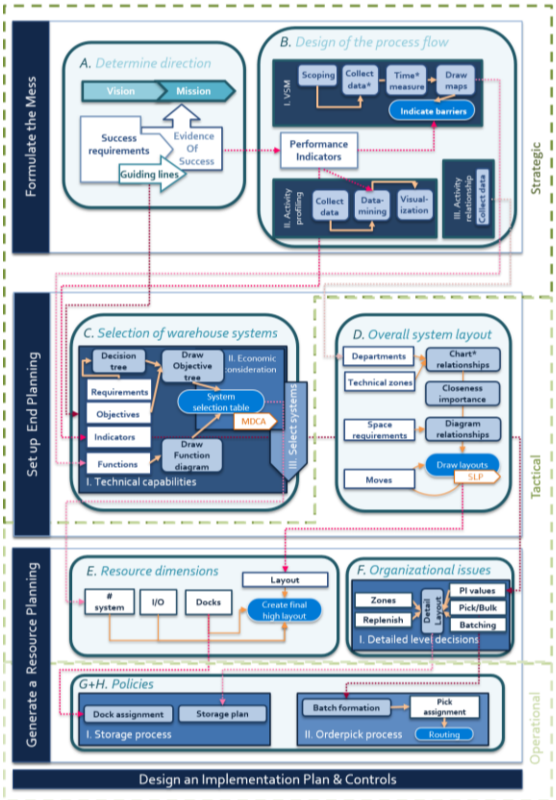

Figure MS-1. The New Integrated Warehouse Design framework

By executing an extensive literature study and with the aid of the 'Idealized Design' approach, we developed the New Integrated Warehouse Design (NIWD) framework. As a backbone of the framework we used the warehouse design structure of Rouwenhorst, et al. (2000), which operates from a System Thinking perspective. This method approaches the design problem from a top-down point of view. Starting with the strategic level, various phases are passed towards the operational level, resulting at the end in a new warehouse design. Despite the strong approach, some important steps were missing, like a detailed description of the different steps. By adding the Model of Success (Tompkins, White, Bozer, & Tanchoco, 2003), the Value Stream Mapping Method (Martin & Osterling, 2013), Activity Profiling (Bartholdi III & Hackman, 2016), Systematic Layout Planning (Muther & Haganäs, 1969) and the Equipment Selection method (Hassan, 2015; Richards, 2011) we established a comprehensive framework that does not require investments in decision or support software (see Figure MS-1). In 3 phases, 'Formulate the mess[1]', 'Set up Ends Planning' and 'Generate a Resource Planning', the warehouse design can be designed.

Additionally, we executed a case study. Given the interests of ATAG Benelux BV, we have used their design problem to validate the NIWD framework. We started with defining the strategic direction of the company and their logistic department. This delivered us objectives and performance indicators; input data we needed further in the process. As a second step, we indicated the gaps currently occurring at the logistic department. By mapping the processes and analysing the item behaviour we generated insights in the points of improvement. These insights we used, together with the objectives and performance indicators, to construct four possible storage and material handling equipment systems. Subsequently, we made the department interdependencies visible. By collecting and then diagramming this information, we could draft two block layouts (see Figure MS-2 and Figure MS-3). Finally, we combined this information with the four possible equipment systems. This has produced four possible warehouse designs:

I. *AS/RS system with layout option 1:* Highly automated Goods-to-Picker (GTP) method for light, medium and heavy weighted items. Full First in First out (FIFO) system, which complies the needs of ATAG by providing low travel distances for labour, an efficient time division and a high accuracy. An extensive Auto-Identification system is required and the AS/RS system fits best with layout 1. The overall system requires a high investment.

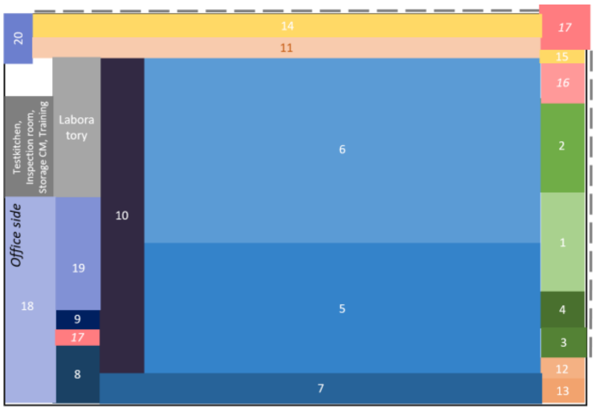

Figure MS- 2. Warehouse layout option 1

II. *AS/RS and Block Stacking (BS) system with layout option 2:* Highly automated GTP method for light/medium weighted items and Picker-to-Goods (PTG) method for heavy weighted items. Complying ATAG needs by enabling high space utilization, being mostly FIFO and providing efficiency in labour allocation. An extensive Auto-Identification system is required and this equipment system fits best with layout 2. The overall system requires a medium investment.

III. *Very Narrow Aisle Racking (VNAR) system with layout option 1:* PTG method for light, medium and heavy weighted items. The system complies ATAG needs by being a full FIFO system, reducing the labour travel distance and providing optimal item allocation due to being independence of pick order and the related route. An accurate AutoID system is required since all items are stored in one system. The VNAR system fits best with layout 1 and needs a medium investment.

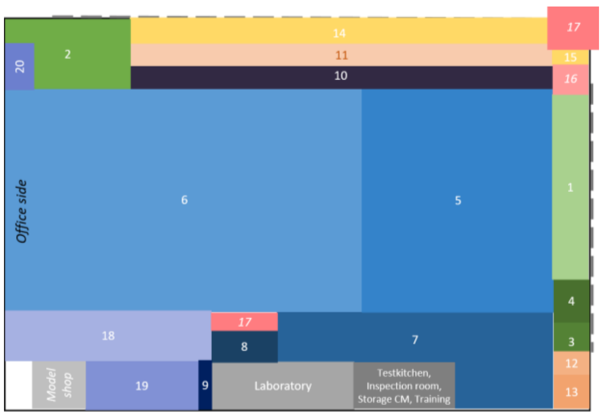

Figure MS- 3. Warehouse layout option 2

IV. *VNAR and BS system with layout option 2:* PTG method for light, medium and heavy weighted items which is used in the current situation. The system is partly FIFO and to increase accuracy, an improved Barcode AutoID or a RFID system is advised. Furthermore the current block stacking policy needs improvements to enable and support the FIFO system. This equipment system requires a low investment.

[1] 'Formulating the mess' is the original step name derived from the 'Idealized Design' framework of Ackhoff.

Based on our case study, we believe the NIWD framework is broadly applicable to a wide range of companies. Due to time limitations, we were unable to perform all steps of the framework on ATAG and therefore a final design is still missing. This has led to six recommendations for ATAG:

- Execute a business case study and a simulation study and apply step E-H: to select the best equipment system of the four options based on both productivity and financial aspects. With the best fitting layout and equipment system as foundation, step E to step H can be performed.
  - (*Potential executive: Graduation intern & Project team*)
- Create future state Value Stream Maps and pursue standardisation: to improve the operational processes.
  - *(Potential executive: Logistic management & Floor staff*)
- Find new batch sizes for combined shipments picking: by simulating the several options to improve the efficiency for the pick process.
  - *(Potential executive: Graduation intern*)
- Apply Step B 'Process Flow Design' and Step C 'Equipment selection' for the service and production warehouse": to improve the overall warehouse.
  - *(Potential executive: Graduation intern & Project team)*
- Involve people from all layers in the improvement process: to smoothen the improvement process and to collect insights throughout the organization.
  - (*Potential executive: Project team)*
- Improve communication within and between departments: to improve all of the process flows and to increase efficiency.
  - *(Potential executive: Logistic management & other department management)*

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Glossary

Term	Description
AGV	Automated Guided Vehicle: automatically programmed vehicles that drive to pre-planned points
Approach	A specific method how to perform a certain task/activity/process
AS/RS	Automated storage and retrieval: computer controlled system for automatically placing and retrieving loads (items)
AutoID	Auto Identification: the activity/system that automatically identifies and stores data
Bottleneck	A point of congestion or blockage within a certain process
B2B	Business to business: trade between two companies/organizations
B2C	Business to consumer: trade between a company/organization and an individual customer
BS	Block stacking: storage system for stocking goods that have a rectangle/cubic form
Consolidation	The process of combining two or more things together in order to send or to transport
Department	A part of an organization that deals with a particular area of work
Distribution logistics	The management of the finished goods flow that distributes and moves items to consumers
ETL	Extraction, Transformation and Loading: process in databases that collects, transforms and stores info
ES	Equipment system: a combination of several equipment tools that together serve a shared objective/task/process
FIFO	First in First out: inventory management method where stock movements are executed in chronological entry order
Gap	A discrepancy between two situations that occurs due to a shortage/lack of resources or insights
GTP	Goods to Picker: an item collection method in which goods are transported from the storage location to the picker
I/O points	Input/Output point: the place in the warehouse where items enter and leave a certain building/department/zone
KPI	Key Performance Indicator: the main instruments used to measure values that supports insight in the performance
LIFO	Last in First out: inventory management method where stock movements are executed in backwards entry order
Logistics	The management of the flow of things between two points to meet requirements of internal/external customers
MCDM	Multi Criteria Decision Making: a decision support method that takes into considerations multiple aspects
MHE	Material Handling Equipment: mechanical equipment used for the movement, storage, control and protection of materials, goods and products throughout the process of distribution and disposal
NIWD	New Integrated Warehouse Design framework: model that explains step by step the design steps for a warehouse
OEM	Original Equipment Manufacturer: a company that produces parts and equipment that is marked by another firm
PI	Performance Indicator: main instruments used to measure values that supports insight in the performance
Production logistics	Management of the item flow in the right quantity/quality at the right time to enable workstations to produce
PTG	Picker to Goods: an item collection method in which the picker travels to the storage location to transports goods
QA	Quality Assurance: the department responsible for preventing mistakes or defects in manufactured goods
RFID	Radio Frequency Identification: method that through electromagnetic fields automatically identifies & tracks objects
SE	Storage Equipment: equipment used for the storage of materials, goods and products throughout the logistic process
Service logistics	The management of item flows which respond to customers on an individual basis to provide a certain service
SKU	Stock keeping unit: distinct type of item for sale
SLP	Systematic Layout Planning: tool used to arrange a workplace/facility based on logical relationships
Stakeholder	A person, group, department or organization that has an interest/concern in an organization that can affect or be affected by the organization's actions, objectives and policies
Technical zones	Department division in zones based on its attributes (e.g., package type)
VNAR	Very Narrow Aisle Racking: a storage method in which the aisle width is the smallest possible, requires a VNA truck
VSM	Value Stream Mapping: tool for visually mapping the processes of a certain department
WIP	Work in Progress: items that are waiting for further processing in a queue or as buffer storage

1. Formulating the Mess[1] - Problem Analysis

1.1 Introduction

In order to complete my studies in Industrial Engineering Management at the University of Twente, I conducted research at ATAG Benelux BV, focusing primarily on warehouse design within the scope of distribution logistics.

Due to the high digitalization that has occurred the last 20 years, a fast globalization of the economy has taken place. This trend has resulted in fast changing, increasingly competitive, and highly dynamic markets, which forces companies to be more agile and to operate more efficiently. To remain a player in these highly variable markets it is important to have a short response time and to offer a wide range of products (Rouwenhorts, Reuter, Stockrahm, van Houtum, Mantel & Zijn, 2000). To be able to meet these requirements a well-organized supply chain and logistics management is needed. A well-designed logistic infrastructure can improve competitive performance by increasing the flexibility of the organisation and by providing a system in which rapid decision is possible (Kherbach & Mocan, 2016). The logistic process includes both the external and the internal processes in which several stakeholders, e.g. suppliers, customers, play an important role.

Just as most other companies, ATAG Benelux BV has three sub-processes that form the overall logistic process: the procurement logistics, the production logistics and the distribution logistics. Although the overall performance of the logistic network of the company is going well, ATAG feels there are some improvement possibilities. Due to some upcoming changes in the current housing situation, ATAG has decided to focus on enhancing the internal logistic process and especially its design. Since the production logistics are already being analysed, the focus of this research will be on the distribution logistics.

This thesis presents a framework to facilitate improvements in the logistic performance of an organization by redesigning the warehouse. The problems encountered at present are addressed and the different steps that are executed are described, based on the several models that are available in the literature.

In the first Chapter insight is given in the main logistical problem that occurs at ATAG Benelux. First the organization is introduced along with their current business environment. Then, the problem is introduced with an associated problem statement and problem analysis. Subsequently, the research design and the foundation of the framework are described. Finally, the further thesis outline is explained.

[1] 'Formulating the mess' is a step name derived from the 'Idealized Design' framework of Ackhoff, which is explained in section 1.5.1

1.2 System analysis

1.2.1 Company profile

ATAG Benelux BV (ATAG) is producer and supplier of domestic appliances within the Benelux. The assortment of ATAG contains, in the range of both built in appliances as independent appliances: hobs, microwaves, ovens, stoves, hoods, refrigerators, freezers and dishwashers (Figure 1-1). Since 2008 the company is part of the large international organization named Gorenje. The main office of Gorenje is established in Slovenia (Velenje) and they distribute mainly in Scandinavia and Australia.

Figure 1-1. Example of the ATAG assortment (Source: www.atag.nl)

ATAG comprises three different brands, ATAG (ASKO[2]), Pelgrim and ETNA, of which each targets their own segment of the Benelux domestic appliances market that is differentiated on income and budget of their customers.

Nevertheless, the three brands share the same overarching ATAG vision that can be described as:

"To provide the best products & services for the home cooks from our shared passion to cook to create an enervating cooking experience".

The mission is the core of the strategy and has formed the foundation for the above-mentioned vision. The mission of ATAG can be described as:

"Be the leading supplier of kitchen appliances and services".

The strategy of ATAG Benelux BV can be visually displayed with the aid of the ATAG house (Figure 1-2). ATAG Benelux BV has two pillars, 'Logistics' and 'After Sales Service', and two foundation

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2 Products of ATAG are distributed outside the Benelux under the name ASKO.

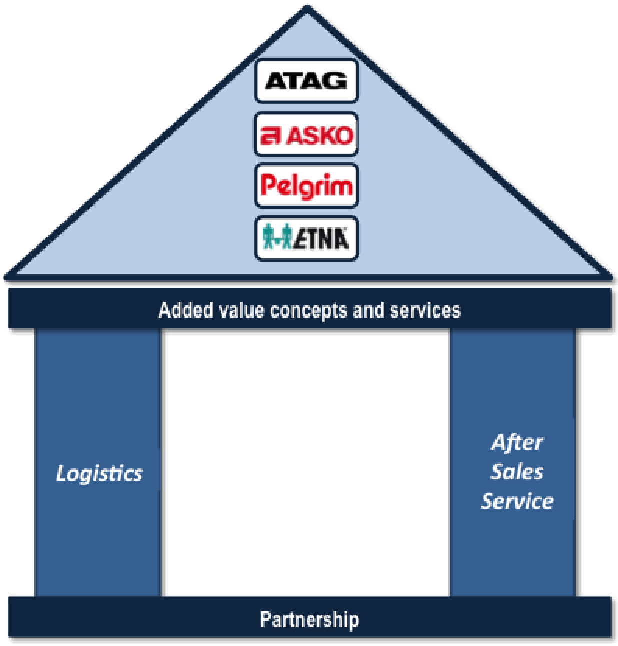

Figure 1-2. ATAG House – Visual overview strategy (source: ATAG)

bars, 'Partnership' and 'Added Value Concepts and Services' that carry the three brands ATAG (ASKO), Pelgrim and ETNA.

To produce and to supply quality products that differentiate ATAG from their competitors, the firm believes that close and reliable partnership is key as well as adding significant value to the existing appliances. However, nowadays customers do not settle for only a high-quality product, the overall process experience is just as important. From the moment a product is ready for sale the logistics are responsible for delivering the product (at the right place, in the desired condition, at the right time) to the customer, a process ATAG highly values. Thereafter, the responsibility does not end when the customer takes the specific appliance into usage. ATAG offers an extensive service program, during the appliance's lifetime, to support the customers with several matters.

1.2.2 Business environment

Smart Industry (4.0)

At a rapid pace a new revolution is evolving and it influences companies and organizations all around the globe (Figure 1-3). The great driving force behind this changing environment is the fast integration of Internet applications throughout the whole value chain. Besides that it enables companies to personalize products and services, the supply chain processes can be improved on efficiency, flexibility and adaptivity (Haverkort & Zimmermann, 2017). Where previously the supply chain consisted of many different individual steps, currently a shift is taken place towards a full transparent network that includes all players (Schrauf & Bettram, 2016). According to Schrauf et al. (2016), integrated planning, autonomous, B2C logistics, logistic visibility and spare part management are key for companies to respond on disruptions in the network and to reduce costs. An increased responsiveness and resilience enables organizations to provide a more efficient and transparent service for their customers, a feature that realizes a better market position. Furthermore the new types of products and services, that comprise integrated intelligence, offer the possibility to connect and to receive information about aspects as usage and life cycle phases (Haverkort & Zimmermann, 2017).

Both *Smart Industry* and *Industry 4.0* are used to denote the global industrial revolution. The biggest impact of the Smart Industry on the supply chain is caused by the concept of Smart Factories and the concept of Smart Logistics (Pfohl, Yashi, & Kurnaz, 2015). Pfohl, et al. (2015) mention seven characterizing features of Smart Industry. Those features are:

1. *Digitalization*: of internal processes, product components and communication with the aid of connectivity.
2. *Autonomization*: within decisions making and performing learning activities with the aid of technologies.
3. *Transparency*: resulting in collaborative and efficient decision making with the aid of data analysis.
4. *Mobility*: provide, communicate, share data and generate values with mobile devices.
5. *Modularization*: of both the products and the whole value chain.
6. *Network collaboration*: between all the stakeholders within the process.
7. *Socializing*: by interaction of machines and/or humans with the aid of the collaboration network.

1800	1900	2000	2015+	2030+
Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0	Digital ecosystem
Mechanical production	*Mass production + assembly lines*	*Advanced automation of production processes*	*Digital Supply Chain Smart Manufacturing Digital products and services*	*Flexible and integrated value chain networks Virtualized process & customer interfaces*
Powerd by water & steam	*Powered by electricity and combustion engines*	*Powered by Electronics, IT and industrial robotics*	*Powered by data analytics*	*Powered by industry collaboration*

Figure 1-3 The evolvement of the industry - the road to Industry 4.0. (Source: PWC, 2015)

Auto-identification

The key concept that links and enables most of the above-mentioned characteristics is '*Auto Identification'* (AutoID) (Pfohl, et al. 2015; Haverkort, et al. 2016). By introducing Radio-Frequency Identification (RFID)-technologies throughout the logistic process, real-time information about the current status of activities is available and machine-to-machine communication is enabled. To implement the RFID-technology successfully an organizational change is required. However, according to Pfohl, et al. (2015) the Business Intelligence that this change will deliver, results in a tremendous cost reduction since efficiency of the process can be ensured.

Digital supply chain (DSC)

All in all, it can be stated that in the current business environment the main change occurring is the shift towards a digital environment. A development that influences every stage in the value chain and therefore has an enormous impact on the organizations within the environment. The business goal of the digital supply chain has remained unchanged, "to deliver the right product into the customer's hands as quickly as possible". Hence, with the aid of the digital supply chain an increased responsiveness and reliability is pursued. A fully responsive supply chain is key to survive in the strong competitive environment, especially since customers are becoming more demanding. Applying automation results in efficiency increase and costs reduction that overall strengthen the position of the company and enables them to respond to the e-commerce trend of customized manufacturing (Haverkort & Zimmermann, 2017).

1.3 Obstruction analysis

1.3.1 Problem analysis

At the end of 2020 the rental contract for the current location of ATAG Benelux BV will come to an end. Based on the current available space, the space utilization and the expected growth for the next years, the decision has been made to end the contract and to move to a new location. The current space division of the office space and the storage space is rather unusual. In general storage locations have a relatively large warehouse and a small office section. However, since ATAG head office is located at the same location as the main warehouse and a part of the production line, the storage-office proportion is uncommon. Due to the relatively unusual ratio between the required office space, the required storage space and the required production space a new building will be build.

As stated in the company description, the two operational key pillars of ATAG Benelux BV are '*logistics*' and '*After Sales Services*' (Figure 1-2). The current layout of both aspects is not optimal due to tremendous growth and a continuously changing environment, which impacts the overall performance.

ATAG believes the performance of both pillars can be improved significantly by redesigning the logistics department in Duiven on strategic, tactical and operational level, which will result in an active anticipation on the strongly changing business environment. This anticipation is necessary to ensure and maintain a good market position. As previously mentioned, the production logistics and the related warehouse are already analysed and therefore the scope is limited to distribution warehouse and the service warehouse. Eventually we will focus on one of the two remaining logistic warehouses due to time restrictions. The choice for the distribution or the service warehouse will be made based on the information we acquire throughout the process. The redesign includes changes in the layout, equipment and operational functions of the warehouse.

Problem cluster

To map the various problems and their interrelations the 'Management Problem Solving Method' (Heerkens & van Winden, 2012) is applied. The method distinguishes two types of problems; *action problems*, the issues currently occurring, and *knowledge problems*, the information that is absent and therefore creating a gap. When the knowledge gap is closed, the gathered knowledge can be applied on the corresponding action problem. An overview of the knowledge problems in more detail can be found in appendix A.1.

To find the action problems that should be solved, a problem cluster is developed presenting the problems that are arising (Figure 1-4). The problems displayed in the cluster have been gathered through interviews with the several internal stakeholders, and during site visits. The causal relations between the various problems are displayed with orange arrows. The left-most problems are the main causes, which indicate the core problems. By solving this particular group of problems the resulting problems will be addressed as well, eventually solving the main problem that is encountered:

"The distribution logistic warehouse of ATAG Benelux BV cannot perform at best capacity with the current warehouse design".

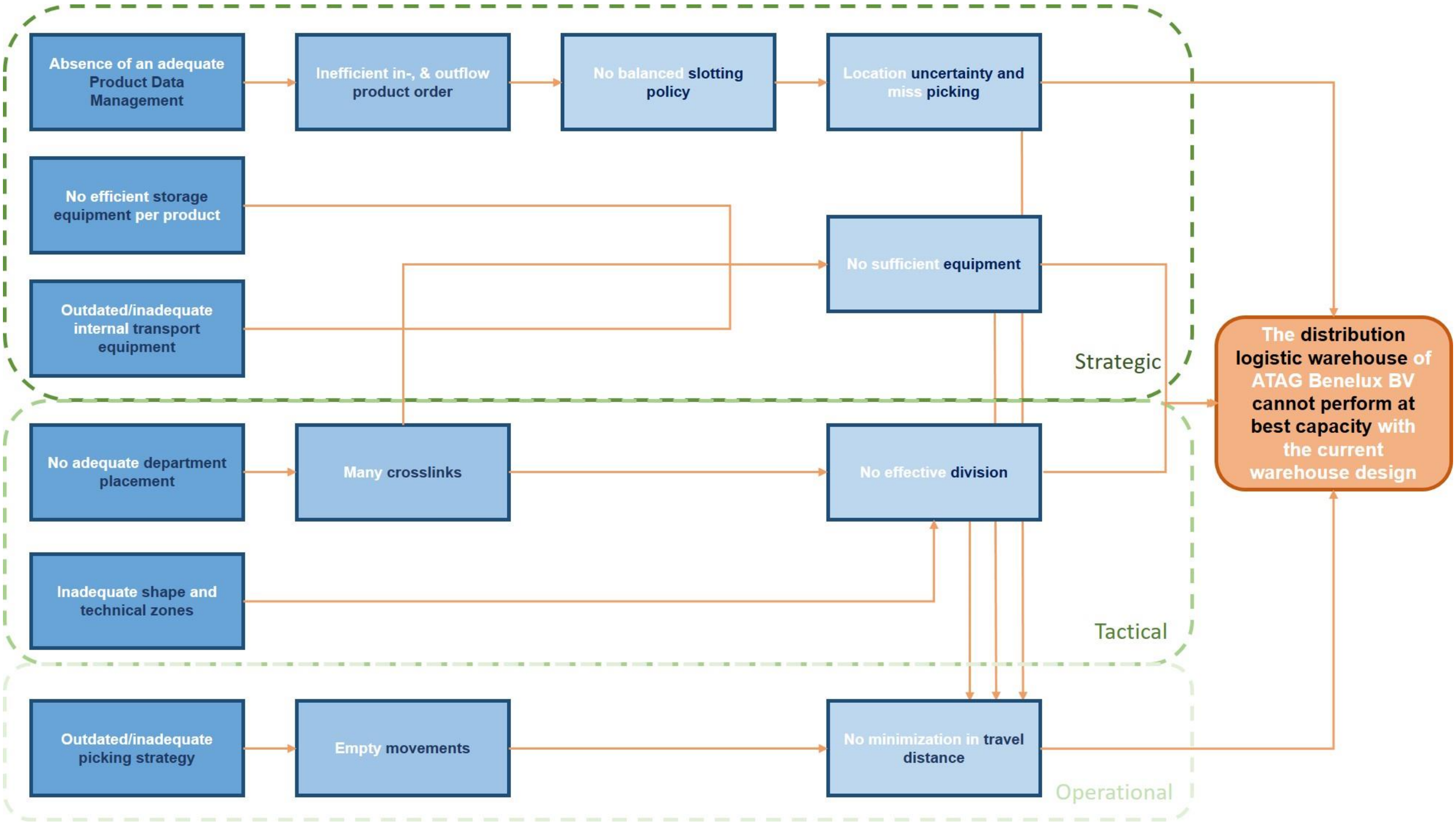

Figure 1-4. Problem cluster presenting the current warehouse problems at ATAG Benelux BV

To create a better understanding of the problems displayed in Figure 1-4, we will explain the meaning of each of the concepts. With the term '*Product Data Management*', the equipment and software that enables product data storage and analyse is meant. The *'departments'* are all the sections within the organization that deal with specific business areas activities (e.g., logistics, production, quality assurance). '*The shape*' comprises the dimensions of the department, whereas the technical zones indicate the several sites within a specific department (e.g., inbound, outbound). The definition of the '*picking strategy*' is: the procedure that is established for the execution of the collection of items.

An overview of all the concepts used in the thesis can be found under the Glossary.

1.3.2 Problem statement & research aim

Yet, with the current knowledge at ATAG Benelux BV a concrete redesign is not available, which is caused by the following aspects;

- They do not possess a suitable process for designing the new warehouse
- There is not enough insight in the current trends and possibilities in intra logistics
- There is not enough knowledge how to anticipate on these trends and possibilities
- There is not enough insight in efficient layout aspects, dimensions and, storage and material handling equipment that fit their activities and materials/products.

Summarizing the above-mentioned causes the following problem statement can be determined:

"ATAG Benelux BV lacks a fitting process for designing their new warehouse to enhance the distribution logistic performance".

In the literature numerous different models and frameworks for the various layout aspects and the related design steps can be found. However, the level of detail for the description of the execution steps differs tremendously. An extensive model that considers the overall process with a detailed description per step is rare. The literature offers models that describe the overall process with a brief explanation per step or models that describe a certain step extensively. Therefore a combination of all the different available knowledge is required. The aim of this research is to provide a general framework, addressing the executive steps on several detail levels that will result in a proper warehouse design. ATAG Benelux BV will be used as a reference to demonstrate the application of the framework.

The following research aim is defined:

"Development of an integrated warehouse design framework, to support the design of a new warehouse that takes into account strategic, tactical and operational aspects on different description detail".

1.4 Research design

To find an appropriate solution for the problem statement established in the latter section, it is essential to specify the research questions that define the research structure executed in this thesis. By answering the three main questions and the related sub-questions the research aim can be achieved.

1.4.1 Research question

In line with the research aim, the following research questions are developed.

First of all knowledge is needed to convert the current situation to the desired situation. This knowledge will be compiled into a general framework that can be applied on the specific ATAG case. To find the adequate information and to set up the framework, the first research question has been devised.

1. *What warehouse (design) models and frameworks are available and how can these be integrated into a comprehensive warehouse design framework?*

   Each of the core problems, presented in the problem cluster (Figure 1-4), has its own knowledge problem that indicates a gap in the design knowledge of ATAG. Those gaps serve as a foundation for the sub-question of the first research question, by focusing on different design aspects. The sub questions are divided into strategic and tactical level, a scope explained in the next section (1.4.2).

   Strategic level:

   a. *What steps should be executed to select the right storage and material handling equipment (MHE) that fits the assortment and the location?*

   Tactical level:

   b. *How can technical zones and shapes be determined and how is this division established?*
   c. *What steps are required for finding a suitable layout and allocation of zones relative to the departments?*

Once the framework is completed, its application can be tested on the case study at ATAG Benelux BV. This results in the second research question:

2. *How can the integrated comprehensive warehouse design framework be applied at the current warehouse of ATAG Benelux BV for a new warehouse redesign?*

This second research question can be sub-divided into four sub-questions. Before the redesign can be executed, insight in the current condition of the warehouse is required. From this point, we can identify the gaps in relation to the desired situation. Lastly, insight in innovative techniques is necessary.

a. *What is the current situation of the distribution logistics at ATAG in Duiven with regard to the processes, layout and interdependency with other departments at ATAG (e.g. production)?*
b. *What are the gaps in the current situation in the transition to the desired situation?*
c. *What storage, material handling and information flow techniques are available at the market that fits ATAG's processes?*
d. *What is the idealized design for the new warehouse of ATAG?*

The answers to the first two sub question provide an overview of the current situation in which the actual inefficiencies can be addressed. By answering question 2c potential techniques are collected that may be employed in the new design. These answers are critical for the design of the desired situation, which can be found be answering question 2d, and will be used as starting point for the redesign process.

When the current situation is mapped and the framework is structured, the desired situation can be designed. However, the time frame of this research project does not include the entire project. At the end of the project the process does not end. The final research question addresses the next steps and the final implementation of the framework on ATAG after the expiry of this research project.

3. *What follow-up (redesign) steps are required for an adequate warehouse design for ATAG Benelux BV?*

1.4.2 Scope

The design of the warehouse is a complex and extensive process. Due to the limits on the available time regarding this research, a part of the designed framework will be actually applied on ATAG. Since the project recently started at ATAG, the first two levels of the framework, the strategic and tactical one, will be (partly) applied on ATAG. This choice is made considering the likelihood that changes will occur the next year. Where the strategic and tactical levels generate aspects of the overall solution that together form the layout, the operational level provides aspects of the solution that are unfold within the layout composed in the above levels. Therefore the third level is much more subject to change and therefore adds no value if already established in this early stage. Furthermore, as we already mentioned in 1.3.1, we will apply the framework only on one of the warehouses at ATAG. During the research process the choice for the warehouse is made based on the information that will be analysed.

1.5 Methodology & thesis outline

Since the research aim is to design a framework and simultaneously to design the warehouse of ATAG, a methodology is sought to facilitate the two design processes. System thinking is a principle that focus on integrating information from different sources and different processes to understand a set of interrelated or interacting elements within the context of the overall system (Skyttner, 2005). Considering the primary aim of the research, the integration of several frameworks that all focus on different aspects of the overall warehouse design process, system thinking is a well-fitting perspective. The method that is chosen to structure the design processes of this thesis is the 'Idealized Design' (Ackhoff, 2001). Ackhoff, (2001) combines the system thinking with a design approach hence a well-applicable model. Because his approach is developed according to the system-thinking concept, the interdependence, and therefore the shared influence, of the several facets of a certain system are taken into consideration.

1.5.1 Idealized design

The 'Idealized Design' approach consists of two parts, the idealization phase and the realization phase. In the first phase the ideal outline is set up, describing the situation the designers would realize in the best case. The first step executed in this phase is to '*Formulate The Mess'*, thus to analyse the current situation. Subsequently, the '*Ends Planning*' is determined by drawing the ideal situation outline. There are two constraints and one requirement that have to be considered during this phase. First of all, the design must be technologically feasible, thus innovations that currently can be developed. Secondly, the design should fit the current business environment. Finally, the design is required to have the capability to improve over time. During the second phase the remaining four steps are conducted; in sequential order; 'Means planning', 'Resource planning', 'Design of Implementation' and 'Design of controls'. The first two steps concentrate on how to reduce the gap between the desired and the current situation, taking into consideration the required resources. The last two steps describe the process of actually reducing the gap, by determining who, what, when and where, with the necessary controls planned (Figure 1-5).

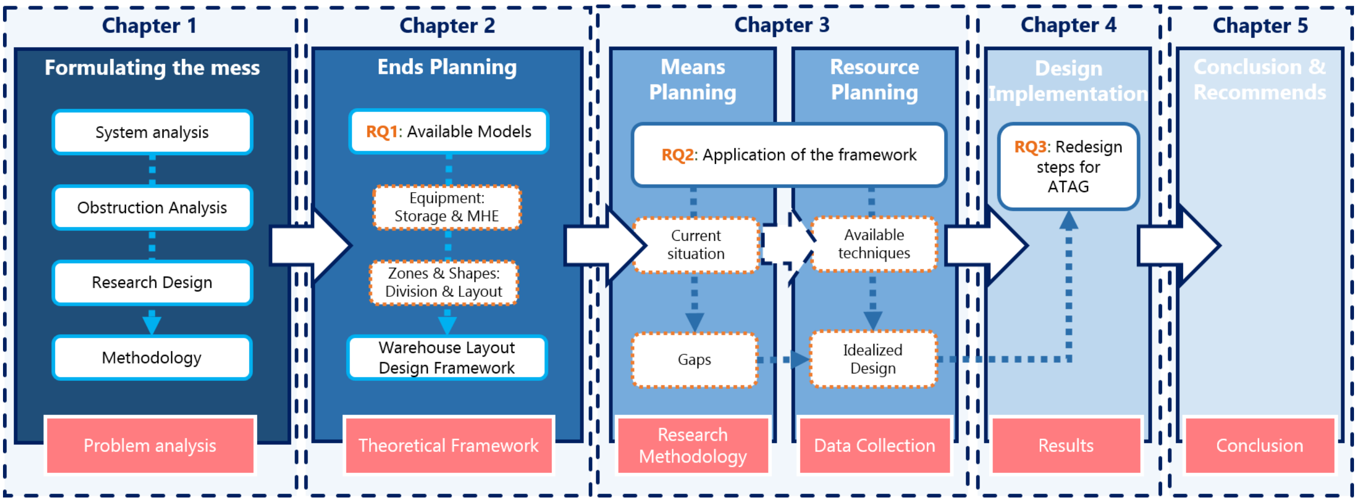

Figure 1-5. Thesis outline according to the 'Idealized Design' approach (Source: Ackhoff, 2001)

1.5.2 Deliverables

At the end of the study a number of deliverables will be provided that can be divided in two categories: The deliverables for *the scientific value* and the deliverables to support *the design of the new warehouse* for ATAG Benelux BV.

For the first category the deliverable is a framework that describes the various steps to be considered and carried out when designing a warehouse. The model is divided in three levels; strategic, tactical and operational, and is a product of numerous other models merged into one comprehensive structure. Besides the outline of the steps, a detailed execution of the sub steps is given.

For the second category an advice report is delivered based on the scientific deliverable. In conformity with the current position of the company on the total design time line, steps of the strategic and the tactical levels are conducted that result in an advice regarding the design of the warehouse and important aspects to be considered. This advice report is developed in order to support the management of ATAG in the future in their choices and decisions in the actual design process.

1.5.3 Thesis outline

The execution of the research by means of the 'Idealized Design' is described in the next Chapters. After the introduction of the problem and research structure in this Chapter, Chapter 2 provides an answer to the first research question by making use of literature. Chapter 3 addresses the required data and the data collection, to map the current situation and to get insight in new technologies. Next, in Chapter 4 the second deliverable is discussed; the new established framework of Chapter 2 is applied on ATAG Benelux BV with the aid of the data collected in Chapter 3. Finally in Chapter 5 the results are concluded, by answering the research question, and the recommendations for ATAG and future research are given. Figure 1-5 presents an overview of the thesis outline.

2. Ends Planning – Idealized Design

Once the 'Mess is formulated' and the problem is identified, the next phase following the 'Idealized Design' (Ackhoff, 2001)*, is the ends planning; the desired outcome. The result at the end of this Chapter is an ideal design an organization could apply to design their new warehouse if no restrictions were in place. During this phase a literature study is executed to lay a foundation for the New Integrated Warehouse Design framework (NIWD).*

The structure of Chapter 2 is composed in such a way that step-by-step the foundation of the framework is created and filled. In the first section (2.1) the characterization of the warehouse is described, to set a context for the subsequent paragraphs. Then, the actual framework will be developed. Throughout the development of the framework, several levels of detail are examined. First of all a general model regarding the design process is explained, functioning as the guidance throughout the overall design activity. Then models on high level, describing the overall warehouse design process, are analysed, summarized and finally combined, to serve as a backbone for the framework. Once this outline is determined, the ensuing sections of Chapter 2 fill the framework in sequential order, eventually resulting in a new integrated warehouse design framework.

2.1 The warehouse design

Warehouse types

To design the new warehouse, understanding of the warehouse characteristics and its major functions is crucial, i.e. their role in the logistic network. Rouwenhorst, et al. (2000) distinguish two warehouse types, the production warehouse and the distribution warehouse, both with their own characteristics. The production warehouse stores raw materials, work in progress goods, and finished goods throughout the production process with as major performance criterion a fast *response time* when serving the internal customers. The distribution warehouse on the other hand stores final products to fulfil external customer demand, while realizing a *maximum throughput*.

Richards (2011) differentiates subcategories, within those warehouse types, for which the distinction is based on three aspects; the type of product stored, the actions undertaken with the products, and the duration of storage. The production warehouse can be divided into intermediate, postponement, customization, and sub-assembly facility. The distribution warehouse division, presented in descending degree of shelf life, is; Finished goods warehouse, Fulfilment/value adding centres, Consolidation centre/transit warehouse and Cross-docks warehouse (Richards, 2011; Baker & Canessa, 2009).

Characteristics

In addition to the general warehouse type specification, the warehouse can be characterized on a more detailed level. Three different aspects are defined by Rouwenhorst, et al. (2000) to characterize the warehouse. The first facet is the flow of items throughout the warehouse, known as processes. Four key *processes* and one support process can be determined, in which receiving, storage, order picking and shipping are main processes and replenishment is a support process (Gu, Goetschalckx, & McGinnis, 2010; Rouwenhorst, et al. 2000). The second facet comprises the *resources*, which are the equipment and labour required to operate. Among resources the following categories are marked by

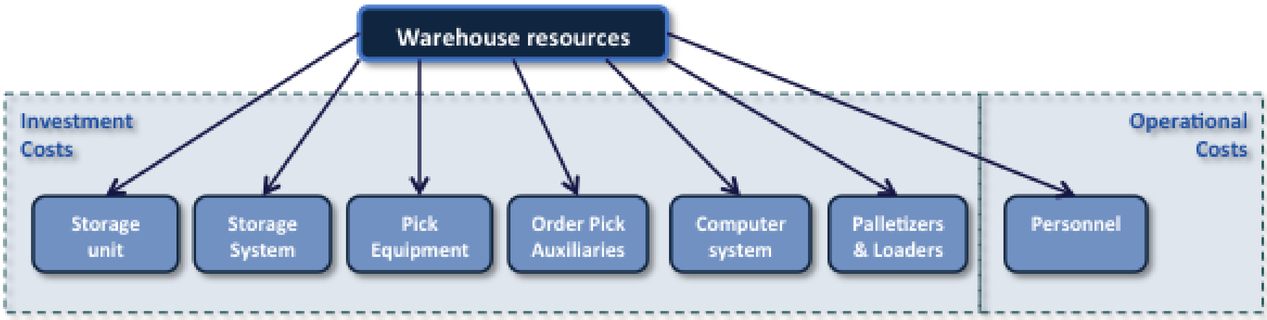

Figure 2-1. Warehouse resources characteristics (Source: Rouwenhorst et al., 2000)

Rouwenhorst, et al. (2000); storage unit, storage system, pick equipment, order pick auxiliaries, computer system, sorter systems/palletizers/truck loaders and personnel (Figure 2-1). The last facet includes all *planning and control procedures* to run the overall system, in other words the organization of the warehouse (Rouwenhorst, et al. 2000). For the overall framework of Rouwenhorst, et al. (2000) see Figure 2-5, Figure 2-6 and Figure 2-7.

In another way, warehouse classification can be performed based on their *functions* and *tasks*. According to Jacyna, Lewczuk, & Klodawski (2015), the functional structures and characteristics are based on the type of business, the production process level, the level of distribution, the storage conditions, the storage type, the inventory turnover, the material flow volumes and the packaging form. The classification can be represented with the aid of a spider plot (Figure 2-2). The legend of each of the axes start in the middle of the figure with the lowest/simplest value and as it progresses

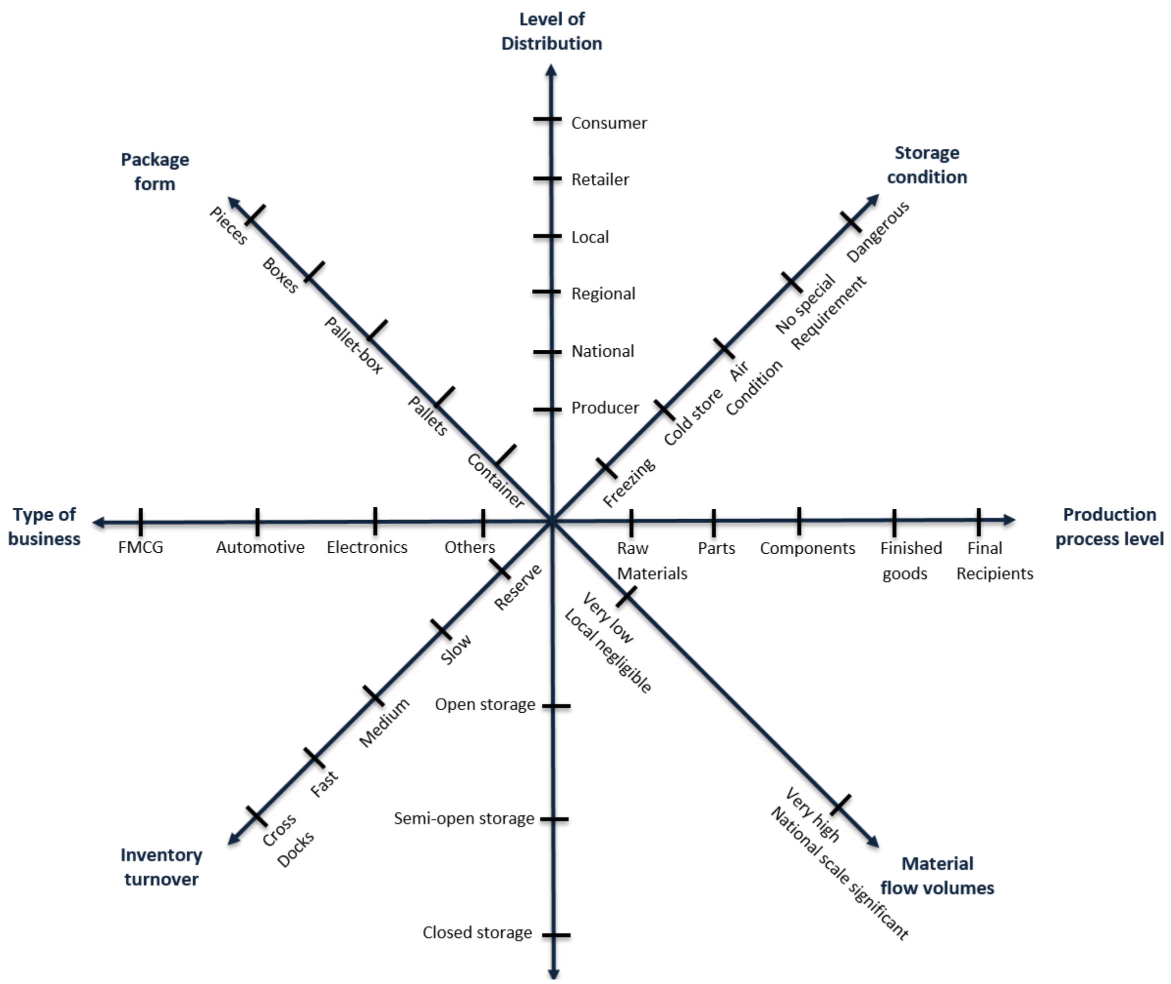

Figure 2-2. Functional classification of warehouse facilities (Source: Jacyna, Lewczuk & Klodawski, 2015)

outwards it becomes more complex. What we can concluded from this information is that the wider the spider plot the more complex the warehouse is.

2.2 High level design models

Although the role of warehouses design within the supply chain is deemed increasingly important, little knowledge is available on comprehensive science based approaches (Baker & Canessa, 2009). However, models and approaches have been addressed regarding the more concentrated warehouse aspects and techniques. Since the small amount of general framework articles, comparison of the several approach structures is available in the literature. By means of this comparison a well-fitting framework structure can be derived, drawn from the strengths of the available information.

2.2.1 General design process

The 'Idealized Design' approach described in 1.5.1 is, except being well applicable for structuring the design of the framework, a good outset for the warehouse design framework. The approach applies interactive planning, which is directed at planning for the future but meanwhile planning for the gap currently existing between now and then too (Ackhoff, 2001). A continuous improvement process that maintains a balance between prediction, preparation and creation, moreover takes into consideration the business environment through the lens of system thinking with a top-down approach. As mentioned in section 1.5.1, the steps included in this approach are, formulate the mess, set up an Ends Planning, generate a Means Planning with a related Resource Planning and finally design the implementation with the related controls (Figure 2-3).

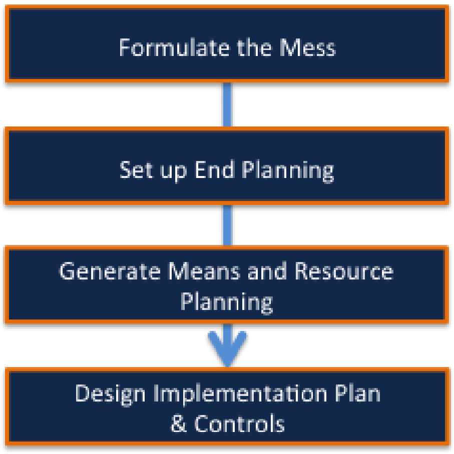

Figure 2-3. Idealized Design steps (Source: Ackhoff, 2002)

Formulate the mess

Following this approach the first step is to formulate the mess; during this step the threats and opportunities are formulated by mapping the desired direction of the organization and the obstacles currently restraining the growth (Ackhoff, 2001). First of all the model of success (Tompkins, White, Bozer, & Tanchoco, 2003) is defined, which includes the vision, mission statement, success requirements, guiding principles and the evidence. The *vision* identifies the direction of the organization or the specific department, where the *mission statement* identifies the significant difference they create among competition and makes objectives measurable, i.e., how to accomplish the vision. The *success requirements* specify the specifications, i.e. the aspirations of the organization and the design. The *guiding principles* determine the values and the instructions on how to realize the aspirations. Finally, the *evidence of success* describes the measurable results that demonstrate that the organization is moving towards its vision and thus performing well. The model of success determines the direction of the organization.

Set up Ends Planning

The second step is the creation of the ends planning. During this step the business environment remains the same but the organization is rebuilt 'from scratch' within the context of technologic feasibility. Furthermore it is important to design the new situation in such a way that rapid learning and adaptation is possible (Ackhoff, 2001). The actual content of this specific step regards the design of the warehouse, is compiled in the subsequent sections.

Generate Means and Resource Planning

The third and fourth steps of the 'Idealized Design', determine the road and resources to reduce the gap between the current and the desired situation. This means the application of the idealized design on the current situation by adjusting the design characteristics such that they result in an achievable design with the required resources e.g. facility layout, equipment numbers and specifications, software.

Design of implementation and control

The last two steps describe the implementation of the adjusted design resulting from step three and four. During this part of the model the planning is made and control aspects are put in place.

2.2.2 Warehouse design methods comparison

Decisions

According to Gu, et al. (2010), five major decisions are involved in the warehouse design process, which all interact strongly (Figure 2-4).

Figure 2-4. Five major warehouse design decisions (source: Gu et al., 2010)

Firstly, the *overall structure* comprises the material flow patterns, the specification of the departments and the relationship flows between the departments. The input needed for this decision are the several departments, the products and the processes executed. Thereafter, the *sizing and dimensioning* includes the size, dimensioning and the subsequent space allocation among departments. The size determines the storage capacity of the warehouse given a certain inventory policy that the dimension translates into actual floor space. The third decision concerns the *department layout,* which describes the detailed structure within the department. The structure encompasses the pallet/bulk storage pattern (lane required specifications given the product and unit load characteristics), the department layout (door location and exact aisle characteristics) and the storage and retrieval configuration. Fourth, the *equipment selection* specifies the storage equipment as well as the material handling equipment and determines the level of automation on the floor. At last the *operation strategy selection* describes the operation strategies and policies regarding the storage. The more detailed operation policies in relation to pick strategies and routing are not part of the design process and therefore not taken into consideration during the design (Gu, et al,., 2010).

A structural approach

Now that the different decision fields are known, it is important to take these decisions in a logical sequence. Especially since the several decisions are interrelated and strongly interact with each other a systematic and structured approach is required. In the literature a few articles are available regarding the systematic approach to design a warehouse. Baker, et al. (2009) have mapped various structural approach frameworks and herein analysed the differences, similarities, strengths and weaknesses. An overview of their comparison can be found in Appendix A2.1 Warehouse design steps overview by Baker and Canessa (2009). What we can concluded from their comparison is that in general the articles comprise the same steps, however in more or less detail expanded. To extract information for our design framework, we first have to decide what we find important. First of all, we believe that the main steps should lay between the six and eight. This number is chosen because it gives a clear and manageable number of steps with just enough detail, that are plain to communicate with the number of stakeholders and progress is easy to indicate. Of course, each of the main steps can be divided in numerous sub steps but for each step-layer the same 'rule' applies. Furthermore, we decided that the focus of each of the steps should be well balanced according to the five major warehouse decisions described by Gu, et al. (2010), in order that every important warehouse aspect receives an equivalent amount of attention.

The general tendency Baker, et al. (2009) found among the different research is that warehouse design is highly complex and an optimum is impossible to be found. Nevertheless, by executing the process step by step with a necessary amount of reiteration the possibilities are more clear, accessible and analysable. Last, a synthesized framework is provided which comprises several steps compiled with the aid of the various articles.

Although the vision of Baker, et al. (2009) is extremely useful, we choose one of the articles analysed by them as main structure for the warehouse design framework above their renewed model. The structure suggested by Rouwenhorst, et al. (2002) is selected for this purpose based on several reasons. First of all they state that a design process passes different consecutive phases in a top-down approach, divided in a strategic, tactical and operational phase. This lens enables the designers to approach the design problem in a system thinking way, something that is increasingly important given the interactions between the different departments within the company and the external network outside the company in the industry 4.0 environment. Secondly, the division in the three management levels allows the various problems, occurring during the design process, to be placed within an understandable context for the stakeholders. The clusters of those problems are defined, by Rouwenhorst, et al. (2002), as warehouse design problems and those bundles contains issues that should be solved simultaneously to ensure a global (near) optimum solution. Besides their step-by-step model complies with the requirements we mentioned as being important for a framework.

Management levels

Let us have a closer look at the Rouwenhorst, et al. (2002) model, starting with the strategic phase. The long-term (5 years) impact decisions are addressed throughout this phase. During this stage equipment is selected by which the processes are made possible. Since the decisions taken during this stage in general require a high investment, a thorough analysis of the current situation is needed. The first step to be executed within this phase is the *design of the process flow,* a step in which all the processes influencing the selection of equipment are examined. As stated in the warehouse characteristic section (2.1) the processes can be divided into basic processes and additional processes.

Subsequently the *selection of warehouse systems* is realized, decomposed in two problems: the technical capabilities problem and the economic considerations problem (Rouwenhorst, et al, 2002). The technical capabilities problem requires as input the characteristics of the products and orders and provides as output a number of limited possible system combinations. The economic consideration problem optimizes the possible system combinations found, by searching for the solution with the minimum investment and operation costs (Figure 2-5).

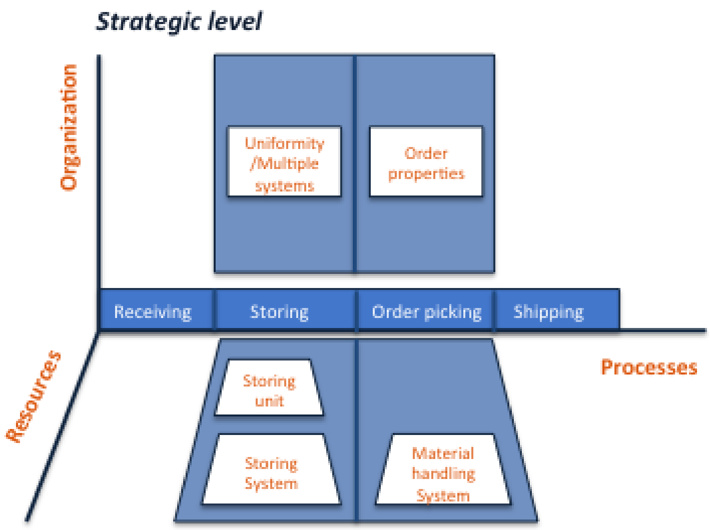

Figure 2-5. Strategic level - Design framework (Source: Rouwenhorst et. al 2002)

The next level is the tactical phase, where the medium term impact decisions are made. The decisions we should made during this stage elaborate on the decisions made during the strategic phase. According to Rouwenhorst, et al. (2002), three steps are executed during this phase, each targeting their own problem cluster. The first step is the definition of the *layout of the overall system*; this entails e.g. determination of the several departments and the multiple zones. Thereon, the *dimensions of the resources* are determined, during this phase decisions are taken regards the balance of the resources; i.e., the system size and the number of personnel are adjusted. The third step focuses on *the organizational issues* that influence the layout and the required number of resources. The optional choices to replenish, to batch and the high-level store policy, i.e., the family group division of the products, are the problems of the cluster solved during this step (Figure 2-6).

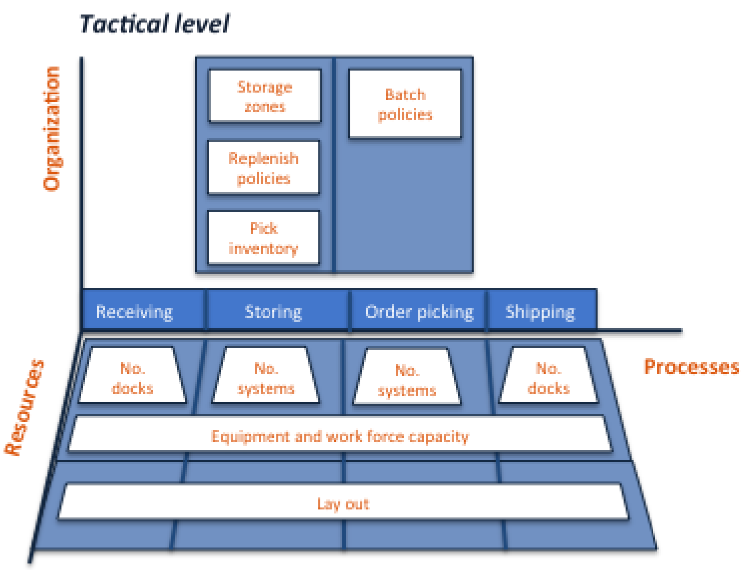

Figure 2-6. Tactical level – Design framework (Source: Rouwenhorst et al. 2002)

The last level is the operational phase and it concerns the short-term decisions that have less interaction than the former phases and can even be considered independently. The decisions taken in the operational stage involve the overall control of the warehouse system. These decisions can be divided in two steps, the determination of the *storage process policies* and the determination of the *order process policies.* The first step specifies the assignment of replenishment tasks and the allocation of items to storage locations. The second step distinguishes the actual formation of the batch, assignment of the pick tasks, the routing and the assignment of docks to trucks (Figure 2-7).

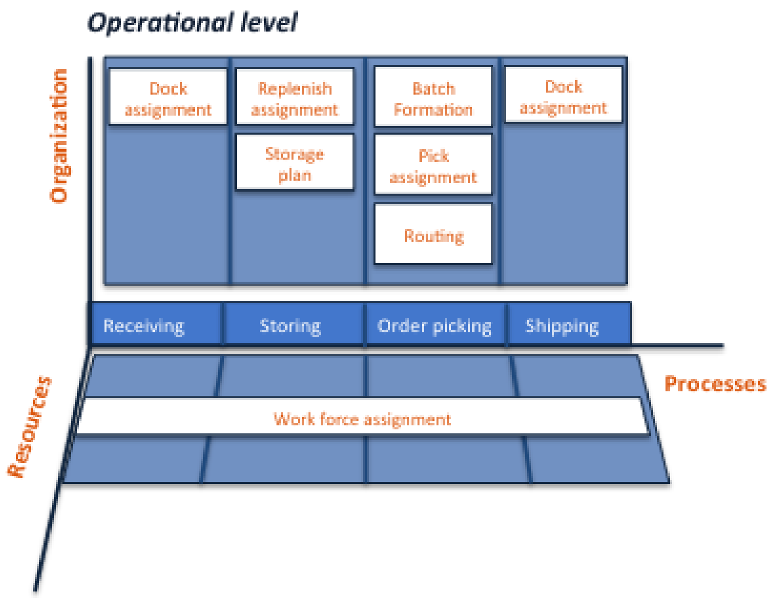

Figure 2-7. Operational level - Design framework (Rouwenhorst et al. 2002)

Although the steps are broken down per management level, the objectives for the warehouse design framework are universal for the levels due to the interrelation between the phases. The objectives are to minimize the investment cost, while maximizing the storage capacity and the throughput all with the lowest possible response time (Rouwenhorst, et al. 2002).

Remainder design attributes

Even though the framework of Rouwenhorst, et al. (2002) contains all of the decision fields appointed by Gu, et al. (2010) (Figure 2-4), the remaining articles compared by Baker, et al. (2009) hold some useful information too. First of all, the most important step that we should add to the steps of the above-discussed model of Rouwenhorst is the determination of the business and or system requirements and the design constraints. This particular step is of great importance because this determines the overall direction of the organization and therefore the framing that the multiple stakeholders can identify with, something that is required to make the new design a success. However, since the framework to develop is created through combination with, inter alia, the 'Idealized Design' (Ackhoff, 2001), this particular step is largely covered by the first phase of the 'Idealized Design'.

Further, the steps and attributes mentioned in the other articles comprehend similar steps but are in general, as we mentioned before, more extensive in the number of steps. The additional steps found in the remainder articles, if not already present, can be grouped under the aforementioned steps of the Rouwenhorst, et al. (2002) framework. The newly added steps from the Baker, et al. (2009) framework are: *Analyse the obtained data,* undertake *data profiling*, establish the unit load, *evaluate and assess* the design (against the requirements).

In addition, Hassan (2015) describes in his article the warehouse design from a more layout-oriented point of view. Due to this more narrow perspective the framework is not useful as main structure for the new framework but nevertheless contains functional information for, in particular, the tactical phase. Given the three steps in the tactical phase of the Rouwenhorst, et al. (2002) design framework, various steps are crucial to add to the 'framework being developed'. The following steps are important to consider; the application of *class divisions*, *departmentalization and general layout* (size and dimensioning – Gu, et al. 2010), *storage partition*, the determination of *space requirements* per department and the *design of aisles* (department layout – Gu, et al. 2010), the determination of *number and location of I/O points* and *docks*.

2.2.3 The framework base

After the analysis of the high-level structure frameworks, we have integrated the information of the different sources while we applied some modifications based on our own judgement. Finally, this results in the framework base, which serves as a backbone for the more detailed steps yet to come (Figure 2-8).

Now that we know the high level structure, i.e., the outline of the framework, the detailed level of the model has to be elaborated. In sequential order each of the steps of our framework is analysed and described with the aid of information found in the literature. The target group this framework is created for, are the organizations that are planning on designing a new warehouse. The framework should be easy in application and should not require extensive software. In the process of filling the framework this condition will be included in the choices. The next sections describe per step the required sub steps for the strategic and tactical levels (given the scope in section 1.4.2)

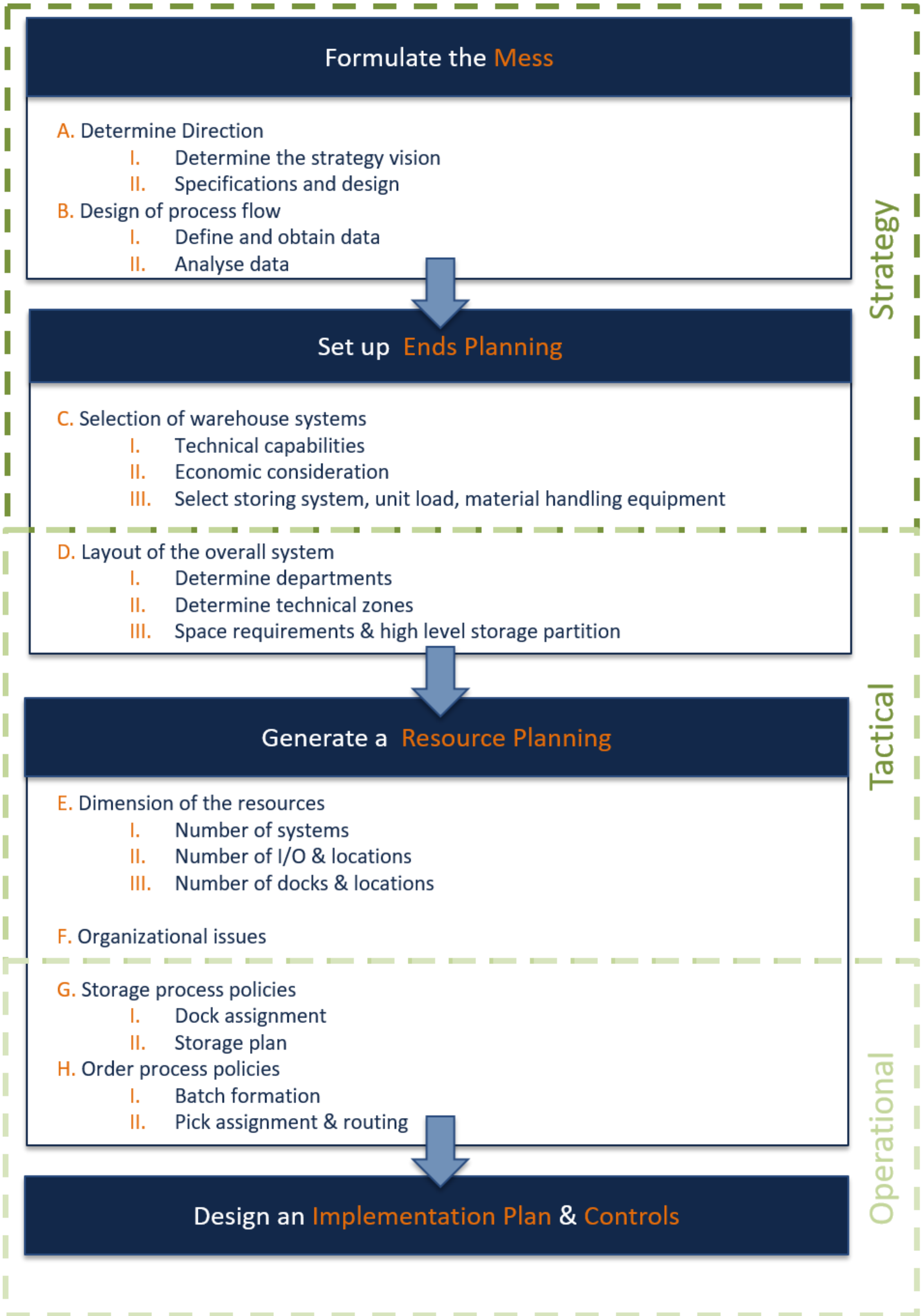

Figure 2-8. High level structure "New Integrated Warehouse Design" (NIWD) framework

2.3 Design of Process Flow – Step B

After the direction is determined in Step A with the aid of the model of success (see section 2.2.1 – Formulate the Mess), the processes should be identified and explored. There are several ways the process flow can be represented, each approach highlighting the processes from a different point of view. It is important to understand which activities are executed with which items and where the activities happen. The three methods supporting this specific data collection are value stream mapping, activity relationship charting and activity profiling. We examine Value stream mapping and Activity Profiling more closely in the next paragraphs, and Activity Relationship Charting is outlined in 2.5.2.

2.3.1 Data method: Value Stream Mapping

Performance indicators

Before mapping the activities within the warehouse, it is important to analyse the logistic performance measures, this to have a focus and to enable indication of (non) value-adding steps within the process. We can distinguish four performance evaluation dimensions among which the various indicators can be positioned. The dimensions are; time, quality, costs and productivity (Staudt, Alpan, Mascolo, & Taboada Rodriguez, 2015). The indicators can be divided in two types, the direct and the indirect indicators of which the last indicator category contains the measures that are complex and therefore too difficult to calculate. Given the purpose of the indicators to determine value-adding steps the direct measures are considered. Three kinds of direct measurements are identified by Staudt, et al. (2015), the *specific indicators* that are activity explicit, the *transversal* indicators that measure the processes, i.e., a set activities, and the *resource indicators* that comprises the labour and equipment related measures. In Table 2-1, we display the indicators per dimension and per indicator type.

Table 2-1 Direct Performance Indicators for Warehouse Performance (Source: Staudt, et al. 2015)

		Receive	Store	Order picking	Dispatch
Specific indicators	Time	Unloading time	Put-away time	Pick time	Consolidation time
	Quality		Storage accuracy	Pick accuracy	Shipping accuracy
	Cost		Inventory cost		
	Productivity	Receiving productivity	Space utilization - turnover	Pick productivity	Consolidation productivity
		Receive	Store	Order picking	Dispatch
Transversal & resource indicators	Time	Dock to stock time		Order lead time	
	Quality				
	Cost	Labour & maintenance cost			
				Order process costs	
	Productivity	Labour productivity & equipment downtime			
				Outbound space utilization	

Value stream map

As soon as the performance indicators are chosen, the processes can be drawn. One of the most well-known methods is the *value stream mapping* (*VSM)* method. With VSM we can create a map of the current situation on a strategic level by linking the information and material flows of a specific department within an organization. Because value stream mapping is a method that operates from the system thinking principle and we find this a suitable method to add to the NIWD Framework. The suitability is based on the earlier mentioned system thinking lens we apply on this particular project (see 1.5.1.) The *objective* of VSM is to give insight in value streams, the related processes and each of the activities within the stream/process (Kaibini, 2015). The *goal* of this method is to remove all the obstacles within the flow by distinguishing the value-adding and non-value-adding steps. According to Martin & Osterling (2013) waste items that can be found are; overproduction, unnecessary inventory, waiting, over-processing, errors, motion, transportation and underutilized people. Both product values, the streams for goods and services, as support values, e.g., HRM and IT, can be mapped.

The VSM approach consists of five process steps and seven drawing steps that result in a clear informative overview that includes the product flow, information flow and a timeline (Martin & Osterling, 2013). Those five main steps are:

1. *Scoping*: Identify the streams, the responsible owner, the involved organizations and the performance measurements.
2. *Determine the required data:* Select the processes that require a value stream map. To create a scope in the complexity, processes can be grouped for product families.
3. *Collect the data on location:* By visiting the workplace and discussing the processes with the executive employee, the processes can be captured.
4. *Draw the Value Stream Map:*
    - 4-I. *Label the map*: denote the Value Stream name, i.e., the main process it shows, and the date.
    - 4-II. *Record all profile information:* determine the inputs, outputs, controls, the responsible owners and the involved organizations for each of the maps.
    - 4-III. *Identify all steps*: describe in a 'block';
        - a. the activities before a break in timeline occurs as verb
        - b. the function of the employee and the number of employees
        - c. the obstacles in the flow
    - *4-IV. Identify all information support:* describe all IT systems and documents used in the flow.
    - *4-V. Connect the steps:* number the process-blocks and connect customer, process and supplier.
    - *4-VI. Identify the WIP:* describe the work in progress before, within and after the process.
    - *4-VII. Add key metrics:* execute a time study, analyse results with the performance indicators and calculate metric summary.
5. *Identify redundant steps:* determine the value adding and non-value adding steps.

However, we would like to expand the last step of the VSM method by focusing on obstacles and barriers within the steps in addition to the added value of the steps. In this way improvements can be found within steps even though those steps are not by default redundant. Thus:

5. *Identify barriers and redundant steps:* determine the value adding and non-value adding steps or/and find obstacles/barriers that interfere the continues flow of the processes.

An example of a value stream recording form we developed for step 3, the data collection on location, can be found in the Appendix A.3. The design elements we advise to use to construct the maps can be found in section 3.2.1 under 'Drawing the maps'. In case process improvements are required, a future state map can be drawn, through conversations with all involved stakeholders.

Time measurement

When the processes are drawn, the execution of a time study is the subsequent step. A common method for continuous time studies performance is *watch measurement*. This method measures the time using a stopwatch. As an event occurs the time is started and at the end of the event the time is stopped and noted. A number of execution steps can be distinguished: first a recording form has to be prepared and thereafter one employee/machine has to be followed at least 5 times per activity. For each activity several machines or employees have to be measured to show variability. Afterwards the results have to be discussed with the process responsible to confirm the findings, interpret the results and analyse the improvement possibilities (Panneman, 2015). Martin, et al. (2013) mention the following key metrics that can be applied when executing a continuous time study:

- *Process time*: time to perform the activity.
- *Lead time:* time from work being available till work is completely passed on the next stage.
- *Activity ratio*: $\frac{\sum Process\ time}{\sum Lead\ time}$
- *Complete & accurate:* percentage of input useable without correcting or adding information.

Though, the extent to which a watch measurement time study can be performed depends on the measurability of the process. Some observations are not measurable due to complexity. Possible issues that might occur and that complicate the measurement are: I. Multiple people work on a specific spot without strict task division, II. Task order is not standard, III. Activities are interrupted for other activities or IV. A combination of those three occurs.

In these complex cases a *work sampling* can be made. Work sampling can be defined as follow: "a collection of moment observations of activities of a group persons or machines, over a certain period of time, to determine the percentage share of de activities in the time duration of this period" (Pollux Beheer & Advies B.V., 2016). The data that is obtained can be applied with the aim to signal bottlenecks, improve the work organization, improve the work methods, and determine fees/time standards.

First of all a fixed route is determined which is travelled for varying intervals. Secondly, during each of the rounds a random 'snapshot' moment is created by tallying the situation. To enable a clear overview a recording form has to be designed on which the observations can be noted (Table 2-2 and Appendix A.4). Once enough observations are collected, the percentage of labour utilized for a certain activity can be specified on different levels of details (Pollux, 2016). These results can be analysed and conclusions can be drawn.

Table 2-2. Example of the Work Sampling recording form (example fill)

Date:		*Number of rounds:*	
	Employee 1	....	Employee n
Activity 1	III		IV
Activity …			
Activity m	IIII	I	II

Statistical significance observations

However, before conclusions can be drawn the sample must meet a certain statistical significance to give reliable and accurate results. The estimation of the work percentages has a binomial distribution. The formula of the distribution frequency is:

$$f(k;n,P) = Pr(X = k) = \left(\binom{n}{k} P^k Q^{n-k}\right)$$

With P the chance a certain event occurs and with Q the (opposite) chance the event will not occur (P + Q = 1). Furthermore, k is the number of times the event occurs of a total of n events.

Nevertheless, under the condition $n\ x\ P > 10$ the binomial distribution can be approximated as normal distribution (Figure 2-9).

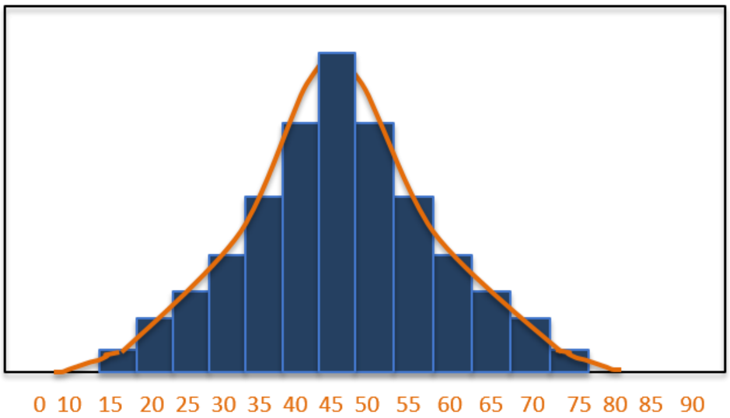

Figure 2-9. Example of a Binomial Distribution (Bars) and Normal Distribution (line)

With the aid of a statistical formula the number of observation (n) can be calculated (Pollux Beheer & Advies B.V., 2016).

$$n = P\frac{(100 - P)}{s^2}$$

- n = Number of samples (observations)
- P = percentage outcome for a particular type of activity or delay – This will be an estimation since P is actually what needs to be found with aid of the work sampling
- s = standard deviation of P (the percentage of the total time) with a certain percentage significance (e.g. 80% and 95%, 99%).

A confidence interval [X, Y] is the interval in which the mean of Z% of the samples lies within. The accuracy of the found activity percentage share is defined with the following formula:

$$s = 2\sqrt{\frac{P(100 - P)}{n}}$$

Once all the data is collected it can be stated that the actual time spent on a certain activity lies in the interval between X *(= P-s)* and Y *(= P + s)* with a significance of Z%.

The desired value of the statistical significance s depends on the objective of the MMO. High significance is requires when the objective is e.g. to set a time standard, but when a global insight in the bottlenecks is required, significance is still important but not as tight as with setting targets.

Since the actual P will be found as the time passes, a regular recalculation of n is needed to maintain reliable results.

2.3.2 Data method: Activity Profiling

Activity measurement

Now the processes, activities, context and the layout are defined, the behaviour of the items is still left to analyse. The item activity is important to understand since the customer orders drive the entire system. According to Bartholdi III & Hackman (2016) to get an accurate insight in what is actually happening *activity profiling* is a conventional method. With activity profiling it is possible to display the economics of the warehouse by means of creating a statistical analysis of the warehouse activities that determines the workload within the overall facility.

Three types of views can be distinguished: The *customer order* profiles, *the item activity* profiles and the *facility layout* profile (Process Group, 2013). In the first view the order pattern of the customer is analysed with the objective to understand the distribution mix that influences the picking system. In the second view the dynamics of the SKUs are studied to gain insight in the behaviour and flow of the items, an insight that can support the slotting and allocation policy. In the last view the general facility characteristics are discussed.

Three main steps can be recognized regarding the executing of the activity profiling method. These three steps are:

1. *Collect data*: the information that is gathered will be used as input for the core activity profiling process.
2. *Apply data-mining & interpretation*: this process is the research for statistical relationships in datasets and understanding the presented patterns.
3. *Visualize the results*: the output, i.e., the results from the data-mining, has to be given a certain meaning and subsequently has to be made visually in a way that they are understandable for each of the stakeholders.

In the following sections we will expand the three main steps.

Input

To be able to execute an accurate analysis, *data* from several sources is required. Bartholdi III, et al. (2016) determine three main data types to enable profiling, which can be found in Table 2-3. A number of things are important to bear in mind when collecting data (Bartholdi III, et al. 2016):

1. General definition agreement: ensure all stakeholders agree on the meaning of the used terms for each data characteristics.
2. Correct interpretation: ensure the meaning of each data field is the same as what we expect it to be (e.g. are we looking at the print date or the date of collecting).
3. Distinguish financial and operational data: ensure the data represent the stream we want to analyse.
4. Be aware of averages: be careful with averages, they can be misleading.

Table 2-3. Overview of data sources and required data fields for activity profiling (Source: Bartholdi III, et al. 2016)

Item Master		Location Master	
SKU Data	○ *SKU ID* ○ *Text description* ○ *Product Family* ○ *Item dimensions* ○ *Storage location: e.g. zone, aisle, section, shelf, position* ○ *Max inventory level per time unit* ○ *Average inventory per time unit*	Layout and location addresses	○ *Unit Load* ○ *Physical dimensions* ○ *Scale of selling unit* ○ *Number of selling units per storage unit*
Order Master			
Oder History Data	○ *Order ID* ○ *SKU ID* ○ *Customer ID* ○ *Special handling needed* ○ *Date/time ordering* ○ *Quantity ordered* ○ *Quantity shipped*		

Data-mining & interpretation

Once the required data is collected, the next step is to execute *data-mining* to discover hidden patterns and knowledge. For this particular process software is needed. Various software packages are available and each of them with its own strengths, however according to Bartholdi III, et al. (2016) the following features should be present at least: row sortation, subsets selection, table entries counting, row joints within and between tables, result graphing and visualizations.

During this phase a number of aspects require some attention (Bartholdi III, et al. 2016):

1. Expect discrepancies in the data: Due to the several sources that provide data, some discrepancies will occur. Ensure an adequate solution for those cases is prepared.
2. Cross check the data: ask several people the same question to ensure the interpretation of the data and the results found are correct.
3. Beware of small numbers: slow-movers can create strange patterns in the results.
4. Beware of sampling bias: estimations and assumptions influences the actual results.

Table 2-4 gives an overview of possible statistical summary values that can be analysed during this phase.

Table 2-4. Example of possible statistical summary values (Source: Bartholdi III, et al,., 2016; The Progressgroup, 2013; Gray, Karmarkar, & Seidmann, 1992)

Dimension	Statistic summary values
Customer order behaviour	○ *Average # of shipments per day* ○ *Average # of lines per order* ○ *Average number of units per line* ○ *Seasonality occurrence trends* ○ *Customer order frequency distribution per time unit*
SKU activity	○ *Total number of SKUs involved* ○ *Fraction of total SKUs ordered* ○ *Pick frequency:* number of picks per e.g., item/family/type/aisle etc. ○ *Distribution of family per order*: Fraction of orders involving 1, 2,.. n families ○ *Family pair analysis*: Frequently family pair orders ○ *ABC distribution in orders* ○ *Number of picks per order*

Facility	○ *Warehouse zones & layout:* available storage facilities ○ *Average # of SKUs in the warehouse* ○ *Average # of shipments received per day* ○ *Average introduction of new SKUs per time unit* ○ *Average # of SKUs storage location per SKU*

Output

When the data is analysed the results have to be displayed in a way that it is understandable to all concerned, i.e., we have to tell stories about the data. With the aid of *data visualization* a large data set can be displayed from various point of views while presenting and comparing information at several levels of detail. There are two major benefits of presenting the data in a visual manner. Primarily visual representations are very intuitive and easily to adapt, furthermore it is even applicable when little is known about the data or when the data discrepancy is high due to inhomogeneous and noisy data (Hearst & Heer, 2005). When visualizing the data it is important to show the data as clear as possible with a minimum of textual explanation. Clarity can be obtained by simplifying the information through reducing clutter and defining a scope with the aid of sampling, filtering and clustering. In this way, the data is most accessible to all.

2.4 Equipment Selection Method – Step C

When insight is obtained in the processes, the equipment that make these activities possible have to be analysed and selected during step C. To be able to take an informed and well-considered decision, a number of different types of information is required. First of all a step-by-step method to go through the selection process is necessary. Subsequently, for this method a balanced selection tool must be chosen to support the actual moment of selection during the process. And last but not least, information on the latest equipment is required as input for the overall selection process. In the next coming paragraphs we will discuss the required information types. But first we will create insight in the concept of material handling equipment and storage systems.

2.4.1 MHE & storage systems

The physical resources of the logistic facility can be divided in several subsystems all with their own facility layout and flow paths (Hassan, 2015). The physical resources consist for the most part of the material handling equipment and the storage systems. A material handling and storage system is a composition of various methods using (different types of) material handling equipment (MHE) and storage equipment (Bouh & Riopel, 2015). The equipment is used for movement, storage, control and protection of materials, goods and products throughout the processes of distribution, consumption and disposal.

Material handling equipment and storage systems can be divided in four subcategories (Tompkins, et al, 2003; Bouh & Riopel, 2015):

- Transport equipment: to move materials from one location to the other.
- Positioning equipment: to handle material at a single location.
  - *Activities*: Feed, orient, load/unload or manipulate materials.
- Unit load formation equipment: to restrict materials to ensure quality when handling a single load during transport and storage.
- Storage equipment: holding or buffering materials under favourable conditions over a period of time.

According to Hassan (2015), an important aspect of this system is the overall design. A well-designed system supports the warehouse to improve their productivity and to reduce operating costs. During the design process a continuous trade-off between minimizing handling costs, easing accessibility and maximizing utilization is encountered.

2.4.2 MHE selection methods comparison

Method selection

In general, the process of selecting the right MHE comes down to choosing the equipment that is satisfying the requirements. According to Saputro, Masudin, & Rouyendegh (2015) MHE selection can be divided into three levels:

1. High level: Select MHE among the categories.
2. Intermediate level: select MHE within a category.
3. Low level: select MHE within a type.

When we take a look at the several available equipment selection methods and frameworks, we find that usually analytical models, Multi Criteria Decision Methods (MCDM) and Expert Systems have been used to minimize the total operational costs (Bouh & Riopel, 2015).

Considering the *analytical models* we find multiple approaches. Webster & Reed (1971) approach the problem with the aid of a heuristic method in which matrices are set up and the lowest values is tried to find. Hassan, Hogg, & Smith, (1985) use an integer programming method and Bard & Feo (1991) solve the problem with a nonlinear cost minimization model.

Within the other common approach, the usage of *multi criteria decision making (MCDM) models* the following methods are mentioned: e.g. Fuzzy models (Yazdani-Chamzini, 2014; Hadi-Vencheh & Mohamadghasemi, 2015; Khandekar & Chakraborty, 2015), Monte Carlo Simulations (Ahmed & Lam, 2014; Momani & Ahmed, 2011) and Analytic Hierarchy Process methods (Chakraborty & Banik, 2005; Momani & Ahmed, 2011).

Expert systems are knowledge based computer systems that imitates the decision making ability of the human expert. In the expert systems field we find, among others, the Intelligent Consultant System that includes a database that contains knowledge on different equipment types. With the aid of a multi-criteria decision making procedure equipment types are selected then with simulators the performance of the equipment model is evaluated (Park, 1996).

Hassan (2015) created a comparison of various articles (see Appendix A2.2) and found that the three method fields mentioned above have two major limitations:

1. Limited number of equipment classes: the methods have a transfer equipment focus and ignore the storage, identification, communication, and information and control equipment.
2. Cost minimization focus: the methods focus mainly or entirely on the costs and ignore other important requirements as safety, throughput, utilization and environment.

Since we are developing a framework that should be applicable by organizations, we are looking for a framework within the *systematic framework approaches* field that is clear and easy to apply and requires no complex mathematical methods or extensive software. Furthermore, the framework has to take into consideration both quantitative as qualitative aspects since we emphasize the importance of the system approach in which more than just costs should be considered. Based on the earlier mentioned limitations and the target group of the framework, the expert system and mathematic analytical driven approaches do not satisfy our requirements.

Hassan (2015) has designed a framework that enables organizations and designers to make decisions without the need for a large database and without complex mathematical models or software systems. The framework enables designers to consider a wide range of equipment while taking into account the requirements and objectives. He specifies the steps that have to be taken by decomposing the complex design task in simpler sub-problems. In his approach he states it is important to differentiate between and within equipment classes and to consider both the quantitative as the qualitative requirements. At last, as with the Rouwenhorts, et al. (2000) and the VSM method (Martin & Osterling, 2013), operates the MH Equipment Selection Method of Hassan (2015) from the system thinking principle.

Given the purpose of our framework and our system thinking approach, we think this is the right approach to serve as a basis for equipment selection. Besides in general the organizations are not in the possession of large databases and do they not have a broad understanding in mathematical models. Because of that, we have selected the equipment selection framework of Hassan (2015) to add to the New Integrated Warehouse Design Framework.

The selection framework

As mentioned before, the basis of selection framework is based on a system thinking perspective and due to this approach the framework takes into account the following aspects:

- The MH life-cycle: The MH system goes through several phases that have to be considered when designed. Those phases are installation, operation, maintenance, retirement and disposal.
- Environment: The environment interacts with the equipment and provides input. The influencing aspects have to be identified.
- Transactions: the material, products and documents that flow throughout the system. The characteristics (type, shape, size, weight and quantity) have to be determined.

The framework consist of three phases each with its own steps, which are shown in Table 2-5. Different from the former part of the New Integrated Warehouse Design Framework steps (2.3 Design of Process Flow), comprises the MH equipment selection method except the strategic level also the tactical level of the NIWD-framework. This means that the steps below are spread out throughout the overall NIWD-framework. Where this occurs the signs SL (strategic level) and TL (Tactical level) indicate the NIWD-framework layer we allocated the MH Equipment Framework step.

2.4.3 The MHE selection framework

Scoping

To facilitate and accelerate the selection process, we add a *pre-step* before the MHE selection method of Hassan (2015) is executed. Based on a number of characteristics it is possible to filter and to focus directly on the equipment that is actual fitting the organization's process. By focusing on a particular storage type, the MHE possibilities are narrowed. The filter characteristics are dimensions, access flexibility and throughput (Rouwenhorts, et al., 2000; Richards, 2011). We have combined the two models into one decision tree, which is displayed in Figure 2-10.

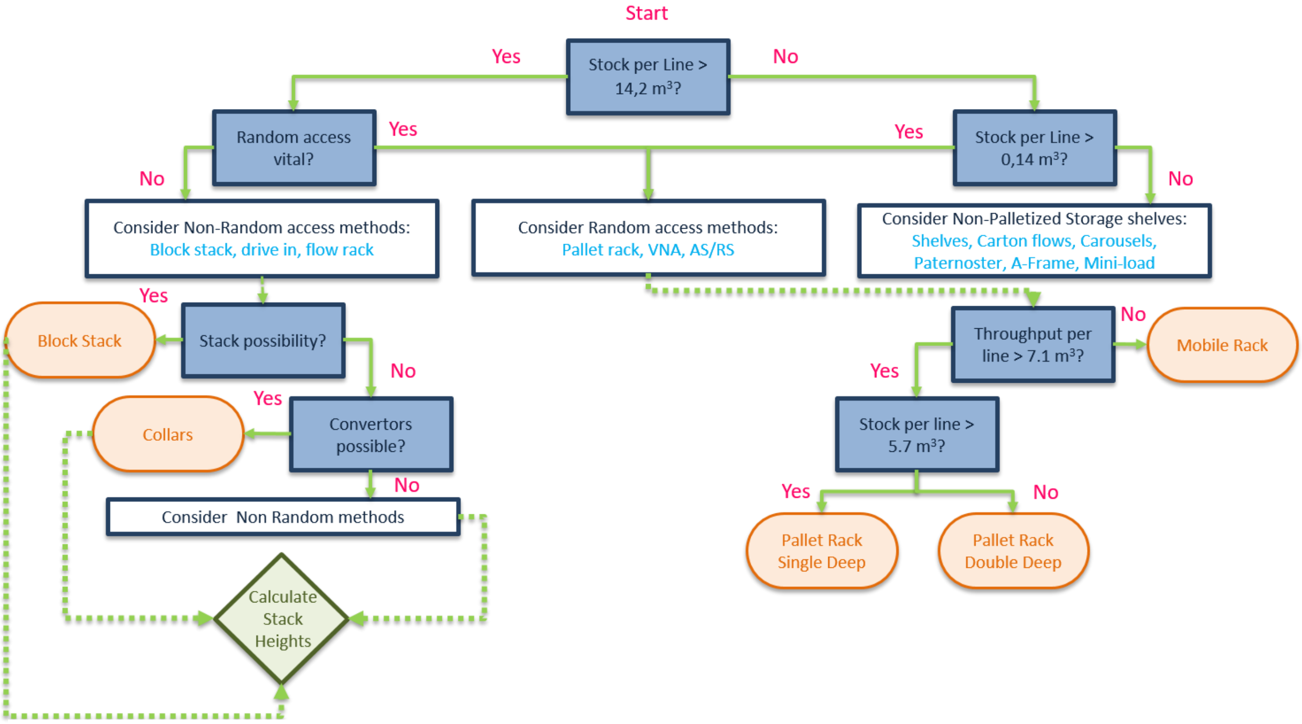

Figure 2-10. Decision Tree for scoping the MHE selection process (Source: Rouwenhorst, 2000; Richards, 2011)

Table 2-5. Overview of the MH Equipment Selection Method steps (Source: Hassan, 2015)

Phase		Step	Sub steps
Conceptual design	1 (SL)	*Specify & prioritize requirements* (What to meet)	a. Specify the requirements for each requirement group[3] b. Convert user requirements (qualitative) into technical requirements (quantitative) c. Prioritize the requirements
	2 (SL)	*Set & decompose objectives* (What to achieve)	a. Identify the objectives of the logistic department and rewrite to MH equipment objectives (In terms of: maximize and minimize) b. Decompose the objectives in sub-objectives and organize all in an objective tree
	3 (SL)	*Establish performance Indicators* (What to evaluate)	a. Specify performance indicators to be measured for each life-cycle phase b. Determine cost elements for the each of life-cycle phases c. Establish formulas that can measure the above indicators
	4 (SL)	*Determine & decompose functions* (What to execute)	a. Identify the major functions supported by the MH b. Decompose in sub-functions and combine with the objective tree c. Identify the maintenance requirements d. Determine the needed equipment per MH function
	5 (SL)	*Select the major classes of equipment*	a. Identify the candidate classes of equipment within each category for the sub-functions (use the pre-selection made with the decision tree) b. Select one of classes of equipment to perform the function based on the requirements
	6 (SL)	*Design the sub-systems*	a. Identify for the equipment of step 5, which are systems in their own right, sub-systems b. Perform step 4 and step 5 again for these subsystems
Preliminary design	7 (SL)	*Identify an equipment type*	a. Select types in the classes of step 5 and 6 based on load, throughput, maintenance and the objectives and requirements b. Create a hierarchy tree with each level representing the: Equipment category, classes and type.
	8 (TL)	*Determine the number of units of the equipment type*	a. Construct an analytical model to determine the # of equipment types and its lay-out b. Perform functional allocation for deduplication
Detailed design	9 (TL)	*Determine the specifications of the selected equipment type*	a. Determine on the requirements the needed dimensions b. Convert this information into specifications c. Identify the equipment that meets the specifications
	10 (OL)	*Evaluate the design*	a. Perform economic evaluation of the MH b. Revise the number of equipment types and some of the specifications

The information for each of the steps have to be compiled in co-operation with the facility managers. Step 1 to 4 have to be completed with the aid of the managers and the other users of the Material Handling equipment. In Appendix A2.3 Requirement classification for the MH Equipment Selection Method can be found that support the selection process of an equipment type within a certain class.

See section 2.7 for the visual overview of the placement of the MH equipment framework within the NIWD-framework.

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[3] *Requirement groups:*
- *System form: Manual, mechanical, automated and/or combination.*
- *Operation form: Push/pull, amount of human interaction and total utilization.*
- *Maintenance: Handling ease, costs and allowed downtime.*
- *Transaction characteristics: type, shape, weight, size, quantity.*
- *Movement: Variable path, fixed path, continuous path and/or intermittent movements.*
- *Facility restrictions: Multiple floors, input/output points and other facility characteristics.*
- *System characteristics: modularity, upgradeability, required training and other conditions*

Multi-Criteria Decision Analysis

Although the MHE selection method of Hassan (2015) is extensive, we want to expand step 5b with a selection tool. In practice not all factors are as important, to balance the several quantitative and qualitative determinants we want to add a manual Multi Criteria Decision Analysis model to the framework. Within this step the economical consideration takes place as well. By comparing the several possibilities the costs are taken into account. The overall goal of the MCDA method is to compare the potential solutions on both technical and economic ground.

The steps for the Multi Criteria Decision Analysis model are (Sullivian, Wicks, & Koelling, 2015):

I. *Assess the set of requirements specified step 1a*: Check completeness, redundancy and operationality. These requirements are the attributes.
II. *Adjust a value to each of the attributes*: choose a value score between 0 and 100.
III. *Create an interpolated Scale*: Decide on the range for each attribute and apply interpolation:

$$Interpolation: \frac{Score\ attribute - worst\ attribute\ score}{Best\ score - worst\ attribute\ score}$$

IV. *Weight the attributes*: agree on weights for each attributes

- Give the main attribute the highest weight N (= number of attributes) and weight the other attributes with N-1, N-2... etc.
- Normalize the weights.

$$Normalized\ weight = \frac{Weight}{\sum Weights}$$

V. *Rank the options*: find the best MHE

- Multiply the normalized weights with the interpolated scale.
- Sum the weighted scales and select the best scoring alternative.

MHE & attribute classification

As mentioned before, most organisations do not have insight in the current available equipment categories, classes and types. However, to select the best MHE type it is necessary to possess some equipment awareness. Bouh, et al. (2015) have used existing technical literature in the field to create a new list of material handling equipment types for individual unit load warehouses and manufacturing plants. This list is unique since they compared and combined all other literature (over 20 articles) without applying any limitations. Although the material handling equipment that are available on the market increase continuously, we can conclude the list is quite up to date since list is only one year old.

The following *material handling equipment categories* can be distinguished (see Figure 2-11):

- Manual: operated by people not automatically.
- Hoist: mechanism for lifting and lowing loads.
- Pipe: tubes in which fluid can move.
- Robot: reprogrammable, multifunctional manipulator that can perform a variety of tasks.
- Automated guided vehicles system: self-controlled vehicle that follows specified paths or moves dynamically to move loads/items.

- Unit load conveyor: Horizontal, inclined or vertical device for moving unit load materials in a predetermined path with fixed discharge or loading points.
- Bulk load conveyor: same as unit load conveyer except handling bulk.

Besides the MHE categories some related equipment are mentioned as well:

- Grippers: device that grasp and hold external objects.
- Identification and communication devices: printers, scanners etc.
- Manipulators: device with the purpose of grasping and moving objects in several degrees of freedom.
- Sortation systems: an automated conveyor system with diverters used for sorting items.
- Unit loads: Any load configuration handled as a single items.

(Source: Institute of Industrial Engineers, 2000)

In Appendix A2.4 we present the New Equipment Classification List that is drafted by Bouh, et al. (2015).

Besides the classification and the types of material handling equipment, the *attributes of material handling* are compared by Bouh, et al. (2015) too. They distinguish four main groups in which the multiple attributes can be classified. Those four groups are:

1. Unit load: characteristics of a single item handled.
2. Movement: characteristics of desired move the MH is supposed to do.
3. Equipment: specifications of the required MH.
4. Environment: characteristics of the surrounding of the MH.

In Appendix A2.5 we present the Material Handling Equipment Attributes list. These attributes can be used as support for the composition of the requirements, step one in the MH equipment selection framework, to include different perspectives and several aspects.

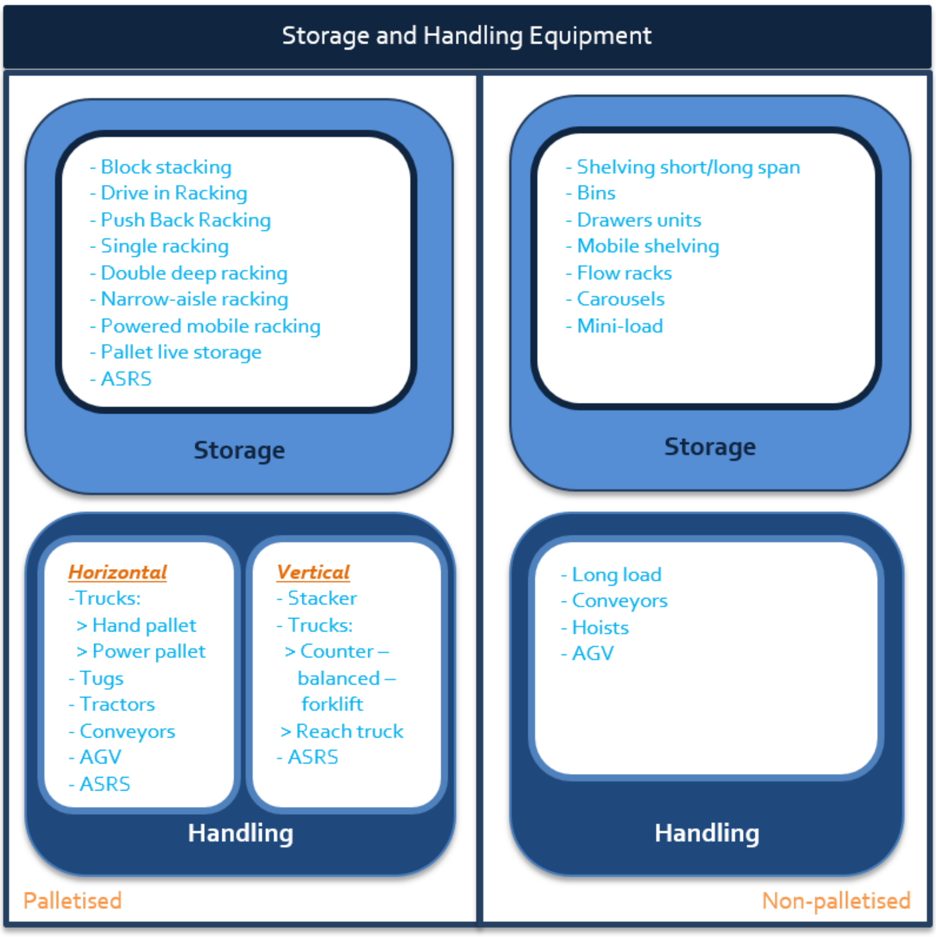


Figure 2-11 Overview of the Storage and Handling equipment categories

2.5 Facility Layout Planning – Step D

Once the warehouse equipment is chosen, we can derive from the framework base (presented in section 2.2.3) that the next step in the warehouse design process is to determine the layout of the overall system. In the next paragraphs methods that solve the layout problem are analysed to finally be joined together to approach the layout problem in a systematic manner.

2.5.1 A systematic approach

When designing the layout of the facility the main steps we have to execute, taken into consideration the physical-, control- and time aspects, are (Tompkins, et al,., 2003):

1. Determine the interrelationships.
2. Determine the space requirements.
3. Generate & evaluate the alternatives.
4. Implement the facility layout.

However, to solve the facility layout problem systematically we have to select a method. A variety of methods are available: there are *computerized* techniques, algorithmic approaches and procedural approaches. For the first category extensive software is required and besides once a solution is found, additional modifications are necessary before it is applicable in the real life setting. To be able to apply the *algorithmic approach* mathematical knowledge is a prerequisite, a skill not every organization that designs a new warehouse possess (Sharma & Singhal, 2016). Since we are developing a framework that should be applicable by organizations, we are looking for an approach that is clear and easy to apply and requires no complex mathematical methods or extensive software. The *procedural approach,* on the other hand is a hands-on approach for designing a lay out (Yang, Su, & Hsu, 2000; Hosseini, Mirzapour, & Wong, 2013). Therefore we seek for a facility layout planning approach within the procedural approaches.

According to Sharma, et al. (2016) the five most commonly used procedural approaches are Nadler's procedure, Immer's procedure, Muther's procedure, Apple's procedure and Reed's procedure. In their research they have evaluated these five methods based on several factors: Initial data required, use of charts, use of graphs and diagrams, future expansion consideration, constraints consideration, procedure implementation and the consideration of material handling selection. On the basis of their research the Muther's procedure is the best method to apply for facility layout design. Relatively a low amount of information is required, there is a high usage of diagrams, graphs and charts, constraints are being considered and once a solution is created it is easy to implement. Given the target group of our NIWD-framework the low input data and the visual representation of the approach are advantages. Therefore we will integrate the procedure of Muther, known as the *Systematic Layout Planning method*, in our NIWD framework.

2.5.2 Activity Relationship Charting

Systematic Layout Planning

The Systematic Layout planning (SLP) method of Muther (1973) had as goal to change the layout of an existing warehouse (Tompkins, et al. 2003). The SLP process includes four stages: first of all the location of the area is determined, then the general overall layout is determined, subsequently the detailed layout plans are drawn and finally the plan is implemented. Five information elements are needed that help to place the decisions in the context. (Gilbert, 2004; Liu & Zhao, 2015).

- The products (P): what work/information is processed.
- The quantity (Q): the volume of the material processed.
- The route (R): the sequence of the activities.
- The service sectors (S): staff or supplier support.
- The logistic operating time (T): when is the output needed.

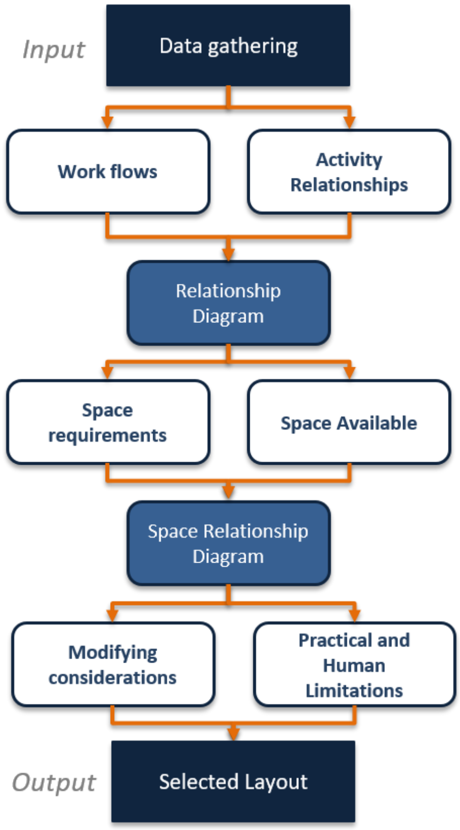


Figure 2-12. Systematic Layout Planning macro map (Source: Gilbert, 2004)

An overview of the method is presented in Figure 2-12. The initial input and final output are displayed by means of the dark blue rectangles. The blue rounded rectangles show the 'between results' and the white rounded rectangles present the input that is required to arrive at the (sub)results.

The SLP method contains the following steps (Liu, et al., 2015; Tompkins, et al., 2003; Mohr & Willet, 1999; Su, Xuan, Li, & Xu, 2010):

1. *Chart the relationships:*
   I. Analyse the logistic- and non-logistic relationship.
   II. List all departments, activities and/or work centres in a logistic and a non-logistic chart (Figure 2-13).

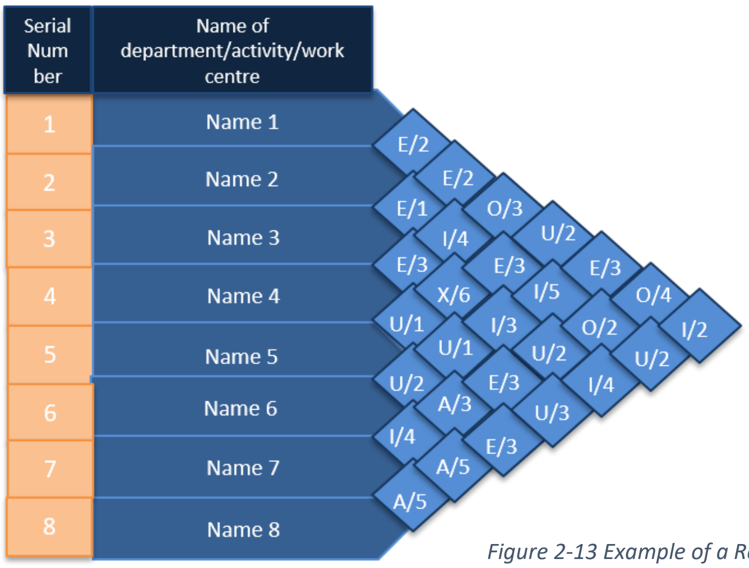


Figure 2-13 Example of a Relationship Diagram presenting the logistic relationships incl. reason values (Source: Tompkins, 2003)

2. *Determine the relative closeness importance of each relationship.*
    I. Define criteria for assigning closeness relationships.
    II. Establish importance and reason values that indicate the closeness relationships (Table 2-6).
    III. Evaluate with stakeholders and create conformity.

Table 2-6. Overview of relative importance values and examples of closeness reasons values

Value	Closeness
A	Absolutely necessary
E	Especially important
I	Important
O	Ordinary closeness okay
U	Unimportant
X	Not desirable

Code	Reason
1	e.g. Movement of Material
2	e.g. Shared dock
3	e.g. Shared equipment
4	e.g. Shared personnel
5	e.g. Movement of personnel
6	e.g. Supervision

3. *Establish space requirements.*
    I. Determine the area required for each department, activity and/or work centre.
        - *Overall squared metres, length and width dimensions.*
4. *Diagram activity relationships.*
    I. Create a graphical representation of the activities and their closeness relationships (see Figure 2-14).
        - *Start with the A relationships, draw the related activity nodes and connect the nodes with an A-specific line.*
        - *Reconstruct the activities to an optimum*
    II. Next, repeat this for the other letters all with their own specific line.
5. *Draw the block layout alternatives.*
    I. Combine the relationship diagrams with the space requirements for each activity.

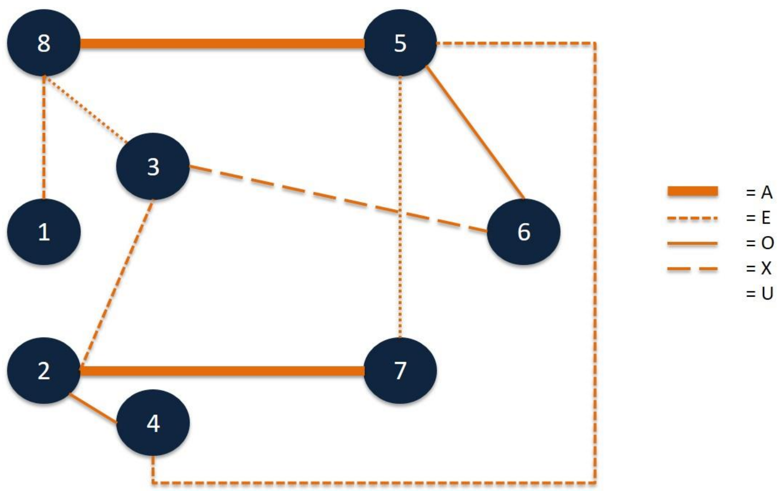


Figure 2-14 Example of an Activity Relationship Diagram

2.5.3 Systematic Handling Analysis

The Systematic Handling Analysis (SHA) method has as goal to map the goods flow in the warehouse given a certain layout (Muther & Haganäs, 1969; Tompkins, et al,., 2003). This methods is developed by the same researcher as the SLP method, Richard Muther. The method is a follow-up step for the SLP method and supports the Material Handling selection process. The method is mainly focusing on the manufacturing facilities, however one aspects of the method is serviceable for our NIWD-framework and we discuss it below.

Analysis of moves

When the moves have to be analysed, we have to create a Movement Summary and it should contain the following information (Muther, 1969):

- The material: the physical and non-physical characteristics.
- The route: the distance to move and the physical situation of the route.
  - Directness and straightness (horizontal, vertical, inclined – straight, bend, zigzagged).
  - Congestion and surface (obstructions).
  - Climate and surroundings (indoor, outdoor).
- The flow: The intensity and the condition of the flow.
  - Quantity (Size, frequency).
  - Service (Regulations, requirements).
  - Timing (required speed, urgency, and steadiness).

The result:

1. A list of all routes: the direction, distance and physical situation.
2. For each move and route: the intensity, condition and the relative importance of the move.

Subsequently, the SLP and the SHA can be combined. By indicating the intensity of the flows on the Relationship diagram and overview of the flows within the layout can be created. This overview can support the optimization process of the facility layout by highlighting the expected busy points within the warehouse.

2.6 The remaining steps in the framework – Step E to step H.

From the moment that the block layout is known, the detailed layout has to be drawn. The high level layout functions as an outline in which the detailed layout can be applied, thus include the detailed facility characteristics. Here among is considered:

- Step E: Resource dimensions:
    - The number of docks, systems and I/O points: based on the expected required capacity.
    - The location of the docks and I/O points: based on the numbers and applied on the high level layout.
- Step F: Organizational issues:
    - Zone classification: the actual distribution of families and items across the different zones.
    - Replenishment policies: the choice whether or not to execute replenishment activities. This choice influences the distribution of the items.
    - Pick/bulk areas: the choice whether or not to distinguish storage areas specifically for long term storage and storage areas for short term pick processes.
    - Batching: the choice whether or not to cluster order pick activities.
    - Performance Indicator (PI) values: the exact value of the performance indicators according to which the performance is determined.
- Step G & H: Policies and procedures:
    - Storage policies: storage plan for each particular item. This influences the dock assignment for arriving trucks.
    - Order pick policies: the actual routing development. In case of batching, the batch formation process and subsequently the order picking assignment to order pickers.

For each of these steps specific methods are available. However, which method to apply depends entirely on the choices of the management in Step A to Step D. The variation in possibilities is large and therefore a standardized roadmap that can be applied on multiple warehouses is therefore difficult to develop.

Therefore we decide to include the steps in the framework, to notify the designers of the steps, but the extensive sub steps are not included the framework. Furthermore, due to time limitations step E – Step H are not included in this particular research project.

2.7 New Warehouse Design Framework

After we draw the high level structure, i.e., the outline of the framework in section 2.2.3 we elaborated the detailed level of the model. In sequential order each of the steps of our framework on strategic and tactical level have been analysed and described with the aid of information found in the literature while we applied some modifications based on our own judgement. Now, let us take a look at the final 'New Integrated Warehouse Design' framework.

The framework building blocks

For each step A-H, a *detailed step block* is drawn. Within this step block we display the *sub-steps*. When several processes have to be executed within this step block, a special *process cadre* is shown. Besides, we draw arrows that indicate the *interconnected information flows* between and within the step blocks.

As in the framework base, we presented in section 2.2.3, the *strategic, tactical* and *operational* level are indicated with the aid of a dashed line. Furthermore, we show the steps of the *'Idealized Design'* (Ackhoff, 2001) with the same indication as in the framework base.

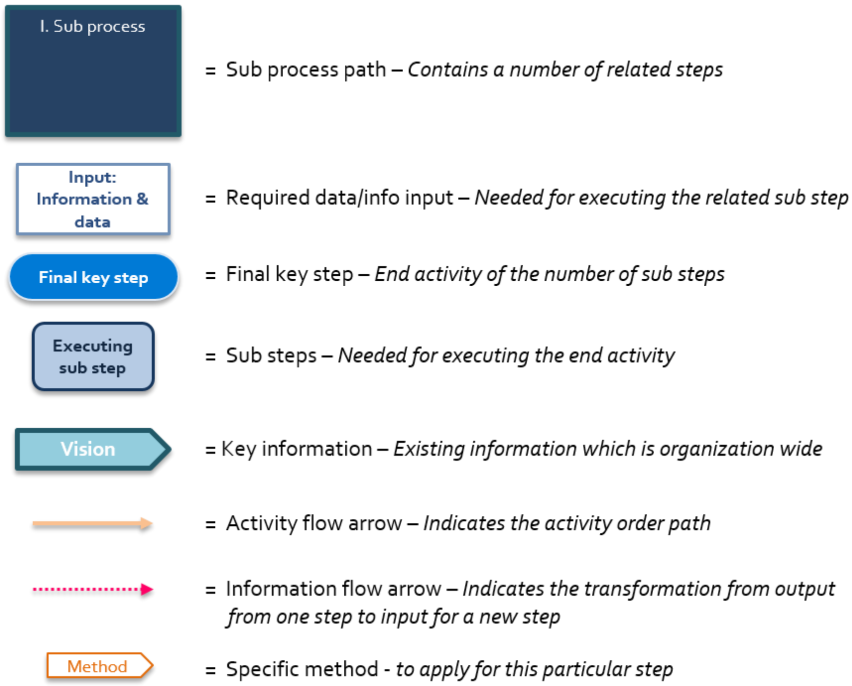


Figure 2-15 Legend for the completed 'NIWD framework' building blocks

Figure 2-15 shows the *elements and building blocks* with a detailed description, with which the entire framework is created.

Some of the steps, require a form that facilitates the execution of the step. We have marked these steps with the aid of a '*'. Per step the following forms are needed:

- Step: B. Design of the process flow: I. VSM – Collect data
  - Form: 'Value Stream Map Data Collection form (sample)'
  - Appendix: A.3
- Step: B. Design of the process flow: I. VSM – Time measure
  - Form: 'Work Sampling Recording form (sample)'
  - Appendix: A.4
- Step: D. Overall system layout: Chart relationships
  - Form: 'Relationship Chart form (sample)'
  - Appendix: A.8

The framework

In Figure 2-16 the 'New Integrated Warehouse Design' framework is displayed.

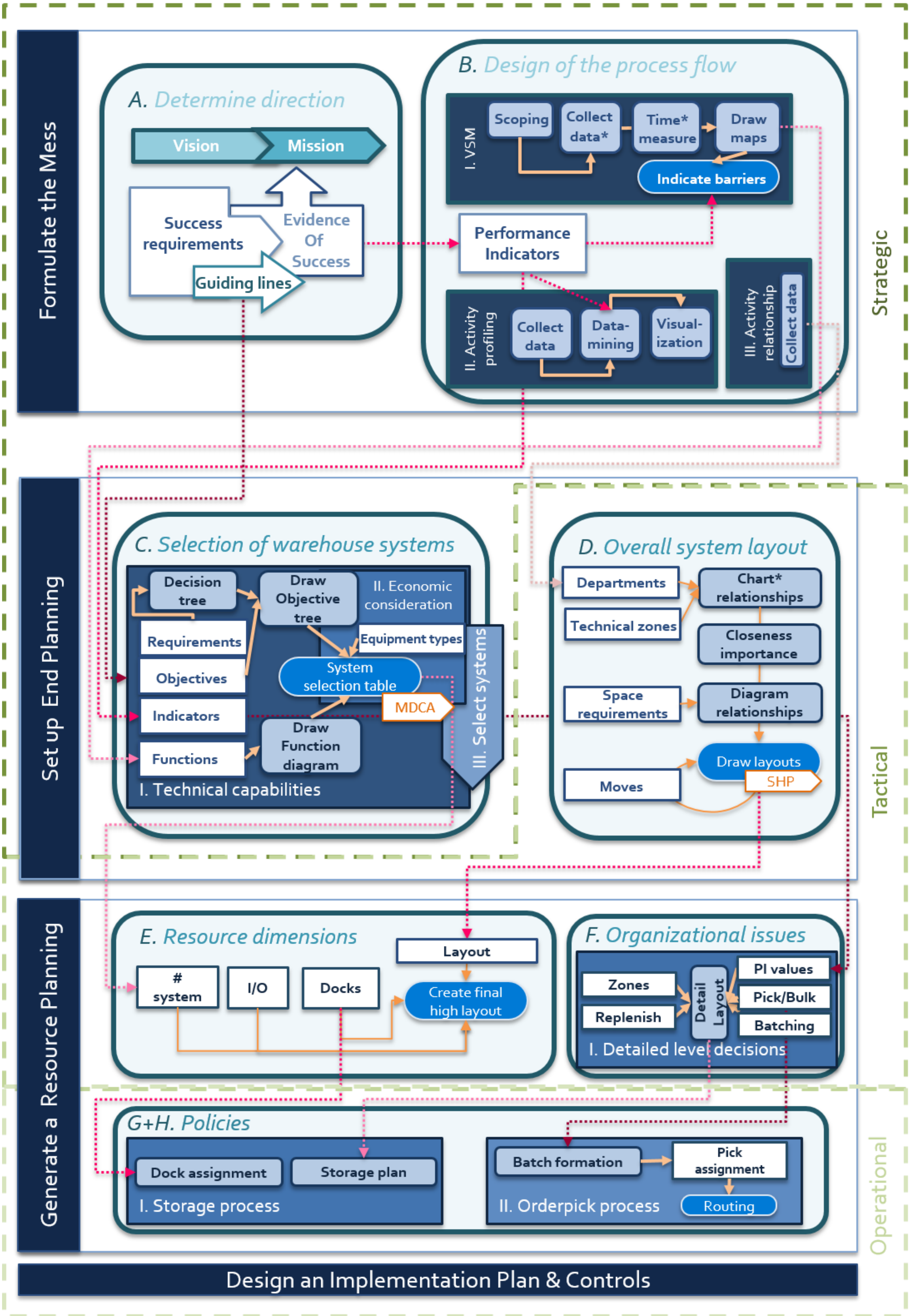


Figure 2-16. Detailed level structure "New Integrated Warehouse Design" (NIWD) Framework

2.8 Warehouse planning do’s and don’ts

Now the New Integrated Warehouse Design framework is completed, there are some last advices to share on aspects to keep in mind when designing the new warehouse. The following points should be considered during each step when applying the NIWD-framework (Link51, 2017):

1. Plan for good space utilisation:
    - Build upwards not outwards: use the available height
    - Provide movement space
2. Plan for efficient material handling flows:
    - Think in straight flow lines
    - Plan flow efficient lay-outs, group on certain characteristics
    - Fit the storage with the handling equipment
    - Use industry standard unit loads and ensure supplier and customers use the same
3. Plan for productivity:
    - Labour costs are controllable minimise them
    - Focus on order picking:
        - *Reduce traveling time*
        - *Maximise accuracy*
        - *Eliminate paper*
        - *Encourage high productivity*
        - *Bring goods to picker*
    - Reward good performance
    - Monitor KPIs and performance
4. Specify building characteristics (e.g., docks, levels, heating, fire protection, offices etc.) after the storage planning and handling systems are known.
5. Future proof the design: To keep up with the market developments of industry 4.0 and more
    - Process flexibility, reliability and process resilience
    - Fine tune the reverse logistics
    - Ensure storage and information technology can cope with change

2.9 Conclusion

Recapping the activities that we have conducted during this chapter, the first deliverable has been accomplished. Through the comprehensive literature study in Chapter 2, we designed the ‘New Integrated Warehouse Design’ framework.

To deliver the second deliverable the next step we execute in this research is, while keeping this do’s and don’ts of section 2.8 in our mind, applying the NIWD-framework at the ATAG Benelux BV warehouse in chapter 4. However, before we can start with the design phase of this research project, there are some gaps that have to be closed.

Now let us continue to Chapter 3 to identify these gaps and to collect the data to close the gaps.

3. Means & Resource Planning – Gap Identification & Resources

Since we have executed step one and step two of the 'Idealized Design' (Ackhoff, 2001) *and the New Warehouse Design Framework is ready, the next phase is the Means & Resource planning. The result at the end of this chapter is the data and information that is required to apply the framework to ATAG Benelux BV and to redesign their warehouse. According to Bemelmans (1992) it is better to develop a partial solution than a total solution that is unusable. Therefore during this chapter the scope of ATAG Benelux, on which we apply the framework, will be narrowed further. During this phase we identify the gap between the current situation, in which the actual design of the warehouse is not yet possible, and the desired situation, the situation in which all the necessary information is available to start the redesign process.*

Chapter 3 is structured in the order of the framework steps we drafted in section 2.2.3 and the 'Idealized Design' approach of Ackhoff (2001) we described in paragraph 1.5.1. First in paragraph 3.1 the current situation of the warehouse of ATAG Benelux BV is drafted and the existing departments at ATAG Benelux BV that are part of the logistic network are described. Then, secondly in 3.2 we identify the data gaps and subsequently we try to close them by drawing the main processes, by collecting insights in the current layout and by analysing the data on the current assortment, the order profiles and the order behaviour of the customer. Next in section 3.3 the remainder resources are defined that we require as input to apply the framework on ATAG in Chapter 4. Lastly in section 3.4 we describe the consequences of the current processes and their influence on the future business if no improvement is accomplished.

3.1 The current situation

3.1.1 The warehouse

If we take a closer look at the current warehouse situation at ATAG, we find that two types of warehouses can be distinguished. The first warehouse is a *distribution warehouse* where the products that are produced at their suppliers are distributed among their clients in the Benelux. The second warehouse is a *production/service warehouse*. As we discovered in 2.1, both warehouse types have their own characteristics, which are shown in Table 3-1. If we apply the classification spider of Jacyna, et al. (2015) the complexity of the two warehouses are displayed for each of the functional characteristics. Table 3-1 presents the classification of both warehouses.

Table 3-1. Overview of the current warehouse types at ATAG Benelux BV

	Production/service Warehouse	Distribution Warehouse
Type:	Sub assembly facility/service depot	Finished goods warehouse & consolidation centre
Functions:	○ **Fulfil demand**: Internal customer (Production, Service engineers) & external customer (B2C) ○ **Storage**: Raw materials, Components & (temporarily) finished goods	○ **Fulfil demand:** External customer (B2B) ○ **Storage & dispatch**: finished goods & OEM
Objective:	Minimum cost and maximum service	Minimum cost and maximum service
KPI:	Response time	Maximum throughput

By diving deeper into the axes of the classification spider and the scores of the two ATAG facilities, we can describe the main features of both of the warehouses. If we analyse the characteristics that we have not mentioned yet in Table 3-1, the first one to distinguish is the *storage condition*. We can conclude that, given the material of the products and the components, no special storage requirements are necessary for either of the warehouses. Considering the second characteristic, the *material flow volume*, we can state that for both warehouses the score can be set in the middle of the axis. The amount of products and components processed at ATAG do influence the national market but on a lower level of significance, however their activities are far too substantial to be called negligible and therefore the middle of the axis is a fitting score. The *storage types* used for the distribution warehouse are block-stacking and racking, which result in a score between open and semi-open storage on this third characteristic. Since for the production and service warehouse a vertical closed storage carousel and racking is used, the third score is set between closed and semi-open storage. The storage type is linked with another characteristic namely *the package form*. The finished goods in the distribution warehouse are placed on the floor (block stacking) or collected on a pallet (racking), whereas the components for both the production and service are kept in boxes on pallets. Arriving at the last characteristic the *inventory turnover* we can state that for the distribution centre a medium score is in its place. This, since the target level for the finished goods inventory is around 50 days but there are multiple items that has a higher turnover. For the service/production warehouse a score between medium and slow, with the gravity centre towards slow, is correct since there is a balance between items that are used quite often and items that are reserve parts with a sporadic demand. When we analyse Figure 3-1 we can conclude that although both the distribution warehouse as the service/production warehouse have their own outstanding aspects, on the average they have the similar medium complexity level. An overall score that states that a considerable amount of

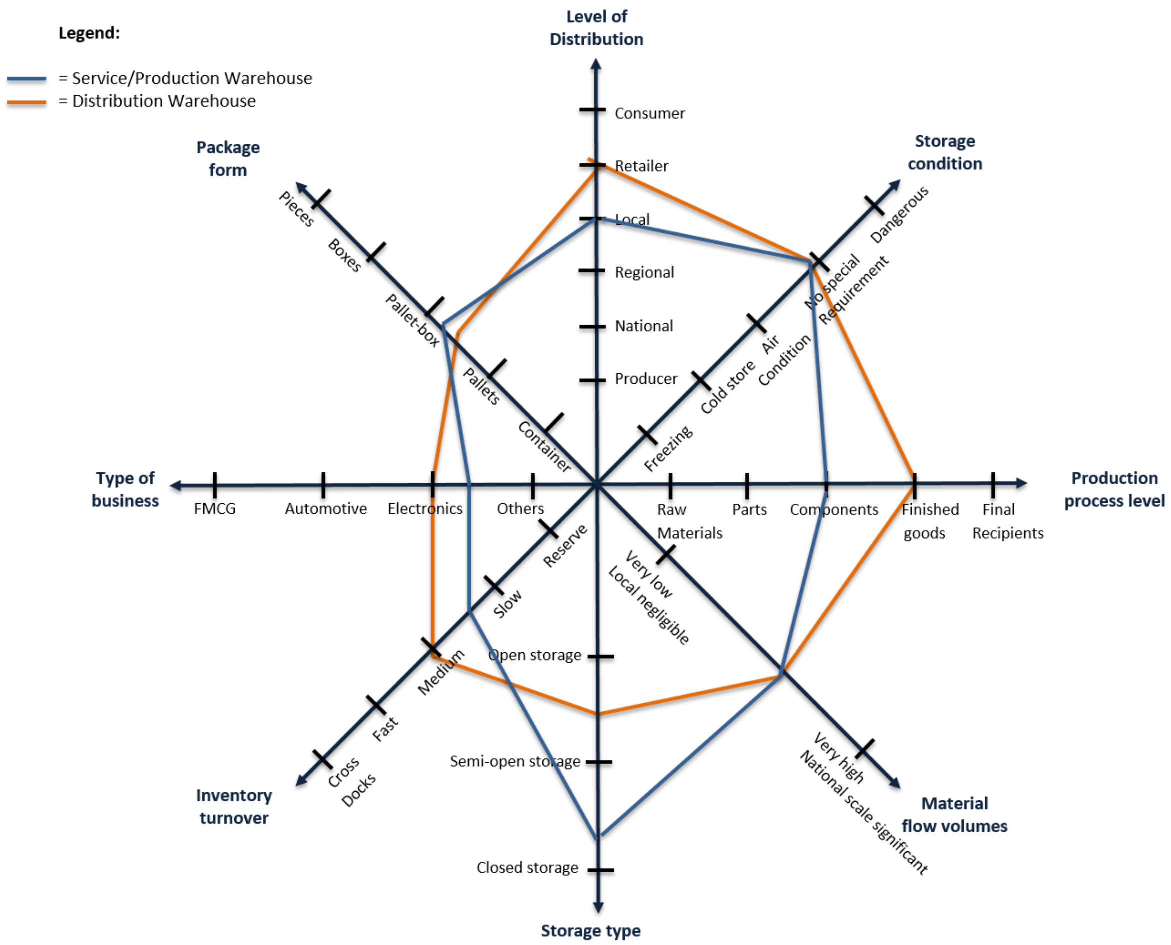


Figure 3-1. Display of the functional classification of the Distribution and the Production/Service Warehouse

attention is required for the processes but the risks are to be oversight. This is reflected in the degree of control by managers and team leaders. When needed they are immediately available and they are regularly present on the work floor, but continues monitoring is not necessary.

3.1.2 Departments

Within the logistic distribution processes several departments play a direct or indirect role. Below we describe each of this departments and the technical zones within the warehouse. Since eventually both the distribution and the service production warehouse will be accommodated in the same building, every department is mentioned below.

- The warehouse: the department that facilitates the entire storage and shipping process. This department can be divide in a number of technical zones, each containing a specific part of the process.
  - Inbound pallet zone: receiving and sorting area pallet stored goods.
  - Inbound clamp zone: receiving and sorting area clamp stored goods.
  - Return service technician boxes: receiving and sorting area for return service goods.
  - Inbound service parts and production components: receiving and sorting spare parts and production parts.
  - Storage pallet: storage area for pallet stored goods.
  - Storage clamp: storage area for clamp stored goods.
  - Storage components: storage area for part used during production.
  - Storage spare parts: storage area for spare parts used during service by technicians or ordered by clients.
  - Storage quality assurance: storage area for items to be checked or checked by quality assurance.
  - Consolidation area shipments: prepare shipment for client dispatches.
  - Consolidation service technicians' boxes: prepare service boxes for service technicians.
  - Consolidation spare parts dispatch: prepare shipments for end user clients with requested spare parts.
  - Dispatch pick up: storage area for items that will be picked up by a courier or by the clients themselves.
  - Dispatch shipments: storage area for shipments that are completed and ready to be loaded.
  - Return receipt: control and analysis area for return goods from clients and items that suffered damage.
- Planning/expedition: department that provide the required documents and information, that plans the shipments, labour and orders, and is a service point for the truck drivers.
- Production: department that assembles products with the different components.
- Quality assurance: department that safeguards the quality of the products by means of randomized control.
- Post room: department that deals with distribution of the postal items throughout the company.

3.2 Gap identification

In the context of this particular project, gap identification can be executed two times, namely once for each of the two deliverables (section 1.5.2). First of all, the idealized design for the New Integrated Warehouse Design framework has been drafted and can be applied on the current warehouse situation of ATAG Benelux BV. However, to do so, we need data on the current situation. The missing data can be identified with the aid of the framework. For each of the steps of the New Integrated Warehouse Design framework, we can analyse the current available in-house information. In this way the steps where an information gap exists are highlighted. Then, this data gap can be closed by collecting the missing information.

Secondly, within the framework itself the 'Idealized Design' of Ackhoff (2001) is integrated as well. When the new warehouse is designed, there will occur a gap between the current warehouse design and the desired warehouse design. This gap most likely will include resources that need to be purchased or collected to convert the current warehouse to the desired warehouse.

Due to the limits on the available time regarding this research, we have to take a decision regarding the width of the project scope. Because during the gap identification phase the current situation is analysed, it is possible for us to narrow the scope and to focus on the elements that require the most of attention. Therefore during the course of Chapter 3, the decision concerning the further project focus is made.

For the first deliverable, the New Integrated Warehouse Design framework, the missing data and its gathering is discussed in the following sections (3.2.1 to 3.3.3). The actual analyses of this data and the required resources to close the gap for the second deliverable are mentioned in Chapter 4.

3.2.1 VSM

Following the steps of the framework, the first data gap we encounter is the absence of a detailed insight in the warehouse processes and activities. We acquire this information by applying the Value Stream Mapping method mentioned in section 2.3.1. Due to the insight that is obtained during this step we can narrow the scope.

Scoping

Before we map each of the processes in more detail, the main streams have to be determined on a high level. By interviewing the responsible owner and the stakeholders (managers) of the involved organizations insight in the main processes is collected. Furthermore we determine the performance indicators based on the interviews and Table 2-1, which can be found on page 20.

- The responsible owner: Logistic manager.
- Involved organizations: Production, Quality Assurance and Supply Chain.
- Performance indicators:
  - Time: Unloading, storing, picking and consolidating.
  - Quality: Storing-, picking-, shipping accuracy.
  - Productivity: Outbound space utilization, downtime.

The cost dimension is left out of consideration, since the financial performances of the specific processes are not analysed throughout this research project. This decision is made based on the overall approach of the project we pursue. We create an advice report based on the idealized design, which can be used as start point for several business cases in which the financial aspects are included.

Determining the required data

After the interviews we determine the required value stream maps. In Figure 3-2 the main processes for both warehouses are displayed. It can be noticed that based on the high level processes the service stream has more similarities with the distribution finished good value stream than with the production

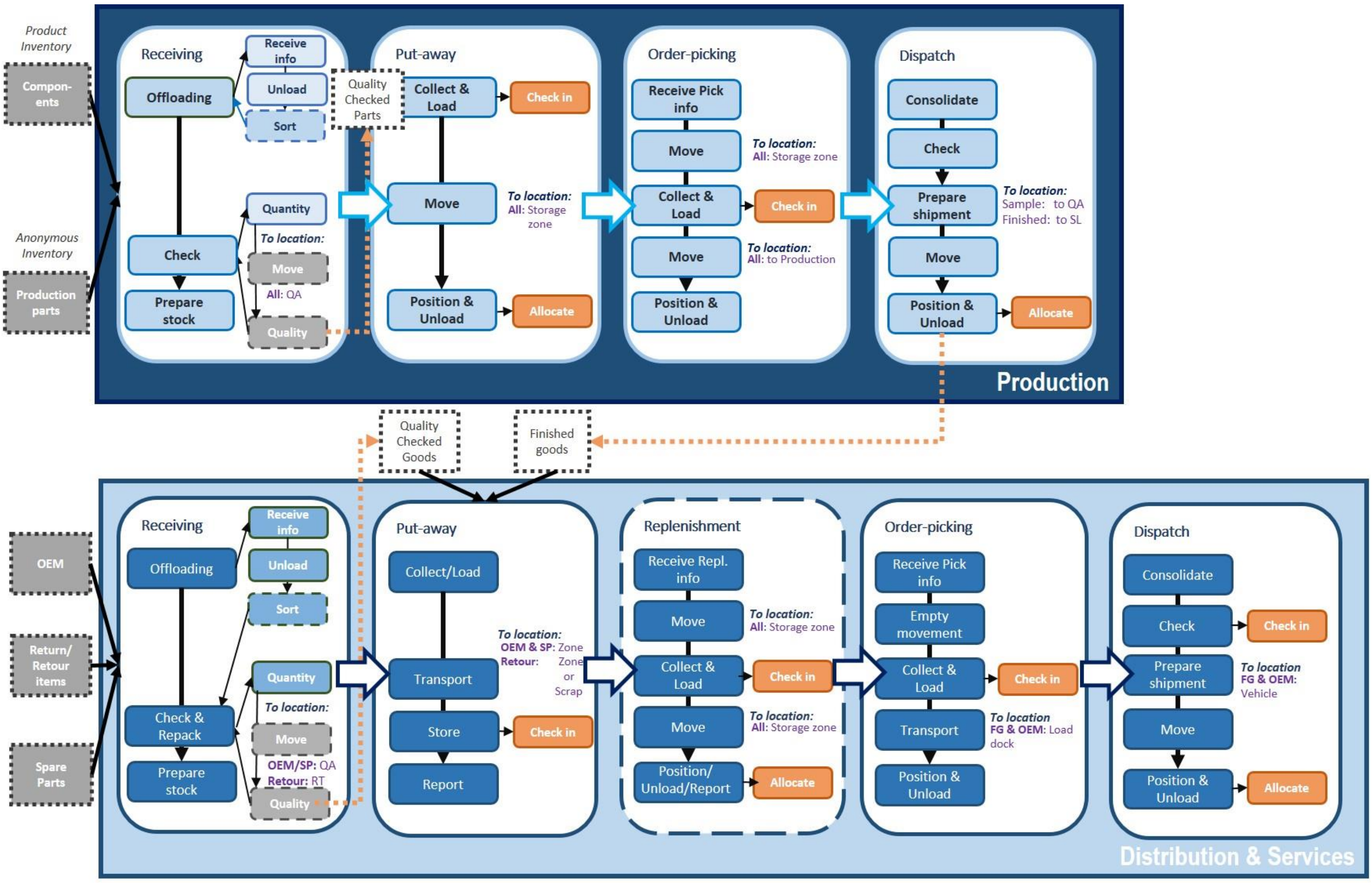


Figure 3-2. Overview of the main processes of the production and the distribution warehouse

value stream. Nevertheless the earlier mentioned division of the warehouses based on their functional characteristics mentioned in 3.1 remains the same. Based on Figure 3-2 we distinguish the following *family groups*: components/production parts, finished goods/original equipment manufacturing (OEM) goods, return items and spare parts.

For each of the family groups a value stream map is conducted containing one or more of the following *processes*: receiving, put away, order picking, dispatch and replenishment.

Collecting the data

Now the high level processes are known, it is possible to create a value stream map for each of the sub processes. By filling the VSM data collection form, of which a sample can be found in Appendix A.3, we can map the processes for the several family groups. During the data collection the processes are viewed and the employees are interviewed for input and explanation of the process steps and subsequently for confirmation.

Drawing the maps

After the data collection the recording forms, which have been filled, need to be converted into visual value stream maps. During the data collection we have discussed with the stakeholders the obstacles and barriers that they encounter when executing the processes. This information can be found under the section 'Identifying obstacles and redundant steps' on page 50. Based on this data we took the decision to narrow the scope to the distribution warehouse. However, since the value stream data collection forms have been filled for the service and the distribution warehouse, those recording forms are included in the Appendix of this report as well.

Distribution warehouse - For the distribution warehouse we have completed nine recording forms, which can be found in Appendix A.5. With the aid of the VSM data collection form, we can draw six value stream maps for the main processes and three for the sub processes. Figure 3-3 presents the nine value stream maps on a high level in a way that the mutual dependencies between the maps are being displayed. On the system overview the different VSMs are indicated by use of dotted lines. Each value stream map contains a specific number, indicated with VSM-#, with which the detailed VSM can be found in Appendix A.6. The main processes are shown in orange frames and the sub processes in yellow frames. Below we have determined which value stream map can be found under each VSM-number.

Main processes:

- VSM-I: Inbound & Put away – Pallet goods
- VSM-II: Order picking – Pallet goods
- VSM-III: Order picking – Full pallets
- VSM-IV: Inbound & Put away – Clamp goods
- VSM-V: Order picking – Clamp goods
- VSM-VI: Consolidation & Dispatch – Pallet & clamp goods

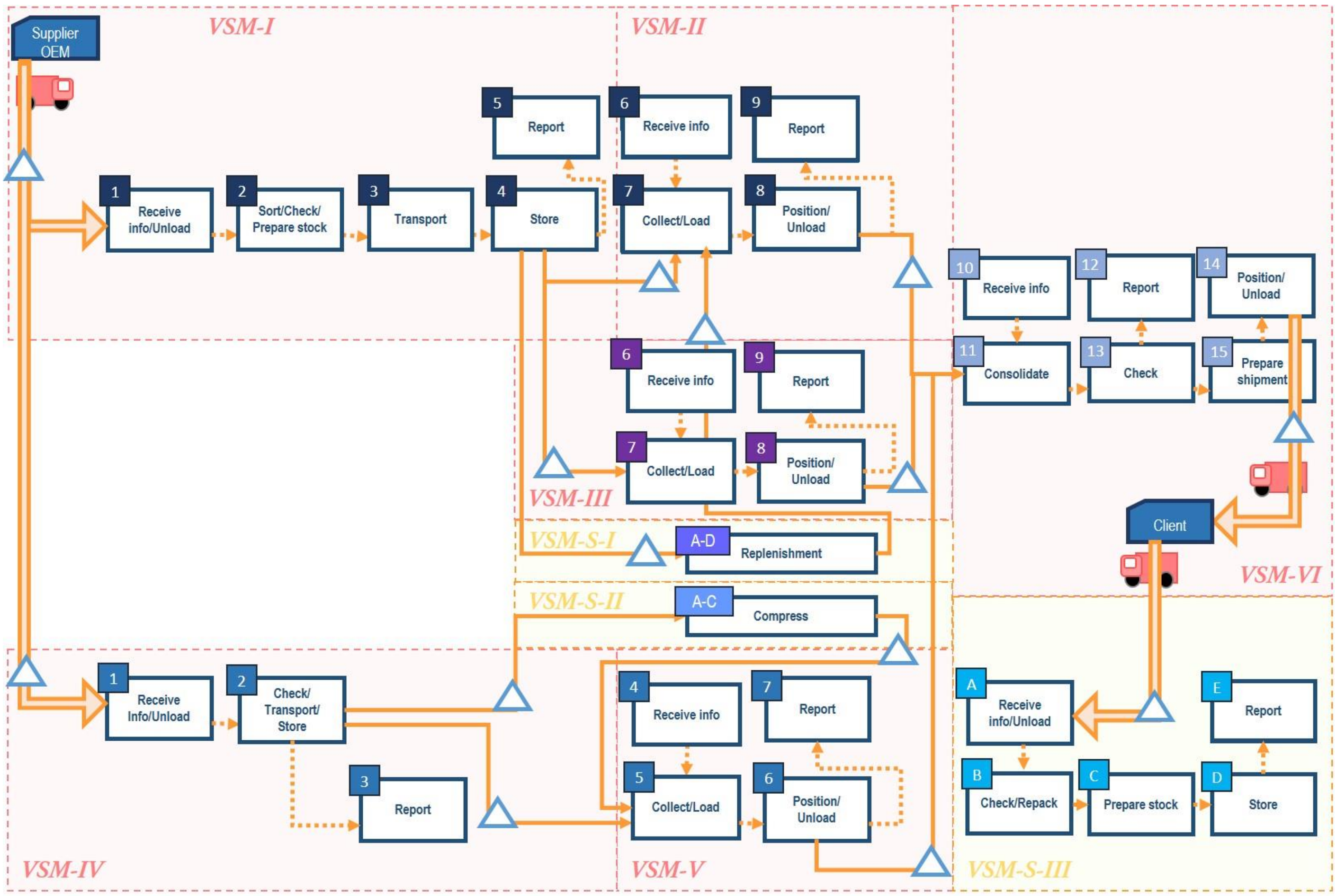


Figure 3-3. Overview of the system displayed in VSMs with the linkages between the various maps

Sub processes:

- VSM-S-I: Replenishment – Pallet goods
- VSM S-II: Compress – Clamp goods
- VSM S-III: Return – Pallet & clamp goods, QA goods and damaged goods

We have numbered the step-blocks in the main process maps in the order that the blocks follow each other up. Since there are different possibilities in the course of the process, repeating numbers are used, indicating the other possibilities for the subsequent step. The sub processes are marked by letters, since those processes occur simultaneously with the main processes. The square dotted lines represent push streams and the uninterrupted lines represent pull streams. Finally, the blue with white triangles represent the goods flows between the several main processes.

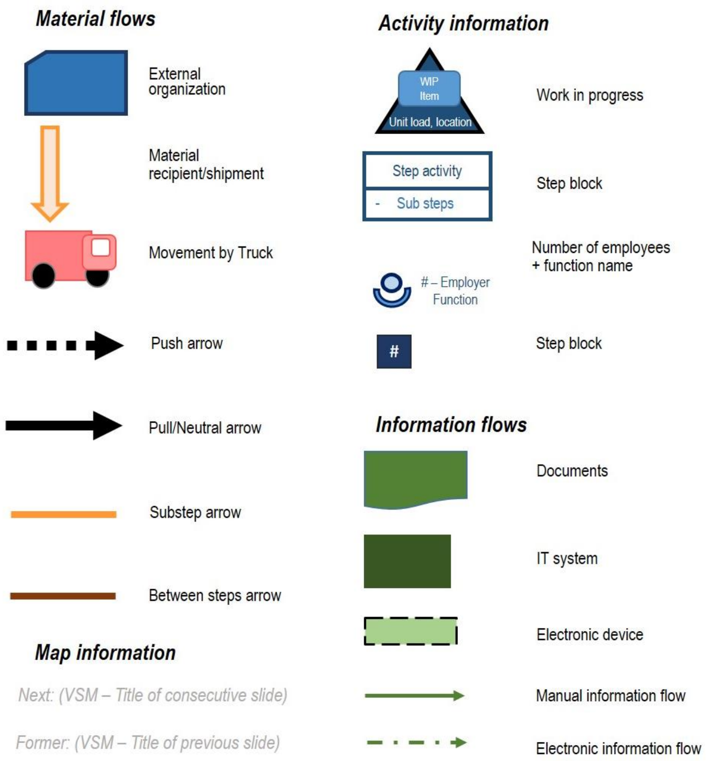


Figure 3-4. Legend for the Value Stream Maps building blocks

Figure 3-4 shows the *building blocks* we have used to construct the various maps on a detailed level. On each of the maps we have placed a pink rectangle that presents information on the time distribution of the available labour. This data is obtained by means of the time measurement method explained in 2.3.1 under the heading 'time measurement'. How we established this exact data will be explained in the next section 'Time measurement – Work sampling' on page 47.

In Appendix A.6, each of the detailed Value Stream Maps can be found. To give an idea of the layout of the Value Stream Maps, one of the maps can be found in Figure 3-5.

Service warehouse - For the service warehouse input for the five main processes value stream maps and one support process stream map are collected. The recording forms for those processes can be found under Appendix 5.8 to Appendix 5.14.

Production warehouse - For the production warehouse two main processes value stream recording forms are filled, which can be found under Appendix A5.15 and Appendix A5.16.

Time measurement – Work sampling

To be able to apply key metrics on the processes we have mapped, a time measurement has to be executed with the objective to gain a global insight in the bottlenecks/time-intensive activities. As mentioned 2.3.1, a time measurement study can be executed in two ways: Watch Measurement or Work Sampling. While performing the data collection step of the VSM method, we discovered that at the distribution warehouse multiple people work on a specific spot without strict task division and activities are interrupted for other activities.

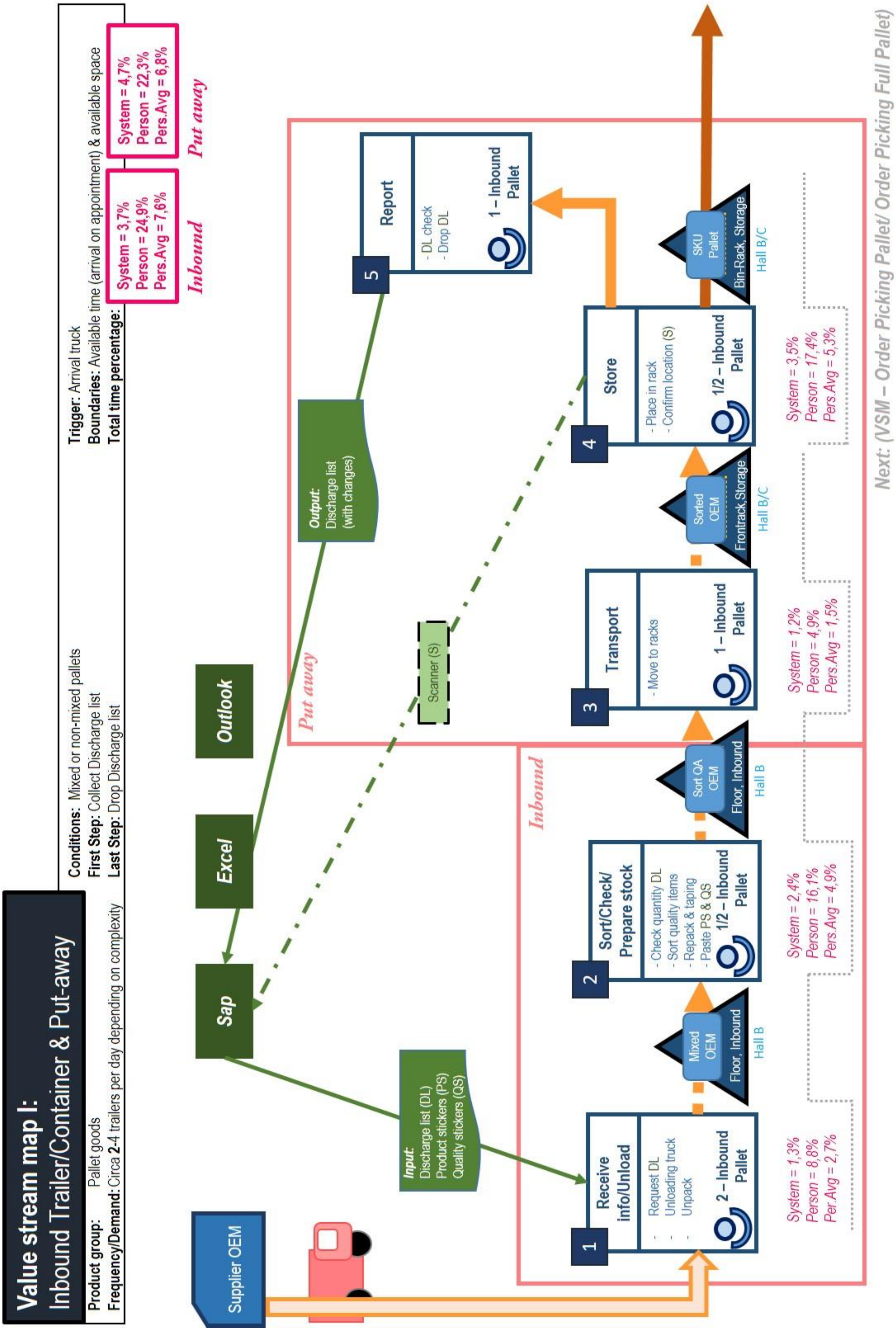


Figure 3-5. Example of a Value Stream Map build with the VSM building blocks

Based on those two details the *Work Sampling* method is the best fit for a time study. This method will result in insight in the time utilized for each of the process steps we found with the VSM method.

The total required number of observations (n) to meet the desired statistical significance can be calculated with the following formula:

$$n = P\frac{(100 - P)}{s^2}$$

(For an explanation of the formula see section 2.3.1 Statistical significance observations on page 23).

To find the standard deviation we have to keep in mind the objective of the time study. To find a suitable value for the variable 's', we divide the system in several sub categories, all with their own sub objective for results of the time study and its own significance (and thus its own calculation).

The significance subdivision is as follows:

- Overall system level significance: The objective is to get insight in the overall time-spent throughout the system. In order to accommodate the data broadly the significance for the overall systems should preferably be high (i.e., 1 or 2 %, numbers based on distribution table of Pollux Beheer & Advies B.V., 2016). **Required number of observations:** *2499*
- Employee level significance: Since the overall objective is to gain a global insight in the bottlenecks/time-intensive activities, the standard deviation of P does not necessarily has to have as significance of 1% for each of the employees. However, considering the goal to be able to deduce to a more detailed level to support findings on an overall system level with credible arguments, a value of 4% or 5% would be desirable (Pollux Beheer & Advies B.V., 2016). **Required average number of observations:** *142*
- Activity level significance: As with the employee level, the standard deviation of P does not necessarily have to be 1% for each of the activities. However, a value of 4% or 5% (Pollux Beheer & Advies B.V., 2016) would be desirable given the objective to support the credibility of the overall system level analysis. **Required average number of observations:** *77*

We have to execute a pilot round to find estimations for the value of variable 'P'. (The observations of this round can then simply be used as input for the entire time analysis).

By filling in the 'Work Sampling Recording form', (Appendix A.4) the activities executed by each of the distribution warehouse floor employees can be counted and mapped. Table 3-2 gives an overview of the main processes and the related sub steps that are present on the sampling recording form (i.e., the possible activities to tally during the observation rounds).

The *total number of warehouse employees*, that perform tasks on the floor, is 20. In this number, we have combined the employees with the same tasks that have a part-time function on the floor. For example the two supervisors that both fill in a part of the supervisor function, which together result in a full time function are incorporated into one employee. We have chosen to merge those functions based on the objective of the time study, to gain a global insight in the time spent on each of the processes.

In Appendix A.7 the work sampling recording form we applied to ATAG Benelux BV can be found.

Table 3-2. Overview of the main & support processes - Distribution warehouse

Main distribution processes					
1	Inbound – *Pallet*	a. Unload		b. Sort/Check/Prepare Stock	
2	Put away – *Pallet*	a. Transport		b. Store	
3	Inbound – *Clamp*	a. Unload		b. Check/Store/Transport	
4	Order picking – *Pallet*	a. Collect items		b. Position/unload	
5	Order picking – *Full Pallet*	a. Collect		b. Transport	
5	Order picking – *Clamp*	a. Collect items		b. Position/unload	
6	Dispatch – *Mix*	a. Consolidate	b. Prepare shipment	c. Position - intern	d. Position - extern
Support distribution processes					
1	Pre-pick	a. Shuttle		b. Transport	
2	Collect/report – info	a. Receive new tasks/info		b. Report finished task/info	
3	Shuttle	a. Production	b. Quality Assurance		C. Service
4	Replenishment – *Pallet*	a. Transport			
5	Compress – *Clamp*	b. Transport			
6	Return process - *Mix*	a. Unload	b. Check/repack/prepare stock		c. Store
7	Others	a. Clean up/Wipe	b. Collect/movement pallets		c. Planning
Others					
1	Waiting	a. Lack of work			
2	Not present (NP)	a. Not in sight	b. Break/Toilet		Travel

In total we executed the work sampling method on four days throughout a month. On the first day we walked 57 rounds, on the second day 66 and on the third day 80 rounds. On the last day we walked only the afternoon, which provided us 30 rounds. With the aid of the formula mentioned on the previous page, we find that the required number of observations for the overall system is 2499. Combining the measurements of all four days together, we collected 3485 observations for the overall system. The workload on the first two days was very high and on the last two days low to medium. The workload division in our measurements create a good balance regarding the generalisability of the results.

Activity	Norm (Pieces/Hour)
Order picking Pallet	95
Order picking Clamp	45
Consolidation	85
Inbound (average)	110

Table 3-3 presents the norm that is currently used as input to calculate the labour planning. However, we should take into consideration that this is an approximation and are not the exact activity rates.

Table 3-3. Overview of the pre-set handling norm

Identifying obstacles and redundant steps

As mentioned before, during the data collection we have discussed the obstacles and barriers that are encountered during the execution of the processes. We have summarized those *obstacles* for each of the processes and thereafter we have linked them with the *performance indicators* that were selected during the scope phase. In Table 3-4 an overview can be found with the various obstacles grouped under one of the performance indicator dimensions. When for an indicator underperformance occurs a certain result can be expected, shown in the table behind 'result' with an orange background. The orange words represent the causes for these results and are displayed in front of the corresponding barrier/obstacle that generates the cause.

Table 3-4. Overview of barriers and obstacles experienced by employees – Distribution warehouse

KPI	Time	Quality	Productivity
Result	Time loss	Inaccuracy	Inefficient execution
Inbound & Put-away *Pallet*	**Time increase:** Unexpected sorting & repacking (*Prepare stock*) **Blocking time:** Space limits create interruption in transport to rack (*Transport*) Waiting on other employees using same aisles *(Transport & Store)*	**Incorrect quantity:** QA check items not reduced on discharge list (*Quantity check + sort)* **Incorrect locations:** Unavailable discharge list (*Store)* **Incorrect inventory insight:** Manual item and quantity check (*Check)* Manual change tracking (*Report)*	**Distance increase:** Space limits for placing goods (*Unload)* Space limits for extra pallets (*Repack)*
Inbound & Put-away *Clamp*	**Blocking time:** Waiting on other employees using same aisles *(Transport & Store)*	**Incorrect inventory insight:** Manual item and quantity check (*Check)* Manual change tracking (*Report)*	**Distance increase:** Different locations clamp buffer and pick location (*Transport & store)*
Order picking *Pallet*	**Blocking time:** Waiting on other employees using same aisles *(Collect)*		**Distance increase:** Not all items fit the order picker at once – multiple rides (*Collect)*
Order picking *Clamp*	**Blocking time:** Waiting on other employees using same aisles *(Collect)*	**Incorrect item:** No stickers paste or correctness check (*Collect)*	**Distance increase:** Items are placed in two different halls (*Collect)*
Dispatch & Consolidation *Pallet & Clamp*	**Blocking time:** Heavy and full pallets miss – interruption process to collect missing items (*Consolidate)* **Double handling:** Restructure of pallets due to missing items (*Consolidate)*	**Incorrect item:** Not all products have a scannable barcode.	**Double handling:** Space limits make optimal pallet setup impossible (*Consolidate)* **Double handling:** Space limits create inefficient placement of dispatch ride (*Position)* **Distance increase:** Exact location heavy and full pallets not known *(Check)*
Replenishment *Pallet* Compress *Clamp*	**Time increase:** Count inventory when incorrect inventory (*Collect)*	**Incorrect location:** Items are not at right location (*Collect)*	**Distance increase:** Searching for goods on locations (*Collect)*

Besides the obstacles of the processes within the distribution warehouse, the obstacles of the service and production warehouse have been collected as well. However, as the VSM Data Collection forms in Appendix A.5 indicate, the processes at the service warehouse experience significant less barriers than the distribution warehouse. The production warehouse does experience some complications, nevertheless this part is disregarded given another research project currently executed at the production department. In Chapter 4, section 4.1.2, the actual analysis of these obstacles and their influence on the performance indicators will be discussed.

3.2.2 Activity profiling

Following the steps of the framework, the next data gap we encounter is the absence of a detailed insight in the behaviour of the items. By applying the activity profiling method mentioned in section 2.3.2, this information can be acquired.

Collecting the data

Since we are dealing with an immense amount of information, it is wise to determine in advance the analyses we want to examine. Because the needed information is not freely available and has to be extracted from SAP, some help from the planning and expedition department is required. By determining the expected analysis direction prior to the data collection, the desired information and the structure of the data can be established, which will accelerate the time-intensive data extraction.

As we stated in section 2.3.2 the data types that enable profiling and that we therefore have to collect are; the items, the orders and the locations. During the activity mapping process we have gained insight in the current situation and current course of actions. Based on this information we want to conduct analyses that require the following information:

Item master:

- SKU ID
- Text description
- Product Family
- Item dimensions
- Storage location:
  - *Bulk/Rack*
- Pick location:
  - *If known*
- Number on a pallet:
  - *Rack storage*
- Demand 2016

Order master: about 2016

- Date
- Shipment ID
- Delivery ID
- Order ID
- SKU ID
- Delivery quantity
- Volume
- Customer ID
- Customer Name
- Customer location
- Order/route type

Location master:

- Floor map hall A-F
  - *Including the aisles*

The structure of the *item master* is relatively simple. For each SKU one line is present in the file and this specific line contains all the different data fields for this particular SKU.

- Total number of documents: 1 - Total number of lines: 3.908

The structure of the *order master* on the other hand is quite complex. Figure 3-6 displays an abstract overview of the structure of the order master. As can be concluded from the figure, a particular shipment can consist of hundreds and in some cases even over thousands different lines. Those lines contain information about several delivery and order numbers with a wide variety of SKUs and multiple clients. On the other hand each client can have multiple orders with multiple SKUs in one or more unique shipments. Due to the complexity of the order master file, the data mining step of the activity profiling method require some extra data adjustments before the true patterns can be distinguished. In the next section we will explain the data adjustments that are necessary to apply.

- Total number of documents: 6 - Total number of lines: 391.364 (incl. 6 documents)

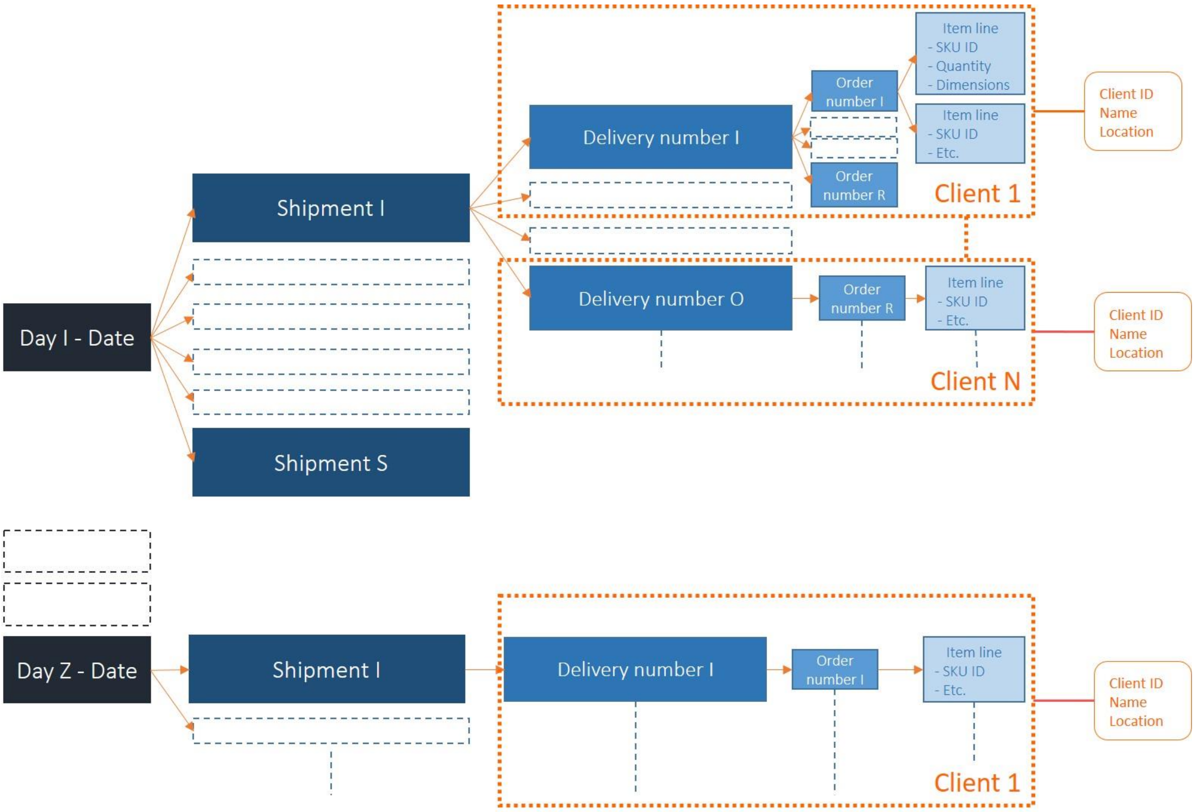


Figure 3-6. Overview of the structure of the order master

Mining the data

To be able to say something useful about the data, the several documents have to be merged and/or linked. However, the total data is too large to integrate in Excel and therefore we need to use a different software program. The offer of data Extraction, Transformation and Loading (ETL) software is huge, but based on the usability we have chosen Alteryx Design 11.0. This ETL tool is easy to use, supports data analyses, and interacts with MySQL. MySQL is an open-source relational database management system that creates a data warehouse in which the data can be stored during the data transformation process. *Alteryx* enables us to blend data, thus combine and integrate the several data sources, and to execute advanced analytics.

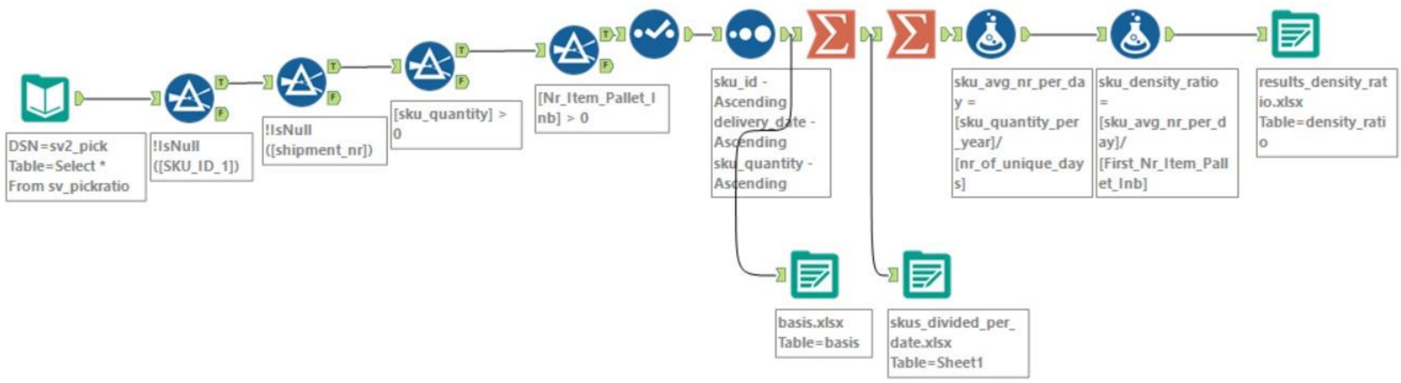


Figure 3-7. Screenshot of the Alteryx Worksheet with the performed data adjustments

Figure 3-7 presents a screenshot of the Alteryx Worksheet on which the workflow has been exhibited. The workflow we have designed contains the following tools:

Input – Filter 1 – Filter 2 – Filter 3 – Filter 4 - Select - Sort – Summarize 1 & Output 1 – Summarize 2 & Output 2 – Formula 1 – Formula 2 – Output 3

In Table 3-5 we give an explanation on each of the tools we use: Their function, our objective of applying this particular tool and at last the result we aim for.

Table 3-5. Explanation of the used Alteryx Design tools and the desired results

Tool	Function	Our objective	Result
Input	Enter data into the module by selecting the needed files or connecting to a database (e.g. MySQL)	Connect the 6 order files with the 1 item file	An integrated database with all information we need for our analyses in one file
Filter	Split data in separate streams based on a certain expression	1. Filter and remove: SKU_ID = 0 2. Filter and remove: Shipment_ID=0 3. Filter and remove: SKU_Quantity=0 4. Filter and remove: Nr_Item_on_Pallet <0	1. *Reduce discrepancies*: SKUs with no ID in order files cannot be coupled with Item file 2. *Delete incorrect info:* lines without a shipment number are cancelled orders 3. *Delete incorrect info:* orders without a quantity are incorrect entered orders 4. *Reduce discrepancies:* given the analysis focus, the SKUs without a strict number of items on a pallet are not usable
Select	Select, deselect, reorder and rename fields	Select the desired fields that we want to use for the analyses to speed up the processing downstream	Additional information like customer name, customer location, item characteristics are not necessary for the analyses. However, we requested this information to be able to link the information later on based on the unique Customer_ID and SKU_ID
Sort	Sort records based on the values in one or more fields	Restructure the information in an easy-to-handle-order	Sort on: SKU_ID – Ascending, Delivery_Date – Ascending SKU_Quantity - Ascending
Summarize	Summarize data by grouping, summing, counting, etc. – Output contains only the calculation results	1. Get insight in order behaviour of SKU and shipments per date 2. Get insight in order behaviour SKU and shipment with order quantities See Figure 3-8 for the settings of each of the two summaries we draft	1. Per SKU the delivery dates are grouped and the number of unique shipments they appeared in that day are counted 2. Per SKU the number of order days, the demand per year, average number of shipments per day and the standard deviation for that day are shown, furthermore the SKU quantities on a particular day are summed.
Formula	Create and update fields using one or more expressions to perform calculations	1. Find average number of orders per day per SKU 2. Find the density ratio for number on pallet and demand per day	1. Formula: SKU_Quantit_per_year/nr_of_unique_days 2. Formula: SKU_Average_nr_per_day/Nr_Item_Pallet
Output	Extract the modified data to a file or database	Create excel files that we can use to visualize the analyses	1. *Basis.xlsx* = file with the integrated, filtered and sorted data 2. *SKUs_divided_per_date.xlsx:* file with the outputs of summarize 1 applied 3. *results_density_ratio.xlsx:* file with the outputs of summarize 2 applied

The filters in the workflow can be combined, however for the sake of a clear insight in each of the filters and the number of lines deleted, we split each of the filter steps. The summary of the data clean-up we execute on the order master file after combination is as follows:

- **Total number of start rows**: 393665
    - SKU ID not present in both files - delete: 11801
    - Shipment number unknown – delete: 1519
    - Order quantity 0 – delete: 111 rows
- **Left over**: 380.234
    - Bulk items or number on pallet unknown – delete: 167846
- **End database**: 212.388 unique order data rows

Figure 3-8 presents the settings of the two summary tools. When creating a summary the top line has the priority, we have to pay attention to the order of the actions because the order determines the structure. Especially in the first summary the order is of interest, because here the data is first grouped based on the SKU ID and then for each of the SKUs the delivery dates are grouped.

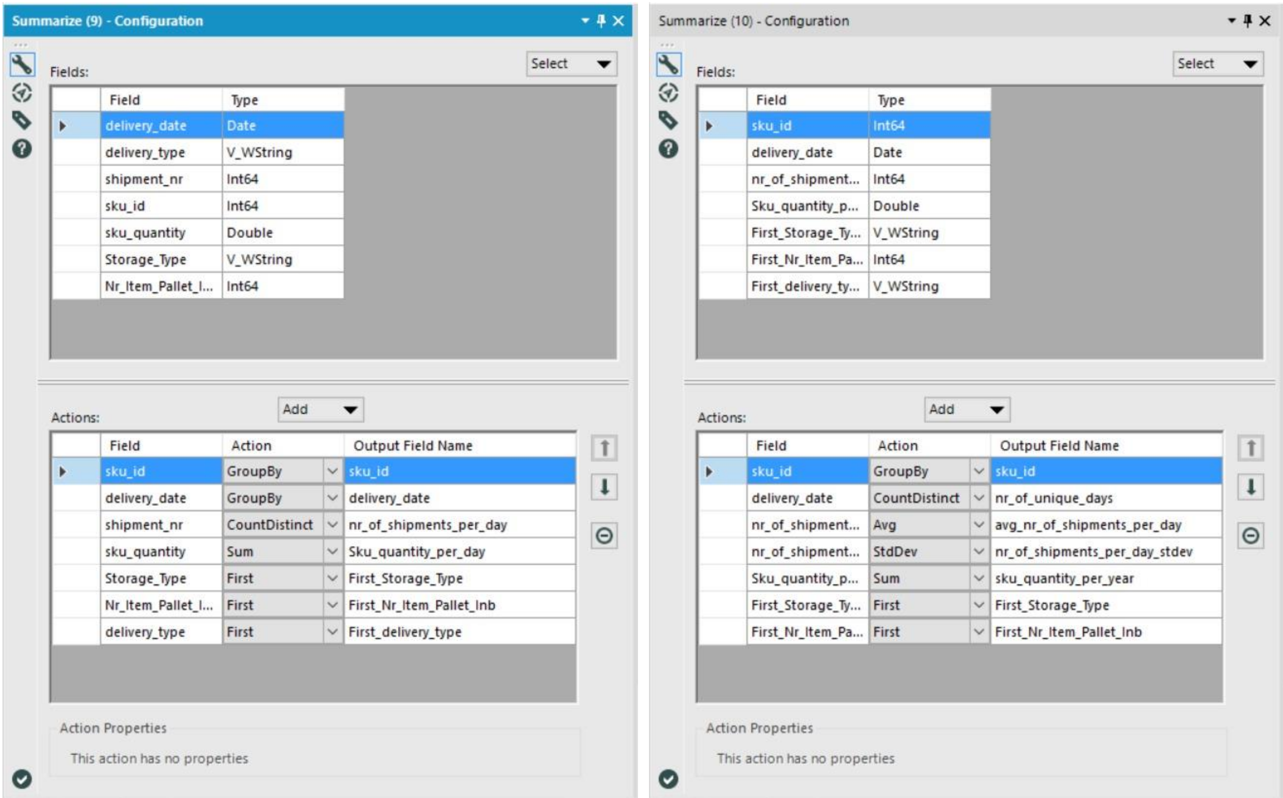


Figure 3-8. Settings for the two summaries elements used in the Alteryx Workflow

Visualize the results

Now the files are cleaned and ordered, it is possible to tell stories about the data. With the aid of *data visualization* we can display the large data set from various point of views while presenting and comparing information at several levels of detail. In section 4.1.2 the data visualisation and the analyses we apply on the data sets can be found.

3.2.3 Activity relationship charting

Following the steps of the framework, the last data gap we encounter is the absence of a detailed insight in the interrelationships between the departments. By applying the activity profiling method mentioned in section 2.5.2, this information can be acquired. The data collection step is executed within this section: the departments are listed, the closeness relationship values are allocated and the reasons for this relation are indicated.

Collecting the data

If we recall the relationship chart template we mentioned in section 2.5.2 and we combine this with the department list of section 3.1.2 'Departments', the relationship chart for the departments related to the logistic process can be drawn (Template to be found in Appendix A.8). However, beforehand we have to define reason values that indicate the underlying thought for the assigned closeness relationships. The reason indications we use to support for the relationships between the departments at ATAG Benelux BV are displayed in Table 3-6.

Table 3-6 Overview of the Reason indications used for the Relationship Chart

Code	Reason
1	Continuous flow of material
2	Shared equipment/site
3	Shared labour
4	Frequent contact and file exchange
5	Management

In Figure 3-9 we present the relationship chart that include the departments, technical zones, closeness importance values and the related reason values. An overview of the number of relationship ratings per closeness importance value are shown in Table 3-7.

No.	Name of department
1	Inbound Pallet
2	Inbound Clamp
3	Return Service Technicians
4	Inbound spare part/component
5	Storage Pallet
6	Storage Clamp
7	Storage Spare parts
8	Storage Components
9	Storage QA
10	Sorting Area
11	Consolidation area Shipments
12	Consolidation area Service Tech
13	Consolidation Spare Parts Dispatch
14	Dispatch Shipments
15	Dispatch Pick-up
16	Return receipt
17	Expedition
18	Production
19	Quality Assurance
20	Post room
21	Docks

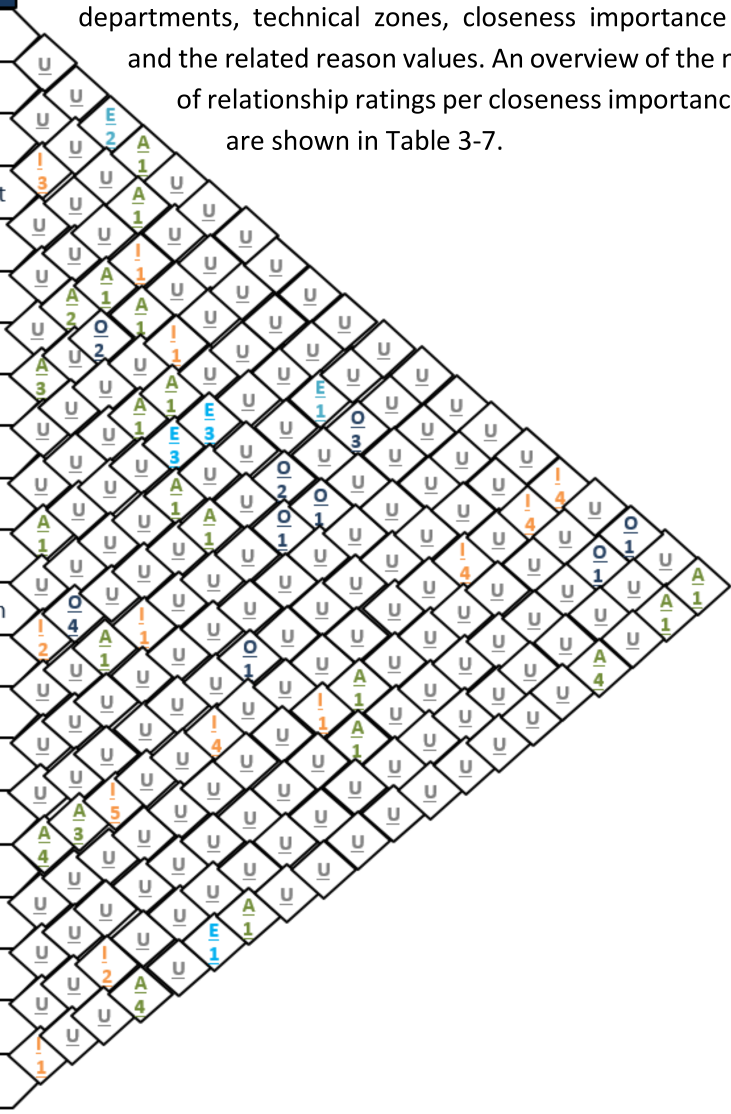


Figure 3-9. Relationship Chart showing the relations between the departments and technical zones at ATAG

Table 3-7. Overview of the closeness importance values with related rating

Value	Closeness importance	No. of ratings
A	Absolutely necessary	20
E	Especially important	6
I	Important	15
O	Ordinary closeness okay	9
U	Unimportant	160
X	Not desirable	0
Total	N(N-1)/2 (N=21)	**210**

Drawing the diagram

Now that we have charted the relationships, we have assigned the values and the chart is evaluated by the stakeholders, the *relationship diagram* can be drawn. This subsequent step with the block layout end result can be found in section 4.1.4.

3.3 Remainder input resources

The last data gap we encounter, when following the steps of the framework, is the absence of a detailed insight in the available resources. In the next sections we identify the MHE, storage equipment and communication and information equipment currently available on the market.

3.3.1 MHE techniques

Transportation unit

Before we go deeper into the material handling techniques, we have to distinct the shape in which the material is moved, the *transportation unit* (see 2.5.3). Based on the products that are handled at ATAG Benelux we can conclude the transportation unit at ATAG for the distribution warehouse are *light to medium weighting items* packed on pallets or *heavy weighting items* handles as single unit loads (stackable).

Material Handling equipment focus

As we mentioned before in section 2.4.2 an extensive list with equipment categories, classes and types is drafted by Bouh, et al. (2015), which can be found in Appendix A2.4. Nevertheless, there are some specific MHE we would like to delve into. In the next section we will discuss the several possibilities of the goods-to-picker methods. Why we want to understand this particular concept is because of two reason. The first reason is the major shift currently occurring within the logistic field from the traditional picker-to-goods methods towards the goods-to-picker methods. The second reason is the current method deployed at ATAG. Currently is the picker-to-goods method executed and regarding this method insight is already present at ATAG. Therefore it is very useful and interesting to get more insight in the yet more unknown methods available in the logistic field.

Goods-to-picker methods

According to Stone (2015) is the most common order picking method the *picker-to-goods (PTG)* concept. However, the picker spends significant amounts of time on moving between the several storage locations. If an order picker spends more than 60% of their time on moving, inefficiency occurs. With the *goods-to-picker* (GTP) concept the items are moved to the pickers. With the aid of the automated system that utilizes the overall system improved efficiency is accomplished (Stone, 2015).

Besides the efficiency the picking accuracy improves as well, because the system only retrieves the items actual needed (Graves, 2012).

GTP solutions can operate in high density storage systems for both pallets as tote-carton goods. The *benefits* of the GTP systems are; improved ergonomics, increased productivity, increased space utilization, increased storage safety and a high scalability due to the modular character of the systems. Nevertheless, the benefits depend on the SKU and its order profile. The solution has to be fitted by means of the *process perspective* and not based on a certain technique. The factors that need to be analysed to find the proper fit are: daily unit volumes, units per order, lines per order, packing sequence, unit cube and cube movement, total SKUs and the percentage of SKUs in the daily demand (Graves, 2012). It is uncommon that one single method fits all the SKUs in a warehouse and a detailed assessment may reveal the need for several systems. From this analysis a distinction can be made between slow, medium and fast movers. In general the fast movers' throughput is more efficient when a more traditional pick method is applied (Graves, 2012). For the medium and slow movers a more automated GTP system is in place when for each order per order line a low or medium quantity is common, preferably in less-than-case amounts (Bastion Solutions, 2017). By making this distinction the capital is better divided and less capital is spent on the automated system. Although for a GTP system a big investment is necessary, the long term benefits outweigh this (Graves, 2012).

The equipment types that enables the GTP concept, differ from simple manual systems to highly automated systems. Below we present the GTP types in ascending automation order (Stone, 2015):

1. Pallet Flow system: A static rack structure with dynamic flow rails – *traditional methods*
    - Type of goods: cartons, pallets, finished goods.
2. Industrial carousel system: rotating shelves in horizontal or vertical direction.
    - Type of goods: small to medium sized articles & medium and slow moving SKUs.
3. Automated storage retrieval: are a combination of computer controlled systems that automatically places and retrieves loads from several storage locations.
    - Type of goods: standard and non-standard loads
        a. Mini-load: ASRS for totes, containers or cartons.
        b. Unit-load: ASRS for single unit movements: pallet loads.
        c. Automated Guided vehicles: ASRS for single unit or pallet movements.
4. Robot picking: Computer controlled systems that deliver goods via complex paths.
    - Type of goods: every kind – very width applicable.

In Appendix A9 an overview of pictures of the several goods-to-picker methods can be found.

Given the specifications of the ATAG assortment and the general order frequency of the SKUs the industrial carousel system is off and therefore not further unfolded, as well as the Robot Picking system which thereby is also financially unattractive. However, the pallet flow (racking) system will be discussed in more detail in section 3.3.2. Moreover, based on the character of the order profile (collected in in 3.2 and explained in 4.1.2) and the assortment of ATAG we have decided to examine the AGV category of Automate Storage Retrieval system, which can be found in the next section.

AGVs

Automated Guided Vehicles (AGVs) are automatically programmed vehicles that drive pre-planned points. It is an integrated system that combines computer systems, sensors, automatic control, mechanical and communication technologies (Zhou, Dong, Gu, & Xia, 2014). With the aid of computer controlling autonomous navigation, automatically path planning, automatically task execution and independent obstacle avoiding can be accomplished. The advantages that can be achieved according to Zhou (2014) by deploying the AVGs are: improved response times, easy scheduling and management, high safety and reliability and an increased accuracy due to the high degree of automation. Especially when flexibility is required instead of fixed paths (e.g. conveyors) this system is an appropriate solution. However, it should be kept in mind that humans remain more flexible and can support on different tasks as well.

The hardware of the AGV systems consist of a motor, an electronic code disk, an automatic guided vehicle power supply, sensors, a control centre and a computer system, which is mostly a PLC (a device with a microprocessor that guides the several outputs based on the several inputs). Related software to support the hardware are the Storage AGV software and the System Control Software (Zeng, Xue, Wang, & Tian, 2016).

The most important aspect of the use of AGVs is the route planning. This activity is prerequisite for intelligent vehicle performing various complex tasks with an effective route in a complex environment. Two types of *navigation mechanisms* for AGVs that are generally applied are (Palaskar & Phatale, 2013):

Figure 3-10. Example of a work area with RFID Tags (source: Lee, Kim, Yu, & Moon, 2016)

1) Wires: Imbedded Guide Wires, Paint strips and Self-Guided Wired Navigation.
   - Functionality: The wire is placed in the ground and the sensor on the AGV detects the radio frequencies. The communication can be between two AGVs, between an AGV and a central device or for local interfaces.
   - Difficulties: Due to the location of wires: maintenance, replacement and reinstallation at different locations is difficult – Result: Inflexibility & costly.
2) RFID: For information on types see section 3.3.3 Communication and information equipment.
   - Functionality: Arrays of short range “passive” RFID tags are located on the entire work field and by scanning the unique locations the AGV can calculate where it is located. The existing Wi-Fi network can be used. Figure 3-10 presents an example of a RFID division at a work area.
   - Benefits: Locate unique items in real time and enables to configure after placement.
   - Difficulties: Sensitive to metal in its close surroundings can interfere with receiving the signal – Result: extra intermediate material is required when attached.

The RFID system increases the flexibility in comparison with the Wires System.

Picking types and productivity rates

The productivity for each task executed in the warehouse depends on multiple internal and external factors. Based on a cross section analysis presents Stone (2014) an approximation for the various pick methods rates. These numbers are not directly applicable on the organization, however to understand the variation between the various picking methods it serves well. See appendix A.10 for the overview.

3.3.2 Storage equipment techniques

As we mentioned at the beginning of this paragraph, the assortment of ATAG consists of domestic appliances with dimensions that fit on a pallet. Based on this data we study alternatives for pallet goods storage in the entire width of the current offer.

Racking & stacking

A common storage unit load is the pallet. There are a number of different storage methods available, each with its own advantages and disadvantages. We have enumerate the options below and furthermore gives Table 3-8 an overview of the comparison of the racking methods (Link51, 2017).

1. Standard Aisle Single Pallet Racking (SPR): each bin can store one pallet, can vary in heights and is accessible with all trucks.
    - 100% access to every pallet – both LIFO (Last In, First Out) as FIFO (First In, First Out) possible
    - Comparison score (average of total scores of Table 3-8): 3.8
2. Standard Aisle Double Deep Pallet Racking (DDPR): each bin can store two pallets, can vary in heights and a double reach forklift required.
    - LIFO
    - Comparison score: 3.5
3. Very Narrow Aisle Pallet Racking (VNPR): rails/wires guided trucks are positioned between two racks and specialised lift trucks are required.
    - 100 % access to every pallet
    - Comparison score: 3.8
4. Push Back Pallet Racking (PBPR): pallets are loaded onto wheels/rollers and are pushed back along inclined beds.
    - LIFO
    - Comparison score: 2.9
5. Drive In Pallet Racking (DIPR): pallets are stored on runners in the depth of the rack and provides 5 to 10 pallet loads places that are accessible with all truck types.
    - LIFO
    - Comparison score: 3
6. Mobile Pallet Racking (MPR): racks mounted on mobile chassis that move on tracks and are accessible with all trucks.
    - 100% access to every pallet
    - Comparison score: 3.3
7. Pallet Flow Racking (PFR): Load is moved from one end of the rack on a conveyor, when a pallet is removed moves the next pallet to the new position. Fits a high throughput organisation.
    - FIFO
    - Comparison score: 3.3
8. Block Stacking (BS): a storage technique with which unit loads are stacked on top of each other and stored on the floor in lanes or blocks (Balance, 2016).
    - LIFO
    - Comparison score: 3.4

Table 3-8. Overview of the Storage methods with (dis)advantages and characteristics (Source: Balance, 2016; Link51, 2017)

	Advantages	Dis-advantages	Space utilisation	Utilisation cubic space	Access to one	Speed of access	Stock rotation efficiency	Stock control efficiency	Special MHE required	Re-location ease:	Install Speed
SPR	Easy to install, Cost effective, Versatile	Low storage density - High number of aisles	3	3	5	3	3	3	No	5	5
DDPR	Maximum utilisation – reduced aisle space	Reduced accessibility	4	4	3	3	3	3	Yes: Reach forklift	4	4
VNAR	Improved safety Excellent floor space usage	Less flexible	4	4	4	4	4	4	Yes: Lift truck	3	3
PBPR	Space and time efficient Eliminate honeycombing Less damage to machinery	Reduced accessibility	5	4	3	2	4	2	No	1	2
DIPR	Maximum utilisation – reduced aisle space	Increases store and retrieval time Difficult to adjust/poor accessibility Increased machinery damage	5	5	1	2	2	3	No	3	3
MPR	Maximum utilisation – reduced aisle space	Increases store and retrieval time	5	5	5	1	2	4	No	2	2
PFR	Provides automatic stock rotation Minimum forklift movements	Expensive option Increase in needed space	5	4	3	4	5	5	No	1	1
BS	Inexpensive Easy to apply High storage density	Reduces safety Limited access to single items	4	5	1	3	2	3	Yes: Clamp truck	4	5

If we analyse the comparison scores, (the average of the scores of Table 3-8) we can state that the *Standard Aisle Single Pallet Racking* and the *Very Narrow Aisle Pallet Racking* are the best choices for storing the materials with a score of 3.8. In Appendix A.10 a storage calculator is presented. This figure gives an indication of the number of pallets that can be stored per level given a certain space for each of the methods shown in Table 3-8. If we take apply this calculator on these two methods, the *VNAR* is the best option regarding the number of pallets it can store.

3.3.3 Communication and information equipment

Identification equipment

Throughout the entire logistic process, organizations desire insight in all the characteristics, aspects and actions of their items by means of controlling the information and material flow. This understanding can be acquired by applying *'Automatic Identification and Data Capture*' (AIDC), which is the generic term for the methods that automatically identify the object and stores its data into the dedicated computer system. The AutoID methods that are commonly considered and used by organisation for storing product data, are *barcodes* and *RFID-tags* (Berthiaume, 2016). We place both techniques side to side to compare and analyse the specifications, advantages and disadvantages Table 3-9 .

Barcodes: parallel black bars representing data, which contain the data by varying the distances the spaces between the several bars. The data can be optically read by means of a scanner with a laser (Trasher, 2013). The application of barcoding provides a short term status report at a certain point in time and enables automated data entry (Myerson, 2015). Bar codes can be applied for product identification and location identification.

Radio-Frequency Identification (RFID): radio waves (frequencies) representing the data, which can be passive or active. The RFID system comprises a RFID reader, tags, an antenna, communication infrastructure and application software (Trasher, 2013; Palaskar & Phatale, 2013).
The application of RFID provides a continuous visibility throughout the logistic process in the long-term (Myerson, 2015). RFID can be applied for product identification, location identification, data storage & rewriting and guidance & support for AGVs (see section 3.3.1) (Ilie-Zudor, 2006; Palaskar & Phatale, 2013).

According to Ilie-Zudor, Kemeny, Egri, & Monostori (2006) there are a number of different RFID tags available:

1. Passive: obtains operating power from the reader – reader sends waves, tag reflects the RF signal.
2. Semi-passive: uses a battery to maintain memory in the tag – enables tag to modify the reflected signal.
3. Active: powered by an internal battery - broadcasts a signal to the reader.

Besides there are a number of different RFID readers available, based on functionality or on fixation (Ilie-Zudor, et al. 2006):

1. Read: read – different types for different frequencies and protocols.
2. Read & write: reads and writes data from/of the tag.

Or

1. Stationary: attached at a fixed place.
2. Mobile: attached at a movable device.

Table 3-9. Overview of the comparison of the Barcode and the RFID technique

	Specification	Barcodes	RFID
Specifications	Read rate	Low throughput, read one at a time – manually	High throughput, multiple read simultaneously
	Read range	Several centimetres to a meter	from 6 to 30 meter
	Line of sight	Required – physically visible	Not required – oriented in each direction – medium constraints do occur
	Human capital	Required – manual system	Not required - Automated system
	Capability	Read only	Read, write, modify and update
	Durability	Low – easily damaged	High – not easily damaged
	Security	Medium – possible to reproduce or to counterfeit	High – difficult to replicate – can be encrypted
	Event trigger	Not capable	Capable
Advantages		Universal: the standard in tracking and tracing	Unique identification: specific unique information – decentralize shipments
		Simple: easy to make, read and understand	Time efficient: read multiple tags at once
		Transparent: insightful for many	High accessible: Read wherever the tags are – even when covered
Disadvantages		Read requirements: clear line of sight	Non-universal: software bounded
		Labour-time intensive: requires high manual input	High start-up costs/high threshold for small businesses: require special software and tags are more expensive
		Interference error: Easy to tear, cover-up and mangle	Interference error: cannot be read through every material (medium dependent). Inability of the reader to pick up information of every item or to distinguish between different shelves.

RFID can be applied for each of the main processes of the warehouse (Angeles, 2005):

- Receiving and check in: read tags and automatically update inventory quantities.
- Put-away and replenishment: head immediately to correct location and correct inventory location levels without time loss for scanning.
- Order filling: directed to the correct picking location, automated verification of right items and updating the inventory level.
- Shipping: Reduced shipping costs since scanning is unnecessary and improved accuracy.

Cost perspective

In 2010 over 51% of companies were not using RFID (Myerson, 2015). The install costs for the RFID system are considerably higher than the install costs of the bar code system. Despite, 75 to 80 percent less time is required to complete the inventory storage with RFID in comparison with bar codes. Besides the inventory accuracy is increased as well, since the tags are getting more sophisticated and counting, tracking and replenishing is possible due to item level tagging. This more precise inventory knowledge enables inventory check to be executed every day instead of twice a year, which reduces the cost by removing the extra costs for manual inventory counting (Roberti, 2009). Furthermore offers RFID the advantages of reducing waste in the overall supply chain since products can be tracked through the entire logistic process to the final transfer to the customer. In short, the RFID system boosts the overall efficiency, visibility and accuracy. To decide the profitability of the RFID system a ROI case has to be developed (Angeles, 2005).

Though, a point of attention is that the increased data availability must be managed correctly because it can create a major 'fuzz'. There is a risk that the focus swifts toward *data micromanagement*. Therefore it is important for an organization to know what data they need and how they can interpret it.

According to Marder (2015) is RFID the face of the future. Although it is currently not for everyone, organizations should make a shift to RFID where they can. The advantages of the medium can help the organization to differentiate their service from other competitors on the market.

3.4 Consequences

3.4.1 The environment

As we discussed in section 1.2.2, the current business environment is experiencing a major shift in its characteristics. To keep up with the international high increasing market, it is important to be part of this development. Especially when the organization itself will grow, which is expected, it is important to catch up on the change.

We predict that if there will occur no change in the plans and policies of the organization keeping the future expected environment in mind, various problems will arise. The problems we expect to happen are:

- A *shortage in space* that results in inefficient operations and a decrease in operation speed.
- An *inflexible character* that results in a responsiveness slowdown, while responsiveness is getting increasingly important in the current environment.
- A *skewed ratio* in labour and yield, which will result in an increase in costs.
- *No clear insight/transparency* in the overall supply chain, which results in a reduction in service assurance.
- A fully on *human depending system* that results in a lower accuracy than necessary, which influences the service.

Ultimately the problems mentioned can result in a diminished market position and a greater effort to keep up with the competitors. To avoid these scenario projections, the new warehouse should not be a copy of the current warehouses with the corresponding processes but has to undergo an improvement plan and an efficiency retrieval.

3.5 Conclusion & final scoping

During this chapter, we have identified the several *data gaps* and thereupon we collected the *missing data* to bridge these. The information we gathered throughout the paragraphs is: process insight in the form of Value Stream Maps, item behaviour understanding by means of data mining and interrelations between departments with the aid of the Systematic Layout Planning method. Aside from the internal data collection at ATAG, an external data research has brought us insight in the current equipment techniques. Showing us that the 'Very Narrow Aisle Pallet Racking' method is the best of the racking storage methods. Last of all, the data collection has provided us the opportunity to apply a final focus on the scope of the project. This focus is necessary given the time span of the project and the related efforts. For this project focus will be limited to the design of the distribution warehouse of ATAG.

In the next chapter we will execute the 'New Integrated Warehouse Design' framework. With the aid of this framework we can designate the inefficient processes and the improvement possibilities. These points will then be analysed and included in the redesign advice report for the new warehouse for ATAG Benelux BV.

4. Design and the Implementation – The Result

Now that we completed the 'Means planning' and the 'Resource planning' of the 'Idealized Design' method of Ackhoff (2001), the last phase of our framework design process has arrived. During the 'Design of the Implementation' phase we apply the framework on our case study of ATAG by implementing the steps, step-by-step.

Chapter 4 is structured in the order of the 'New Integrated Warehouse Design' framework, which can be found in section 2.6. As we mentioned in section 1.4.2 and 3.5, the scope of the case study within this research is limited to the Distribution Warehouse and the application of the framework restricted to the strategic and tactical level. First in paragraph 4.1 the framework is applied to outline a first draft of the warehouse (the idealized design). Subsequently, we give advice on the idealized design and the implementation process in section 4.2. and 4.3. Now, let us start designing the new warehouse of ATAG Benelux BV.

4.1 Application of the framework

4.1.1 Step A - Determine direction

The first step for us to undertake, is to detail the direction for the Distribution Warehouse of ATAG with the aid of the 'Model of Success'. We start with the *vision*, which is as we stated in section 1.2.1:

"To provide the best products & services for the home cooks from our shared passion to cook to create an enervating cooking experience".

This vision is shared among every department at ATAG, the mission on the other hand is tailored for each specific department. For the logistic department, the mission focuses on the service part of the vision. The mission identifies the significant difference which distinguishes ATAG from their competitors. The vision is accomplished by targeting the *mission* on:

- Internet compliance: Shifting from Business to Business towards Business to Consumer.
- Flexible delivering hours: Working towards 24 hours service (i.e. Next day delivery).
- Reliability: Pursuing a 'deal is a deal'-mentality.
- Customizable: Serving customers' wishes (e.g. consolidation commission, flexible unit loads).
- Just in time management: Improving processes towards excellent operational performance.

In order to make the mission feasible we have to concretize it. By specifying aspirations/specifications, values and necessities that are essential for this success, this can be accomplished. These aspirations have to be aligned with the global warehouse changes (see Figure 4-1) to be future proof. The *success requirements* for the logistic department can be formulated as follows:

- Suitable layout: A layout and space division that fits nowadays norm and that suits the future.
- Up-to-date and convenient technology: Equipment and software that complies with the latest technology and the operations at ATAG.
- Increased automation: Operate more efficiently and again comply with the latest technology.
- High accuracy: The right product, from the right location, at the right moment for the right receiver and preferably with a FIFO oriented system.
- Cost-Benefit balance: proper balance between the required costs and the gained benefits.

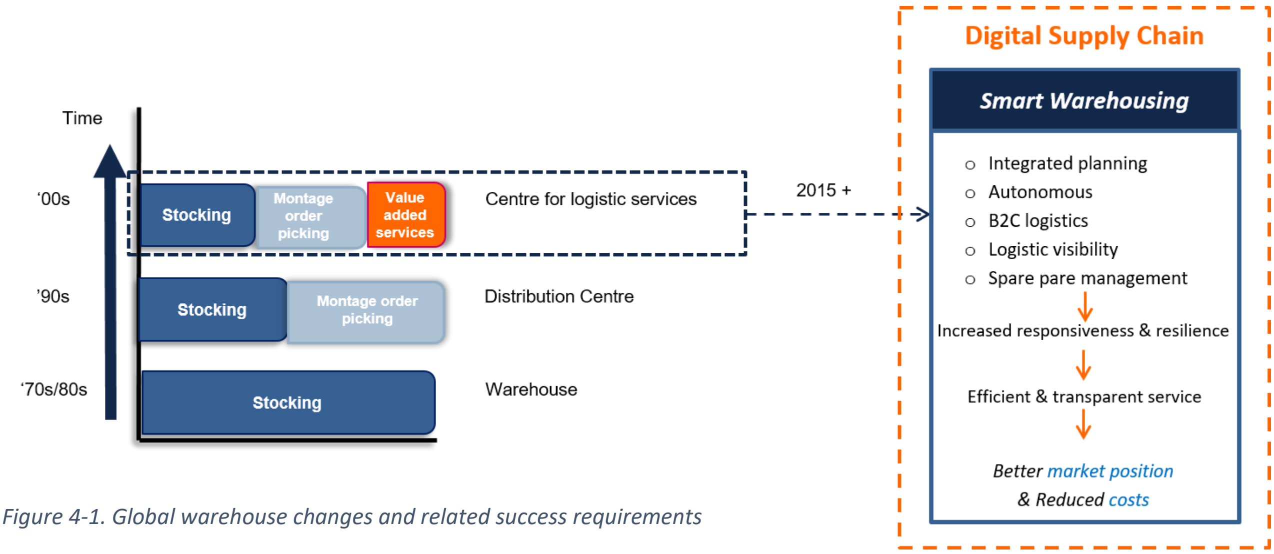


Figure 4-1. Global warehouse changes and related success requirements

Nevertheless, to realize the aspirations certain objectives and values have to be drawn. In consultation with the several stakeholders we drafted a number of *guiding principles* that concretize the success requirements, also known as objectives. These objectives are:

- Maximum quality: Two types of quality are distinguished at the Logistic Department at ATAG:
  - Maximum product care: Handling products carefully to prevent/minimize damage.
  - Minimum error sensitive: Right product from the right location.
- Maximum safety: Compliance with legalisation concerning ergonomics, fire safety and other calamities.
- Maximum productivity: Two ways that improve the productivity at the logistic department:
  - Minimum distance: Increase operating efficiency, optimal deployment of labour.
  - Minimum handlings: Reduce the number of 'hands-on' moments.
- Minimum variable costs: Increase automated control and reduce operating costs: e.g. reducing labour costs, error costs and shipment costs.

To maintain control on the development towards the mission and eventually to fulfil the vision, the successes have to be measured. With the aid of performance indicators the *evidence of success* can be demonstrated. The measurements that are determined to monitor/ensure performance quality are:

- Throughput: The average number of inbound items and the average number of outbound items and the related ratio between a minimum and a maximum value.
- Productivity: Compare norm with real time performance (Inbound, Order picking, Replenishment, Consolidation).
- Space utilization: Optimal use of the available space with a ratio above a pre-set value.
- Accuracy: The total number and type of errors under a pre-set value.
- Transport costs: The total costs for each shipment/per colli below a pre-set value.
- Transports density: Utilization of the dispatch/transport equipment above a pre-set value.
- Returns and return types: The amount of recurring goods and the causes for each return.

The direction of the warehouse is the foundation for the overall warehouse strategy and the related operations and therefore it has to be taken into account throughout the design process. As we display in the NIWD-framework, this information is the key input for several design steps.

Conclusion

Now that we have insight in the desired direction of the logistic department, the next step to execute is the design of the process flow. In the next section the fulfilment of this activity will be described.

4.1.2 Step B - Design of the process flow

Following the NIWD-framework (section 2.7), three sub processes for step B - the Design of the Process flow - can be determined. Those sub processes are: Value Stream Mapping, Activity Profiling and Activity Relationship Charting. For each sub process we have conducted the data collection during Chapter 3. The results of VSM and Activity Profiling we will discuss in this particular section. The results of the Activity Relationship Charting can be found under section 4.1.4 Step D – Layout of the overall system.

Process flow and average time spent

The Value Stream Mapping process has yielded three results. The first result is an overview of each of the distribution processes, which can be found under Appendix A.5.

For the second result, i.e. understanding in the time spending within system, we have to examine the time study results to extract meaningful and useful information. In Appendix A.11 the observation data per activity, collected with the aid of the work sampling method, are shown on a detailed level. We visualize the most important data of this detailed level overview in Figure 4-2. Based on this data we can draw some conclusions. Every activity that uses more than 5% of the total labour is included in this analyses.

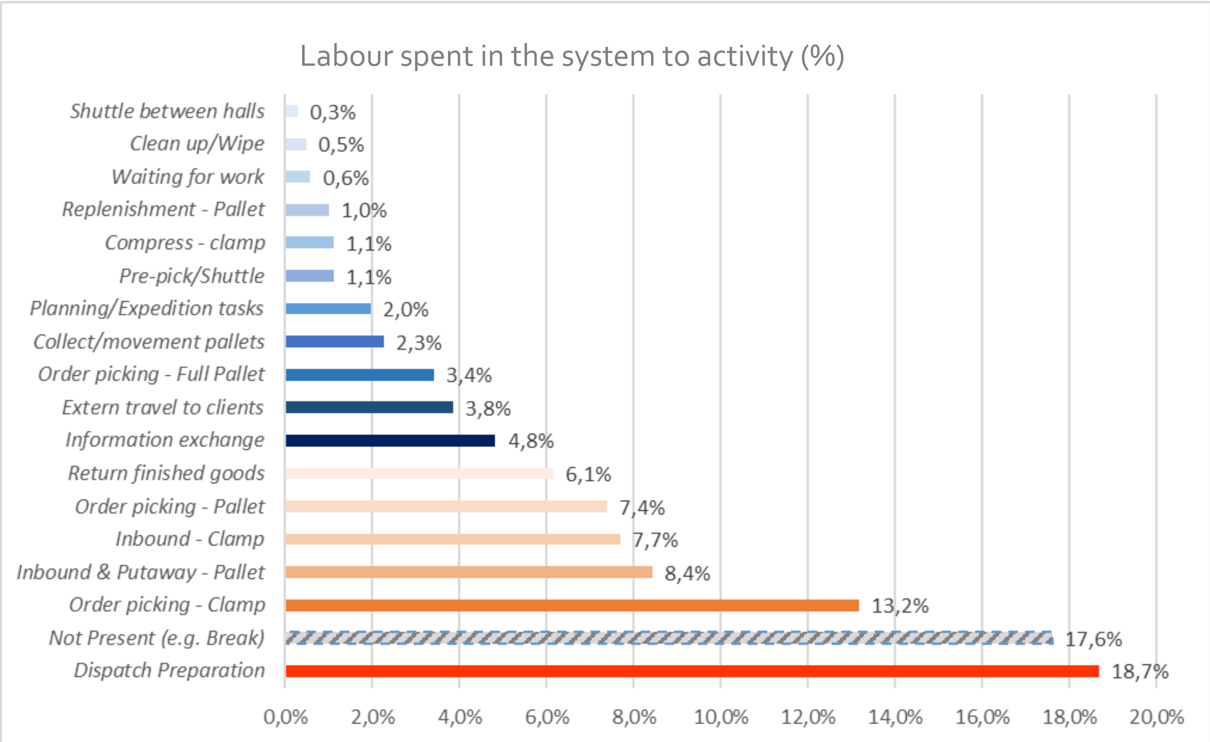


Figure 4-2. Work Sampling results - Percentage labour spend (horizontal) in the system for an activity (vertical)

The most time-consuming activity at the ATAG distribution warehouse is the preparation of the shipments, followed by order picking clamp, inbound & put-away of pallet goods, inbound of clamp goods, order picking pallet and handling or returned goods.

Let us now dive a bit deeper, in these six time-intensive-activities. In Table 4-1 we show the activities in more detail by presenting the time spent among the sub-steps of the activities. By improving those six particular activity areas, major time efficiency can be achieved. Starting with the *'Dispatch*

Preparation' we see that the consolidation step requires the most labour, something that is caused by the service focus of ATAG in which consolidation customization is offered. Automation of the consolidation step is undesirable because this will reduce the flexibility that human interaction adds. And since this service is continued to be offered, a major improvement here is not expected. When we continue to the '*Order picking – Clamp*', it can be stated that both the collecting (including moving) and the unloading/positioning of the goods for consolidation requires a similar amount of labour. As we mentioned in section 3.1.1, inefficiency occurs when more than 60% of the time is being spent on movements. The collection step includes the movement of the picker and although this percentage is almost 60%, picker to goods may remain more attractive for this particular pick process. This because within this 60% the actual pick-process is included as well, which is well spend-time. If we analyse the '*Inbound & Put away-Pallet'* time division we see that more than 40% of the time is spent on the storage of the goods. This is a large amount of time spent in the aisles, considering the fact that the order picker uses simultaneously the same paths. A situation that guarantees inefficiency. As with the inbound of the pallets, the storage step demands the most time during the '*Inbound Clamp'* activity. However, since the 60,1% of the storage time spending includes both movements and storing this itself step can still be considered efficient. Nevertheless, The aisle occupation with the view on the usage of the order picker has room for improvements.

Table 4-1. Detailed insight in time spent for most time consuming activities

Main process	Sub step	Number of observations	%
Dispatch Preparation	Consolidate	301	46,2%
	Prepare ship	203	31,2%
	Position Intern	103	15,8%
	Position Extern	44	6,8%
	Total	***651***	***100,0%***
Order picking - Clamp	Collect	275	59,9%
	Position unload	184	40,1%
	Total	***459***	***100,0%***
Inbound & Putaway - Pallet	Unload	46	15,6%
	Sort/prepare	84	28,6%
	Transport	43	14,6%
	Store	121	41,2%
	Total	***294***	***100,0%***
Inbound - Clamp	Unload	107	39,9%
	Transport/store	161	60,1%
	Total	***268***	***100,0%***
Order picking - Pallet	Collect	215	83,7%
	Position unload	42	16,3%
	Total	***257***	***100,0%***
Return process	Unload/provide	24	11,2%
	Check & Prepare	172	80,4%
	Store	18	8,4%
	Total	***214***	***100,0%***

Next, we arrive at the '*Order picking – Pallet*' activity. Something that immediately jumps out is the striking distribution between the two sub steps. The activity of collecting the pallet goods requires more than 80% of the time, which can be divided in moving and picking. Given the 60% rule there is a high chance inefficiency occurs. In the subsequent sections it is therefore interesting for us to consider and analyse alternative options. Lastly, we arrive at the '*Return Process'* activity. The most time-intensive step of this activity is the Check and Prepare step. Offering the return service is part of the service policy of ATAG and needs to be done extensively. Therefore it is difficult to reduce this activity.

The last result the VSM has yielded is insight in the obstacles and redundant steps. When redesigning the new warehouse, it is important that we keep these issues in mind to reduce them, or even better, to prevent them from occurring. In section 3.2.1 we presented a table that contains all the obstacles plotted against the main performance indicators. Now that we know the mission, success requirements and the related objectives, we can analyse and summarize the obstacle results from this point of view. This gives us the opportunity to identify the most important improvement points and to actively solve them in a way it complies with the mission, and eventually the vision, of the logistic department of ATAG.

Table 4-2. Summary of the results and its causes of the distribution process obstacles

Result	Cause	Violated KPI
Time Increase	- Inaccuracy - Unexpectedness	Productivity
Blocking time	- Waiting due to space limitations - No complete subsequent processes	Productivity
Incorrectness	- Manual/human interaction with the process - Incomplete information available - No fully automated control	Accuracy
Distance Increase	- Space limitations - Inaccuracy - Incomplete information available	Productivity & Accuracy
Double handling	- Space limitations	Productivity

In Table 4-2 we summarize the results of the obstacles and the causes that generated them. The KPI that is influenced by these results are displayed in the latest column. If we recall the KPIs that were presented in the former paragraph we can conclude that only two out of the seven KPIs are influenced by the obstacles within the logistic processes. This can be explained by the fact that the other KPIs are under control by other departments. Throughput is handled by Inventory Management, transport costs and transport density by Planning, and Return Items policies are set by General Management.

Now that the main result and causes are known, we can think about solutions for the new warehouse situation. The following actions can improve the situation:

1. Increase space/reduce space limitations: by increasing the work area processes can be executed more efficient, interruptions and waiting can be reduced which eventually increases the productivity.
2. Improve communication suppliers: by communicating on the condition of goods when receiving them, a better time estimation can be made and the required time will decrease.
3. Increase automated control: by improving the system control with the aid of automated checks, the human interaction error can be reduced and accuracy will improve.
4. Improve the processes flow: by connecting the several processes more thoroughly, miscommunication, and through this inefficiency, reduces, which increases the productivity.
5. Improve the processes information flow: by ensuring an integral data flow, errors are less likely to occur and this increases the accuracy tremendously.

The first action will be achieved by changing the location, i.e., the driving force behind the whole project. However, what should be kept in mind that a space enlargement influences the total distance to be travelled. We have to take this into consideration when selecting equipment and drawing layouts. The second action can be arranged by the department that is in charge for the supplier relationship management, the Inventory Management department. The third action we will give attention in the next section. The fourth and fifth action can be covered by transforming the VSM current states into the VSM future state, a process that requires input from all involved stakeholders.

With this, we have arrived at the end of the first part of step B. The second part of step B encompasses the activity profiling, during this step we will discuss the data results of the data mining executed in section 3.2.3.

Activity profiling

Given the results of the Value Stream Mapping, a focus for the activity profiling can be set. As we mentioned in the former section, the order picking process of pallet goods is the process that can use an additional item behaviour analysis. For the clamp a slightly smaller behavioural analysis is performed. Besides the order picking process is the inbound process also of interest, however this is on an item basis less to influence. The possibilities for improvement for the inbound process are more in the choice of equipment, which we will discuss in Step C - Selection of warehouse systems.

Now, it is time for us to visualize the results that we created with the data mining step in section 3.2.2 Activity profiling. First of all, we should observe the facts regarding the *order throughput at the logistic department* at ATAG.

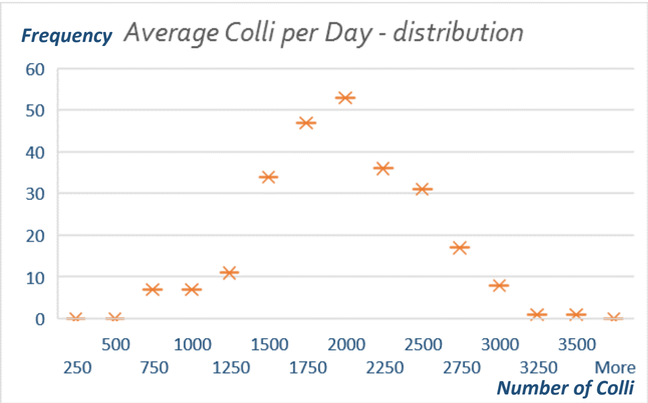


Figure 4-3. Distribution of frequency of the average number of Colli per day

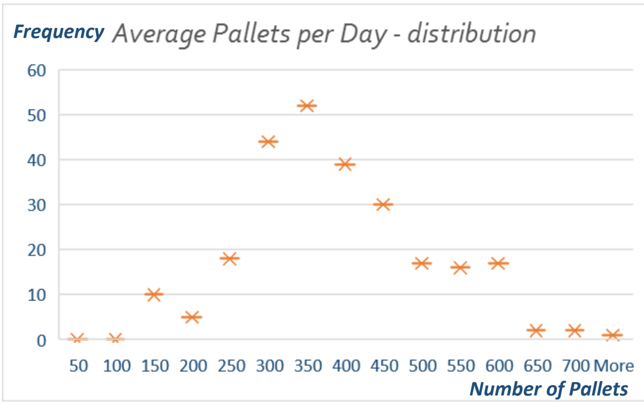


Figure 4-5. Distribution of the frequency of the average number of Pallets per day

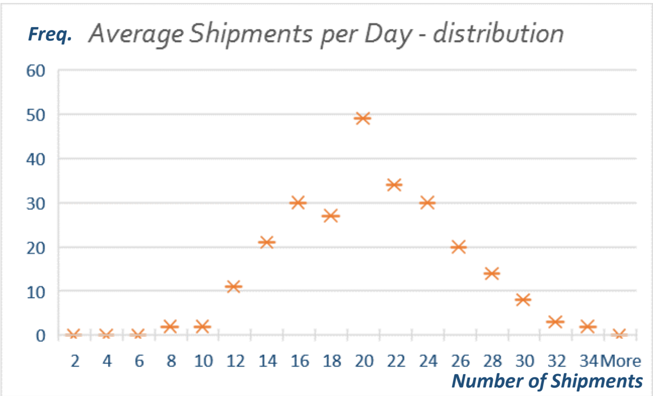


Figure 4-4. Distribution of the frequency of the average number of Shipments per day

In Figure 4-3 to Figure 4-5 we display the distribution of the average number of colli, pallets and shipments that is planned per day. In reality this number will be much higher, since there are some not planned shipments as well. However, as each of the figures show, approximately a normal distribution can be recognized. This data can be useful for a simulation study. By performing a statistical T-test the distribution can be confirmed. Below we summarize the data facts.

- Shipments: Mean: 20 Median: 20 Std. Dev[4]: 5
- Pallets: Mean: 362 Median: 349 Std. Dev: 117
- Colli: Mean: 1281 Median: 1571 Std. Dev: 957

[4] *Std. Dev:* standard deviation - the spread of the values below and above the mean of shipments, pallets or colli.

From this information, we continue to *the customer behaviour*. Figure 4-7 shows the distribution of the order frequency of client orders during an entire year. The distribution we can derive from this figure is approximately a negative exponential distribution, which can be validated with the aid of a Chi-Square test. Again, this data can be useful for a simulation study. Figure 4-6 shows the division of the order frequency of client order as a percentage.

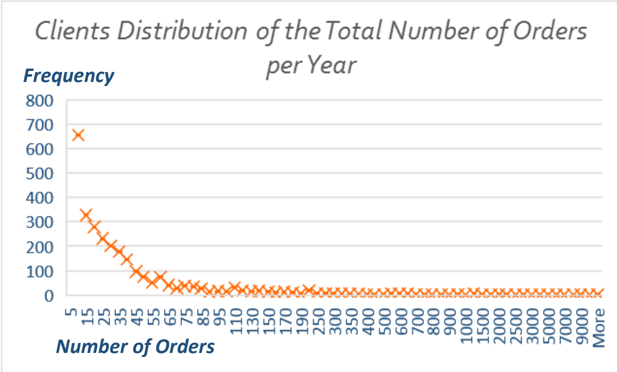
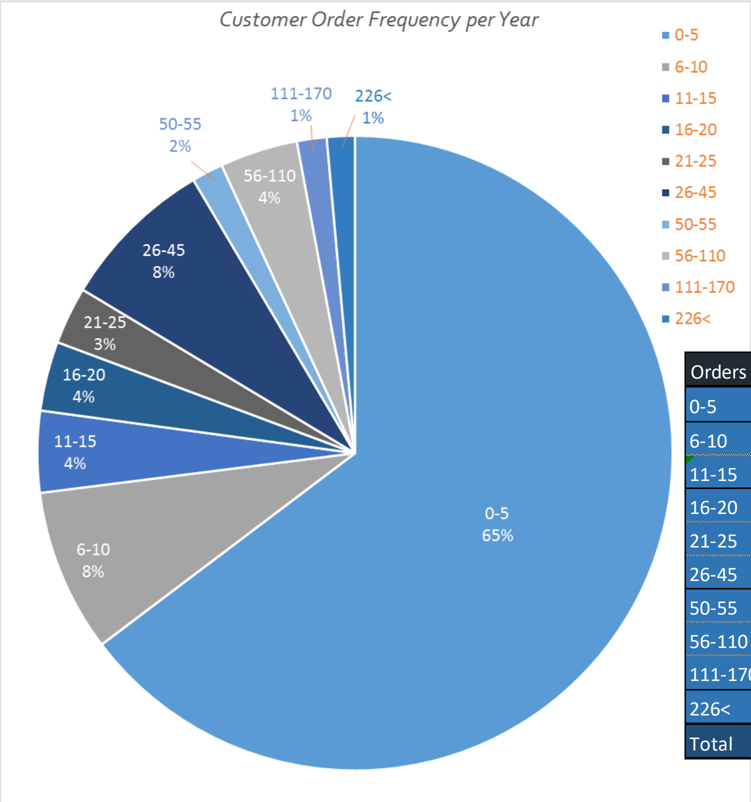


Figure 4-7. Distribution of the number of orders yearly placed by a client



Orders a year	Percentage		
0-5	65,0%	Few x per year	
6-10	8,3%	Per 1 or 2 months	12,5%
11-15	4,2%		
16-20	3,6%	Several x per months	14,4%
21-25	2,9%		
26-45	7,9%	Once per 2 weeks	
50-55	1,6%	Once per week	7,1%
56-110	4,0%	Twice per week	
111-170	1,5%	3 a 4 x per week	
226<	1,4%	Daily	
Total	100%		

Figure 4-6. Pie chart overview of the client order frequency per year (Legend: Orders a year – Percentage of clients).

If we analyse this frequency percentage, the following conclusion can be made. The vast majority, 65% of all clients, receives between the 0 and 5 shipments per year. Around 12,5% receives one- or two-monthly a shipment. 14,5% of the clients receive shipments several times per months and 7,1% several times per week. Only 1,4% of the clients receive shipments on a daily basis. Resulting from this data, an overall conclusion can be drawn. Since a large majority of the clients (over 90%) do not order weekly, merging shipments per customer is not a point where major improvements can be made (especially since this is already tried to pursued by the Planning department).

After we gained insight in the shipments from a handling point of view and a customer point of view, the actual composition of the shipments and thus the item behaviour is next. In the current situation, orders are picked for one specific shipment. This shipment is consolidated and prepared for dispatch and then a new shipment preparations is started. In the new warehouse more space will be available and therefore a different pick policy can be attractive if this reduces the pick time and the overall movement.

Let us first get some insight in the distribution of clamp and pallet goods within the shipments. By calculating the ratio of the clamp and pallet goods we can draw conclusions. This calculation can be approached in two ways. From an unique SKU point of view or from the total number of order lines point of view. In the first point of view the actual different SKUs are analysed. In the second point of view the order lines are analysed, within those order lines the same SKU can appear multiple times.

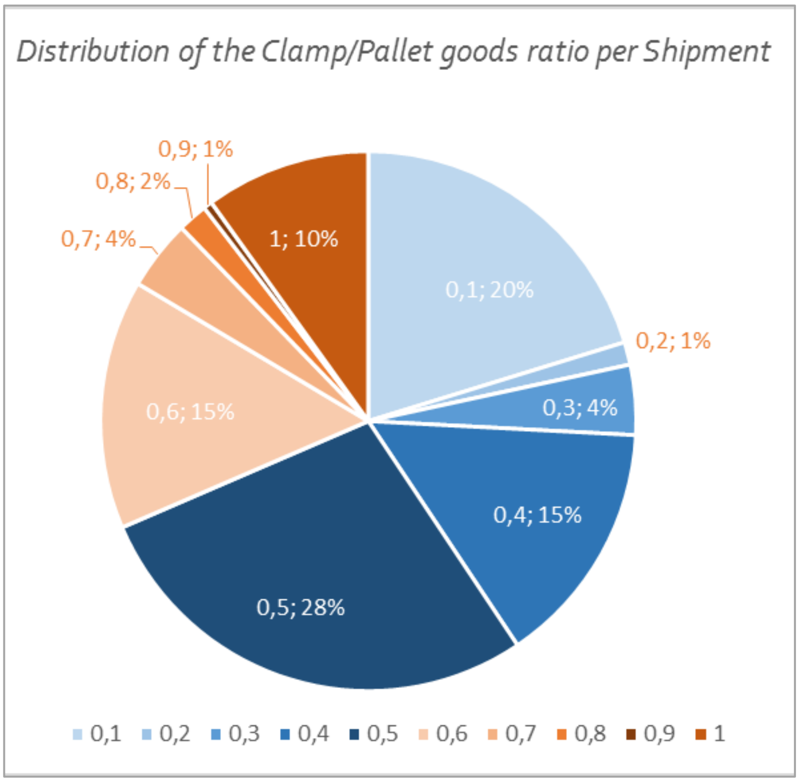


Figure 4-8. Pie chart overview of the average clamp/pallet goods ratio in each shipment based on unique SKUs
(Legend: Ratio - percentage of shipments with this ratio)

Figure 4-8 shows the average clamp/pallet ratio of the *unique SKUs* division within the shipments. The graph can be read as follows: The ratio's 0,1 to 1,0 indicate the division. Thus 0,1 indicates that 10% of the SKUs in a shipment are unique clamp goods and the other 90% are unique pallet goods. For example in 15% of all the shipments in 2016, there were 60% unique clamp SKUs and 40% unique pallet goods. Based on the figure we can state that:

- 40% of all shipments contained more unique pallet SKUs.
- 22% of all shipments contained more unique clamp SKUs.
- 28% of all shipments contained on average as much unique clamp as pallet SKUs.

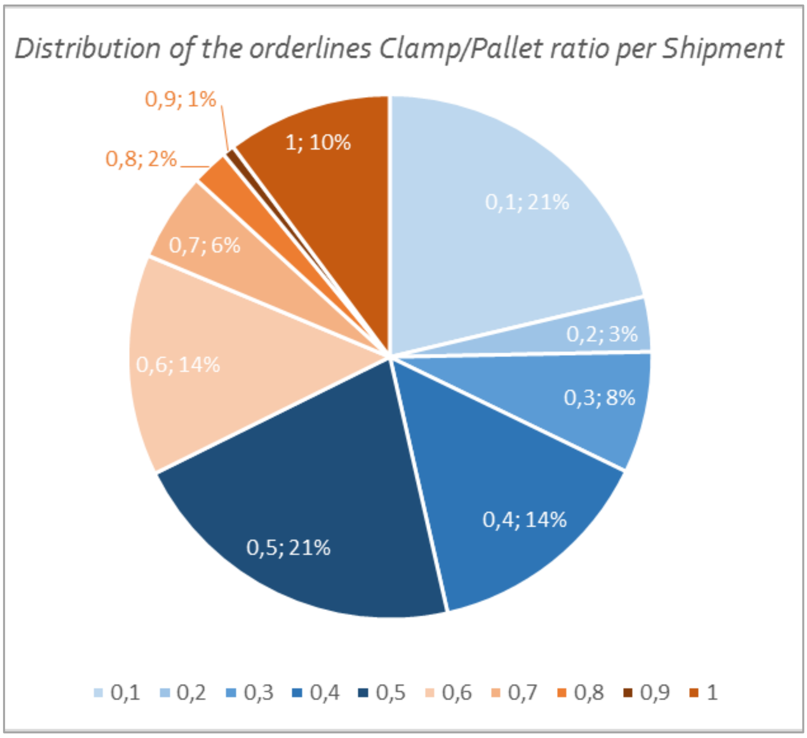


Figure 4-9. Pie chart overview of the average clamp/pallet goods ratio in each shipment based on order lines
(Legend: Ratio - percentage of shipments with this ratio)

Figure 4-9 shows the ratio of the average clamp/pallet of the *order lines* division within the shipments. The graph can be read in the same way as in Figure 4-8 where the ratio indicates the division clamp/pallet goods. For example in 21% of the shipments 10% of the order lines were clamp goods and the other 90% of order lines were pallet goods.

Based on the figure we can state that:

- 46% of all shipments contained more pallet goods order lines.
- 33% of all shipments contained more clamp goods order lines.
- 21% of all shipments contained as much clamp as pallet order lines.

Now that we gained insight in the shipments distribution, we dive a bit further into these shipments by analysing the pallet goods behaviour and the clamp goods behaviour separately.

First of all, we approach the *order data from the shipment point of view*, by taking a look at the unique average number of pallet order lines per shipment. Each shipment consist of a number of client orders. Each order includes a number of order lines and this order line contains one specific item (see 3.2.2 for the detailed overview). By analysing the average number of pallet order lines per shipment, we gain insight in the average variation of pallet SKUs within a particular shipment.

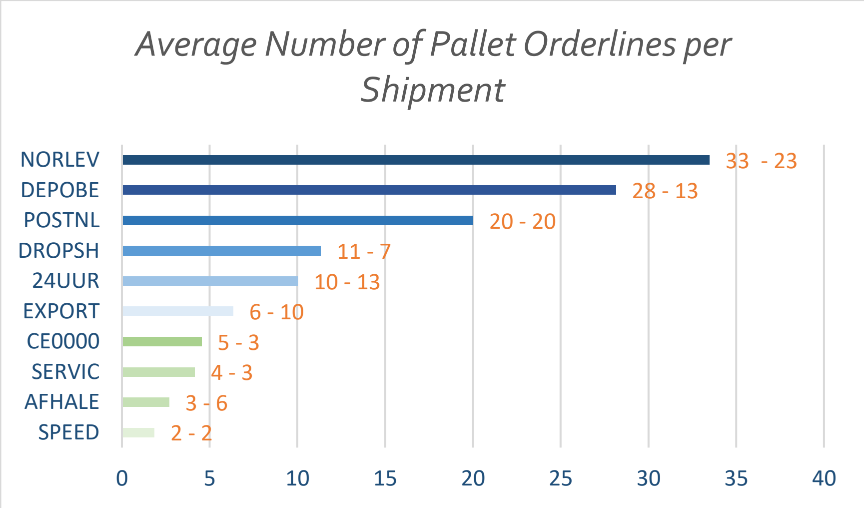


Figure 4-10. The average number of order lines per Shipment per Shipment type (Legend: Mean – standard deviation)

Ten different types of shipments can be distinguished at ATAG. In Figure 4-10 we present the average number of order lines with the related standard deviation. The average number indicates that if each customer within the shipment orders something different this are the number of follow ups to prepare a shipment.

Secondly, we approach *the order data from the SKU point of view* by examining the average number of shipments a certain pallet SKU appears in per day. Figure 4-11 displays the distribution of this data. What we can conclude from this figure is: Almost halve of the times an item is needed on a specific day, only one shipment demands this SKU. However, the opposite of that is that more than halve of the time at least two shipments request the same pallet SKU during a day. Determining this a bit further, the following division can be distinguished: nearly a quarter of the total requests, two shipments needed the same item. 12% of the requests were divided among 3 shipments, 7% among 4 shipments and even 10% of the requests were distributed among 6 to 9 different shipments on a day.

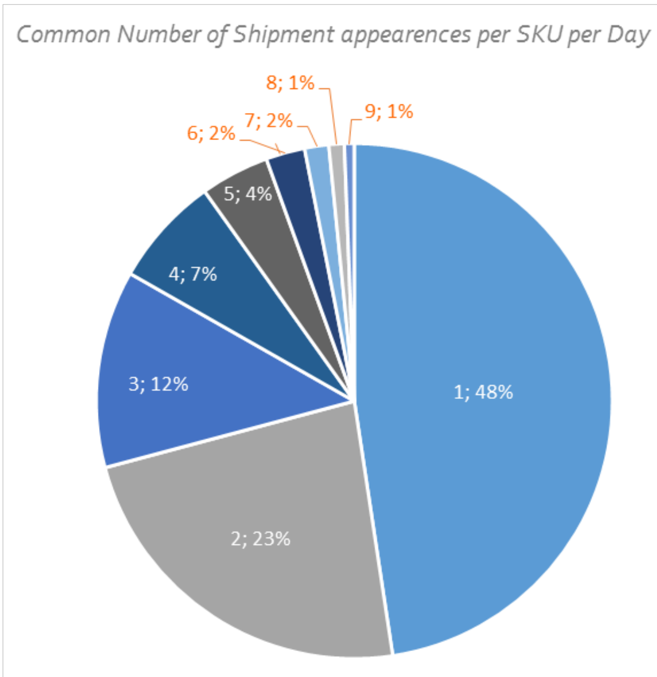


Figure 4-11. Pie chart overview of the number of Shipments per day a pallet SKU appears in (Legend: Number of shipments appearance; percentage of SKUs)

Besides the pallet SKUs we analysed the clamp goods from a shipment and SKU point of view as well.

As for the pallets goods we display in Figure 4-10, we present in Figure 4-12 the average number of order lines with the related standard deviation for the clamp goods. The average number indicates that if each customer within the shipment orders something different this are the number of follow ups to prepare a shipment.

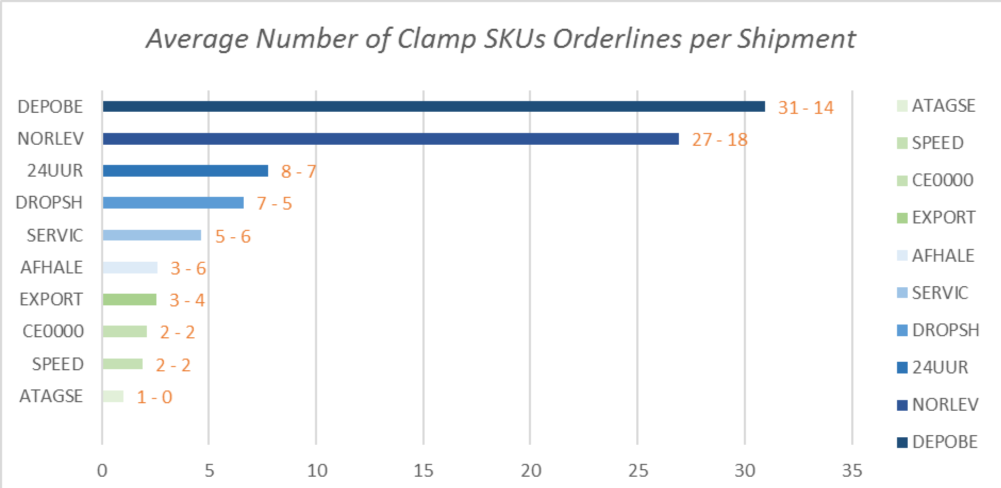


Figure 4-12. The average number of clamp order lines per Shipment per Shipment Type (Legend: Mean - standard deviation)

Figure 4-13 displays the average number of shipments a certain clamp SKU appears in per day. The conclusions we can draw from this figure are:

When an item is needed on a specific day, a bit more than 40% of the time only one shipment demands this SKU. This means that almost 60% of the time more than 1 shipment requires a specific SKU. In 23% two shipments, in 13% three shipments, in 8% four shipments needed the same SKU on the same day. The other 14% of the requests were divided among 5 to 10 different shipments on a day.

Now that we discovered the fact that on average there exist overlap among the shipments on a day, we dive deeper into the details of this phenomenon for the pallet goods.

By analysing the detailed data we hope to find a synergy that can support improvements in the order of the picking process on the long term.

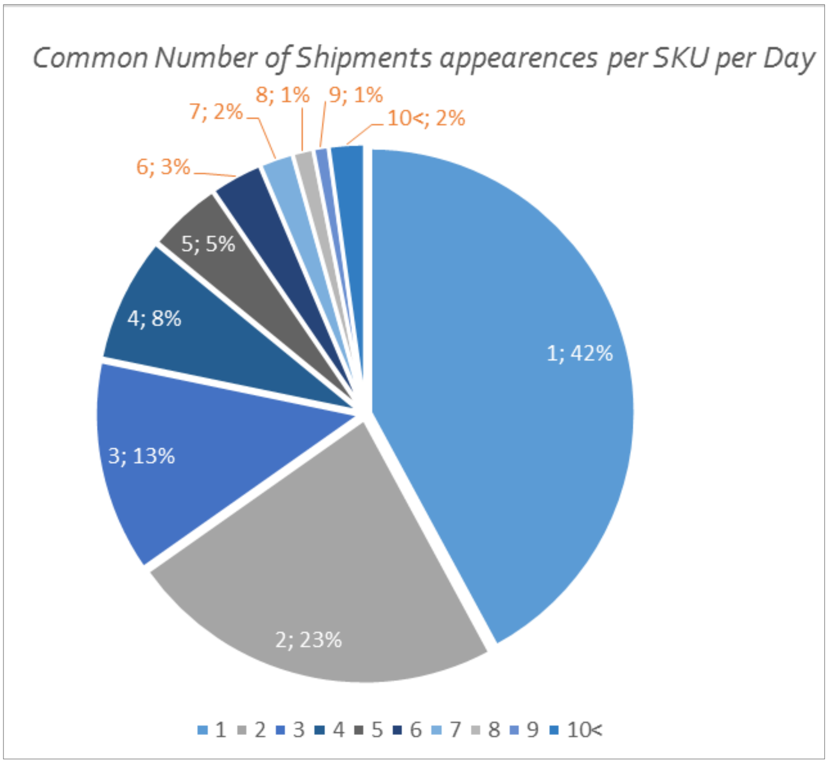


Figure 4-13. Pie chart overview of the number of Shipments per day a clamp SKU appears in (Legend: Number of shipments appearance; percentage of SKUs)

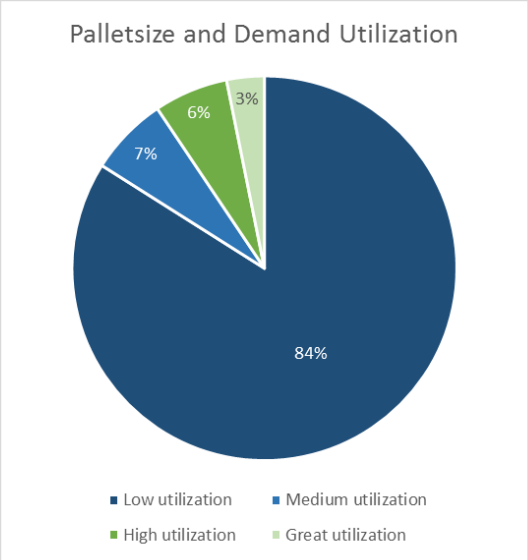


Figure 4-14. Pie chart overview of the pallet and demand utilization

Instead of picking per shipment, picking per SKU might be beneficial. Especially when the numbers of the required pallet SKU per day comprise more than halve of a pallet or, even better, full pallets. By comparing the number of stored SKU items on a pallet with the number of SKU items demanded by multiple shipments on a day, we can determine the pallet-demand utilization (see Figure 4-14).

In 84% of the item requests less than half of a pallet is needed on a day. In the other 16% more than half of the pallet is needed. The division of this percentage is: in 7% of the cases a half to a full pallet is needed, in 6% more than 1 pallet is needed and in 3% of the cases more than two pallets are needed that day.

When this 9% of one or more full pallets is collected in once, less empty pallets are left on the shelves and that results in more efficient operations. Since empty pallets in the racks have to be collected during the day and this time can be used for other activities.

Third and last, we approach *the order data from the location point of view* by reviewing the number of pick rounds per aisle. Figure 4-15 displays each of the pallet aisles (BA-CH) with the average number of pick rounds, the average number of unique SKUs picked within that aisle during a day, and the average number of picks per unique SKU. From this data, we can draw a number of conclusions. Comparing the average number of picks (dark blue bar) and the average number of unique SKUs picked (light blue bar) we can conclude that in general an aisle is visit more often than the number of SKUs that there are SKUs picked that day. This means that during a day an aisle is visit multiple times for the same SKUs. A finding that is emphasized by the average number of picks per SKU (orange line), which is for every aisle above one. This results in a distance increase, an inefficiency that eventually will violate the productivity, which can be reduced by combining shipments. Besides, we analyse the

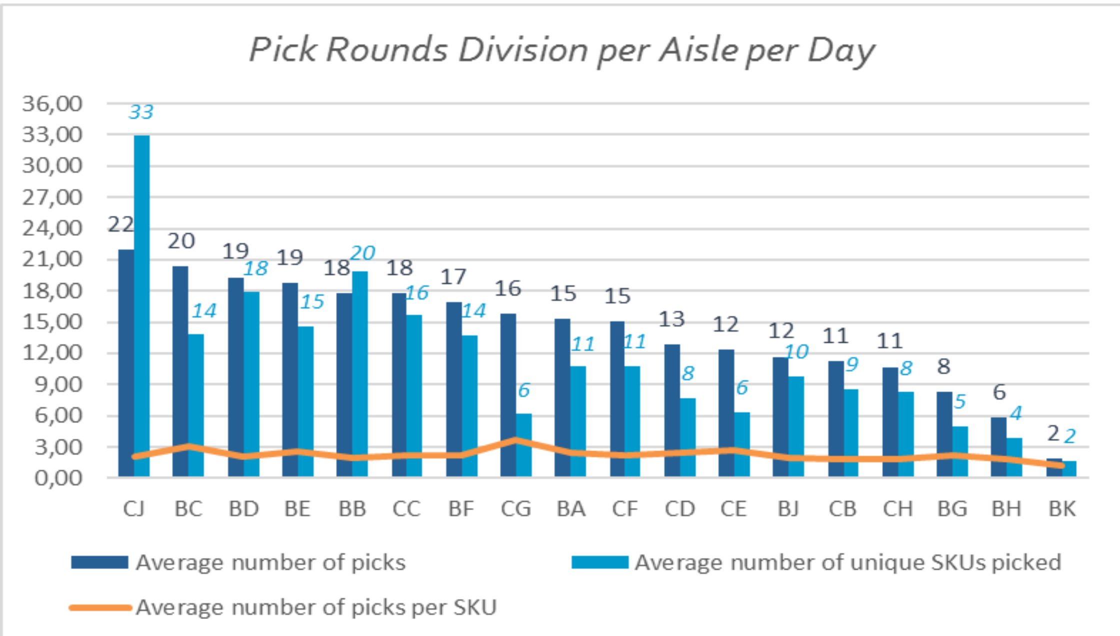


Figure 4-15. Bar chart overview of the average number of pick rounds per aisle per day (Dark Blue bar)
The average number of unique SKUs picked per aisle per day (Light Blue bar)
The average number of picks per SKU per day (Orange line)

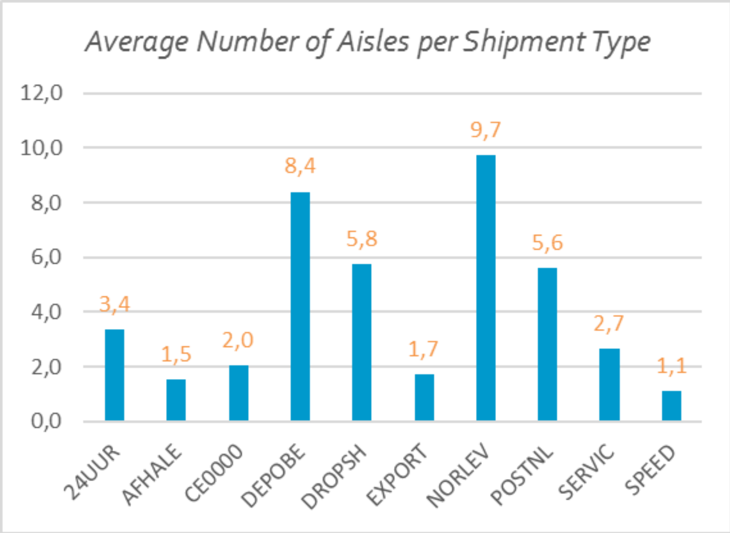


Figure 4-16. Bar chart overview of the average number of aisles visited per shipment pick per shipment type.

average number of aisles that have to be visit for a particular shipment (Figure 4-16). From this data we can see that for the normal delivery shipments more than half of all the 18 aisles are used during a day. One note to be stated here: the number of visits per aisle is an approximation, since the full pallet pick and heavy pallet pick is executed on top of the 'normal pallet pick rounds'. Therefore the real visit number of the aisles will be a bit higher.

Conclusion

Now that we have discussed all the results that the activity profiling has brought us, we have arrived at the end of step B and is it time to start with step C. During this step a potential warehouse system will be selected with the aid of several sub steps. In the next section each of these sub steps will be explained.

4.1.3 Step C - Selection of warehouse systems

If we follow the NIWD-framework (Section 2.7 Figure 2-16), various input values are required to enable the execution of the sub paths and steps of step C. We can extract these input factors from the information we collected and created in step A and B. Below we discuss the sub paths and sub steps.

Decision tree - Requirements

The first process sub step path is '*technical capabilities'* path. Within this path several sub-steps have to be executed. The first sub-step is the application of the decision tree to select a certain storage type to narrow the MHE possibilities. To be able to apply the decision tree a *requirement list* is needed. As mentioned in 2.4.3, there are seven requirement groups that support the drafting process of this list. By combining this with the attributes of Appendix A2.5 we created Table 4-3. Since we have two type of unit loads within the product family 'finished goods' (see section 3.3.1 Transportation unit), we distinguish the requirement list for the light-medium weighted items and the heavy weighted items.

If we prioritize the requirements we find that the order of importance from high priority to lower priority can be determined as follow: Since the main purpose is the handling of items, the first priority is that the transaction characteristic requirements must be met. Then, the surrounding still can be adjusted a bit and therefore the movement requirements could possibly be adjusted, however this is not desirable and therefore we sets this requirement group on the second importance place. Once the equipment can handle the unit loads and is able to move within certain conditions, the productivity becomes important. This brings us to the third group, the equipment and maintenance characteristics. Then as fourth, the extent of automation is important, a characteristic included by the system form. From this point the amount of human interaction can be distracted, a requirement arising from the operation form. At last in the priority order, the system characteristic of the entire network is included.

Table 4-3. Overview of the MHE characteristics and requirements based on the requirement groups and attributes (A2.5)

Requirement group	Light – medium weighted	Heavy weighted items
Transaction characteristics	- Type: Pallet - Shape: Rectangle, Horizontal elongated, Squares - regular - Weight: 0,1 – 49,0 KG - Volume: 0,001 - 1,642 m^3 small -medium - Quantity: items on eu-pallet – med/high - Height: 10 mm – 1140 mm short – medium - Length: 100 – 1600 mm short – medium – high - Bottom surface: rigid, flat - Nature: compact, robust - Storage properties: stackable	- Type: individual - Shape: Blocks, Vertical elongated, Squares - regular - Weight: 20 – 209 KG - Volume: 0,168 – 3,199 m^3 Medium-high - Quantity: single unit - low - Height: 240 mm – 2000 mm medium – high - Length: 360 mm – 1900 mm short – medium - high - Bottom surface: rigid & flat - Nature: compact, robust, block - Storage properties: stackable
Movement characteristics	- Aisle length: long - Aisle width: small - Available height: high - Automation Level: semi/automatic - Coverage area: confined to variable/fixed - Cross traffic: absent/present - Direction: horizontal and vertical - Distance: short - medium - Flow: controlled - Frequency: continuous - Interface equipment: manual/programmable - Location: Indoor - Management mode: FIFO required - Output: high - Path: Straight	- Aisle length: short - Aisle width: small - Available height: medium - Automation Level: semi/automatic - Coverage area: variable - Cross traffic: present - Direction: horizontal and vertical - Distance: medium - long - Flow: controlled - Frequency: continuous - Interface equipment: manual - Location: Indoor - Management mode: FIFO desirable - Output: high - Path: straight
Equipment characteristics and maintenance	- Down time: low (conform success requirement - flexible delivering hours) - Equipment battery: high - Equipment compatibility: yes - Lifting/(un)loading speed: medium - high - Movement speed: high - Operation costs: uniform - Product protection: yes - Transport method: carry	
System form	Automated & manual combined	
Operation form	- Push & Pull - Low human interaction desired	- Push & Pull - Low human interaction required (ergonomics)
System characteristic	Upgradability required	Upgradability required

Now that the requirements are drawn up, we can apply the *decision tree* (Figure 4-18 pink circles). Based on this figure we can conclude that the Pallet Rack method, AS/RS system or Very Narrow Aisle system are the best fitting storage systems for the ATAG assortment. However, the heavy weighted items are mostly received as a single item without a pallet. And although the volume does not meet the requirements one-to-one, we would like to add a fourth potential storage system: Block stacking. Based on this four storage methods the selection of handling equipment can be facilitated.

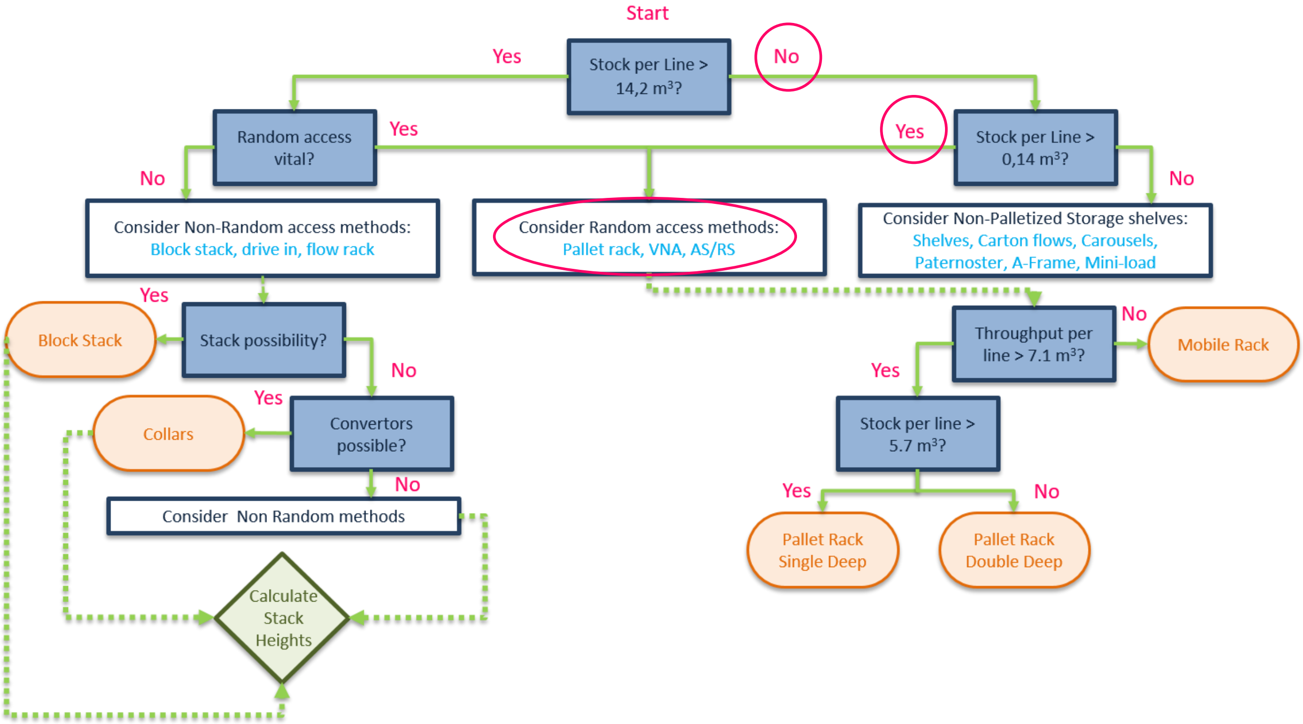


Figure 4-18. Decision tree applied on ATAG Benelux BV

Objective tree - objectives

Now that the requirements are known, we can concretize these by determining the objectives. The objectives will serve as an input factor for the second sub step of the technical path, which is '*Drawing the objective tree*'. The objectives are an extension of the guiding principles we appointed in step A

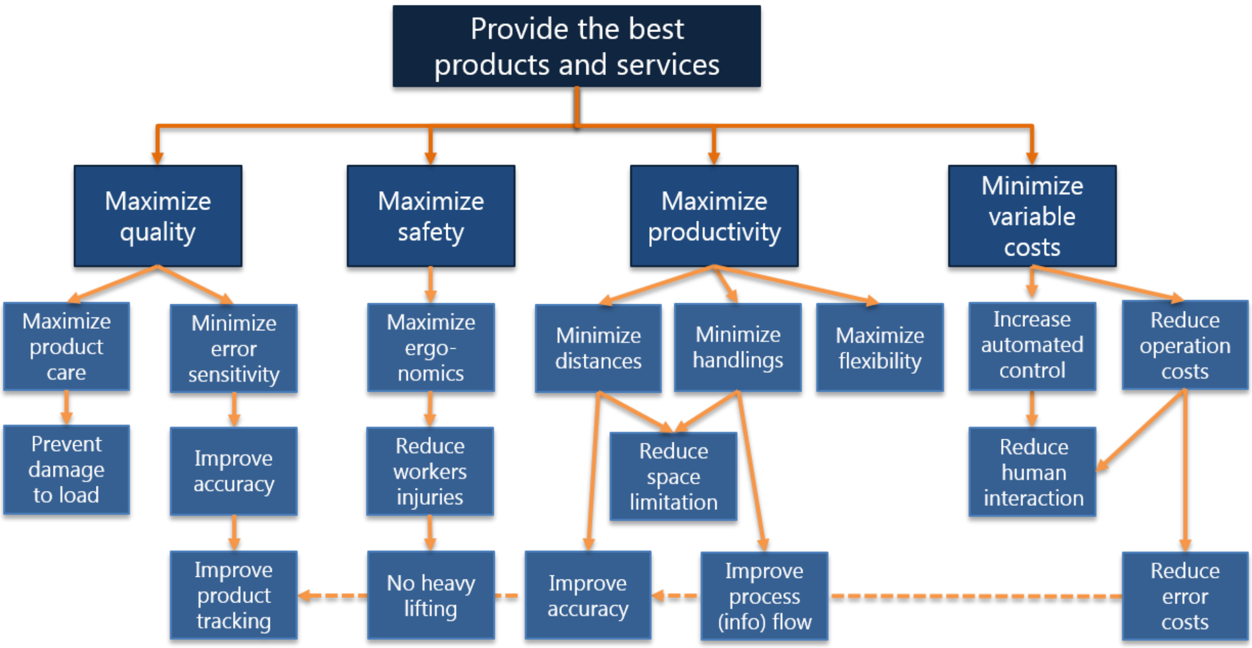


Figure 4-17. Objective Tree with the objectives and sub-objectives for the MHE

and the solutions we determined for the obstacles in Step B. Summarizing the main objectives we find: *maximize quality*, *maximize safety*, *maximize productivity* and *minimize variable cost*. These objectives with their related sub-objectives are displayed in the objective tree in Figure 4-17. The first two levels of the objective tree are objectives of the facility and the lower tree levels are the objectives of the MHE.

Performance indicators

The third data source in step C contains the performance indicators for the logistic department. We have mentioned these during step A. Recalling these we find: *Throughput*, *productivity*, *space utilization, accuracy, transport costs, transport density* and *return and return types*. The exact values of these indicators have to be determined in the future tactical phase during Step F – Organizational issues. A step not covered during this research project (see section 2.6).

Function diagram - functions

For the third sub step of the technical capabilities path, '*Draw the function diagram*', a fourth data source is required: an overview of the different functions. This function diagram can be drafted based on the VSM and the high level overview of the main processes we drew in Chapter 3. For the function diagram (Figure 4-19) a simplified version of Figure 3-2 'the main process overview for the distribution warehouse' is used. The dotted boxes represent the different input streams, the white rounded rectangles presents the main functions, whereas the blue coloured rectangles show the functional decomposition per function.

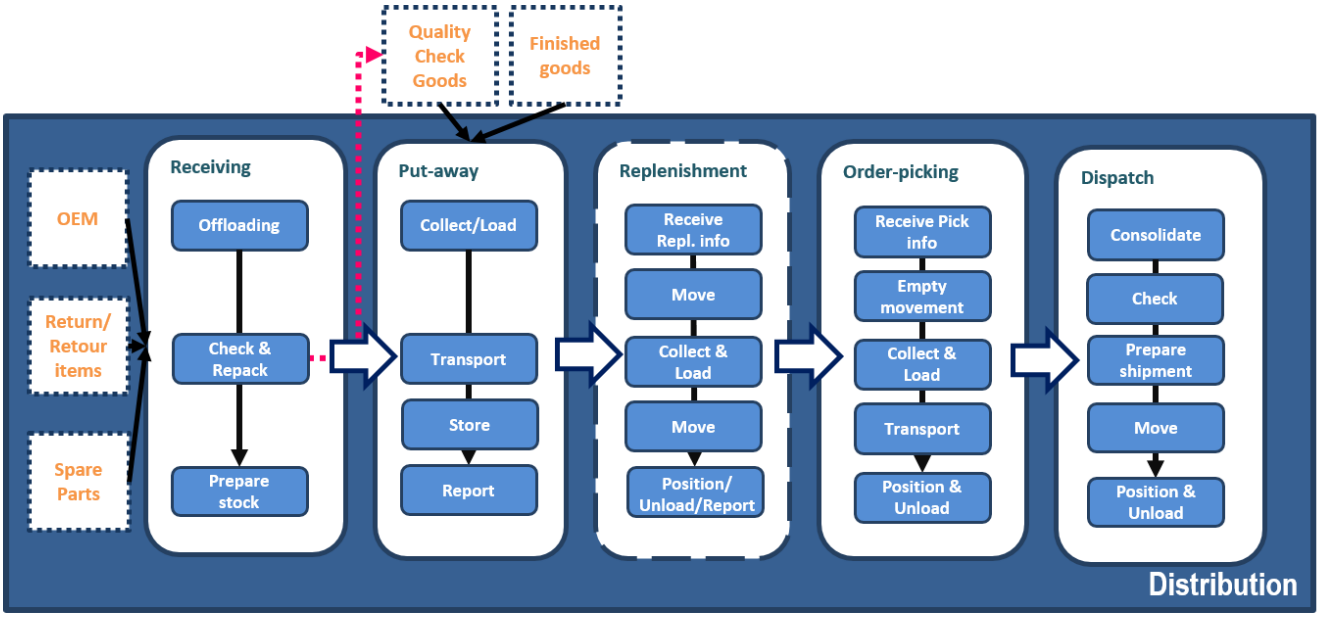


Figure 4-19. Function diagram showing the major functions for the MHE

System selection table

As a result of the decision tree, the objective tree and the function diagram, we can select a couple of systems for the economic consideration. By combining the functions with the potential storage methods and the objectives, a *'System selection table'* can be compiled that show the various options for the MHE systems per function. As input for the MHE classes we used Appendix A2.4. Interesting categories within this appendix are: Pallet trucks, Automated guided vehicles, Lifting devices, Continuous material handling and Self-propelling trucks.

Table 4-4.System selection table for the MHE classes selection

Function & sub functions	Candidate classes: *heavy items*	Candidate classes: *light/medium items*	Actual select classes: *Heavy*	Actual select classes: *Light/med*	Requirements and objectives: *Heavy*	Requirements and objectives: *Light/Med*
1. Receiving *I. Offloading* *II. Check & repack* *III. Prepare stock*	I. Clamp truck (Clamp)/Pallet Jack (PJ)/Platform truck (PT) II. Clamp/portable lift device + AutoIdentification/paper III. Labour + AutoID/Paper	I. PJ/PT II. Labour/Portable lift device + RFID/barcode III. Labour (L) + AutoID	I. Clamp II. Clamp III. L+AutoID	I. PJ II. Labour III. L+AutoID	I. Min handlings (Quantity capacity) II. Max ergonomics (No heavy lifting) III. Min error sensitivity	I. Max ergonomics II. Max flexibility III. Min error sensitivity
2. Put-away *I. Collect/load* *II. Transport* *III. Store* *IV. Report*	I. Clamp/PJ II. Clamp/PJ/Conveyor III. Clamp/Power lift truck (PLT)/AVG IV. Paper/AutoID	I. PJ/PT II. PJ/Conveyor III. PLT/AVG IV. Paper/AutoID	I. Clamp/PJ II. Clamp/PJ III. Clamp/PLT/ AVG IV. AutoID	I. PJ II. PJ III. PLT/AVG IV. AutoID	I. Max ergonomics II. Min handlings + min distance III. *Requires business case* IV. Min error sensitivity	I. Max ergonomics II. Max flexibility III. *Requires business case* IV. Min error sensitivity
3. Replenish/Compress *I. Receive info* *II. Move III. Collect & Load* *IV. Transport* *V. Position & unload*	I. AutoID scanner/AGV computer II. – V. Clamp/PLT/AVG	I. AutoID scanner/AGV computer II. – V. PLT/AVG	I. AutoID scanner II.-V. Clamp/AVG/PLT	I. AutoID scanner/AGV computer II.-V. PLT/AVG	I. *Former choice based* II.-V. *Requires business case*	I. *Requires business case* II.-IV. *Requires business case*
4. Order-picking *I. Receive info* *II. Move* *III. Collect & load* *IV. Transport* *V. Position & Unload*	I. AutoID scanner/AGV computer II. – III. Clamp/PLT/AVG IV. Clamp/PLT/AVG/Conveyor V. Clamp/Labour/portable lift device	I. AutoID scanner/AGV computer II. – III. PLT/AVG IV. PLT/AVG/Conveyor/PJ V. Labour/portable lift device	I. AutoID scanner II. –III. Clamp/PLT/AVG IV. Conveyor V. Clamp	I. AGV computer/ AutoID scanner II.-III. AGV/PLT IV. Conveyor V. Labour	I. *Former choice based* II.-III. Max ergonomics IV. Prevent damage to load (min # of clamp handlings) + min distance V. Max ergo + flexibility	I. *Requires business case* II-III. *Requires business case* IV. Min distance for labour V. Max flexibility
5. Dispatch *I. Consolidate & Check* *II. Move* *III. Prepare shipment* *IV. Position & Unload*	I. Labour + AutoID/Paper II. PJ/PT III. Labour/Plasticizer IV. PJ/PT		I. L+A-ID II. PJ III. Labour/Plasticizer IV. PJ		I. Min error sensitivity II. Max ergonomics III. Max ergonomics + increase automated control IV. Max ergonomics	

In Table 4-4, the first column represents the functions and sub-functions. For each of these functions candidate system classes are listed in column 2 and column 3. In column 4 and 5 the best classes' options are selected based on the requirements and objectives presented in column 6 and 7.

Warehouse system alternatives

Now that we have established the system selection table, the end of the '*technical capabilities*' path is almost there. The last thing we have to do, before the '*Economic consideration*' path start, is to specify the various system options. Below each of the possible systems, the potential combinations of storage equipment (SE) and material handling equipment (MHE), is listed. For each system a description, the required MHE, the benefits and drawbacks are discussed. With the aid of the decision tree (Figure 4-18) we found that Standard Aisle Pallet Racking (SPR), Very Narrow Aisle Pallet Racking (VNAR), AS/RS and Block Stacking are fitting storage options. As we discovered in section 3.3.2, based on the several criteria, is the VNAR method a better racking option than the SPR method. Therefore is the SPR method is left out of consideration. The systems are in order from least to most benefits.

1. 'Very Narrow Aisle Pallet Racking' for Light/Medium items + 'Block Stacking' for Heavy items.

a. Description:

The first option is to store the light/medium items with the VNAR method and the heavy items with Block Stacking, which is the current work situation (Figure 4-20). After the items are checked the light/medium items are placed in the racks while the heavy items are stacked. Both item types are picked and brought by the picking truck to the consolidation area. Labour consolidates the pallets for dispatch. Accuracy is important and an adequate system is required.

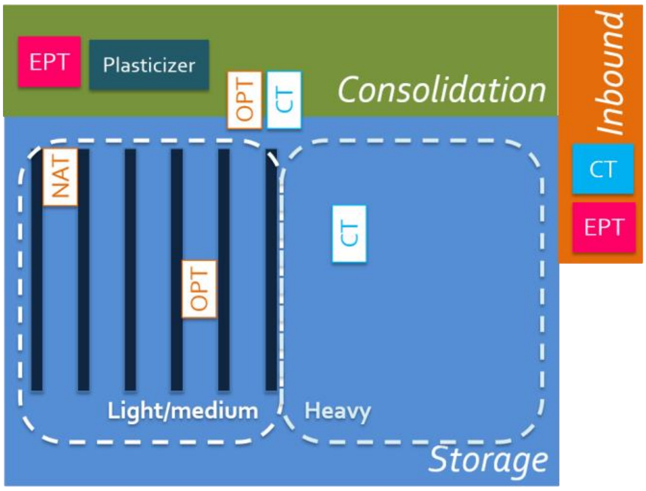


Figure 4-20. Warehouse system option 1: VNAR + BS

b. Required MHE:

Power lift truck – Clamp truck (CT)	Unload truck with heavy items, store items in the block stack area, pick items in block stack area, transport to consolidation, compress.
Pallet jack - Electric Pallet truck (EPT)	Unload light/medium items, transport light/medium items on pallets to storage, transport items to and from the plasticizer.
Power lift truck – Narrow Aisle truck (NAT)	Store the light/medium items on pallets in the racks, pick heavy item pallets or full light/medium pallets, replenishment.
Power lift truck – Order picker truck (OPT)	Pick light/medium items, transport to consolidation area.
AutoIdentification – RFID/Bar code scan	Store and rewrite data at the spot.

c. Benefits:

- Maximize flexibility: the equipment is very flexible + movement in variable directions is possible. Besides, human interaction is high, increases flexibility even more.
- Maximize ergonomics: by using different type of trucks heavy lifting is unnecessary.
- Minimize error sensitivity: RFID is very accurate and improves store and pick accuracy.
- Minimize space usage: both the VNAR + Block stacking increase the space utilization.

d. Drawbacks:

- Product care not maximized: clamping increases the damage risk.
- Distances not minimized: labour is part of all the distances to be travelled.
- High human interaction: increases the error sensitivity.
- Mostly FIFO mix: VNAR enables FIFO, BS delivers in FIFO per batch but LIFO per lane.

2. 'Very Narrow Aisle Pallet Racking' for Light/Medium items and Heavy items.

a. Description

The second option is to store every item, both light/medium as heavy items, with the VNAR method. Each of the light/medium items arrive on a pallet, but the heavy items have to be placed on a pallet. Once everything is on pallets the items can be stored in the rack. Within the storage section distinguishes between a heavy item section and a medium/light section is required for the pick equipment. To pick heavy items the whole pallet has to be collected. For the light/medium items an order picker satisfies. (Figure 4-21). When the items are picked they are transported with the aid of a conveyor to the consolidation area to reduce the distances for labour. The conveyor is now applicable since every item is stored on a pallet. There, a clamp truck places the heavy items on the right pallet for consolidation and labour places the light/medium weighted items on top. Since every item is placed in the racks, accuracy is more important and thus a highly accurate data system.

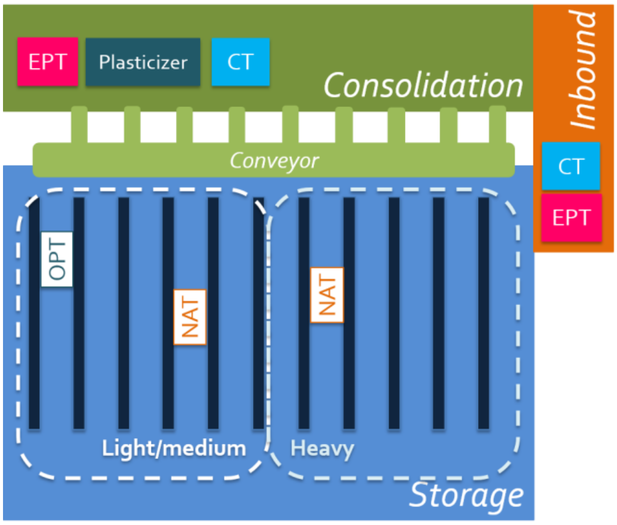


Figure 4-21. Warehouse System option 2: VNAR

b. Required MHE:

Power lift truck – Clamp truck (CT)	Unload truck with heavy items, place heavy items on pallets inbound, place heavy items on pallets outbound.
Pallet jack - Electric Pallet Truck (EPT)	Unload light/medium items, transport light/medium items on pallets to storage, transport items to and from the plasticizer.
Power lift truck – Narrow Aisle truck (NAT)	Store pallets in the racks, pick heavy item pallets or full light/medium pallets, replenish.
Power lift truck – Order picker truck (OPT)	Pick light/medium items.
Conveyor – Sort conveyor	Transport and sorts pallets from storage to consolidation area.
AutoIdentification – RFID	Store and rewrite data at the spot.

c. Benefits:

- Maximize product care: clamping reduced to a minimum (clamp = damage risk).
- Minimize error sensitivity: RFID is very accurate and improves store and pick accuracy.
- Minimize distances for labour: conveyors cover the long distances.
- Maximize ergonomics: by using different type of trucks heavy lifting is unnecessary.
- FIFO: possible for the entire system.

d. Drawbacks:

- Space is not minimized: stacking is a more space efficient method than racking.
- Higher variable costs than option 1: RFID is required for the entire system, which is an expensive AutoID system.
- Medium human interaction: system is sensitive for violation by human interaction.
- Handlings not minimized: every heavy item has to be placed on a pallet and the capacity of picking heavy items is reduced. Same amount of items require more handlings.

3. ‘AS/RS’ for Light/Medium items and Heavy items.

a. Description

The third option is to store every item, both light/medium as heavy items, with the AS/RS method. As with option 3, each of the light/medium items arrive on a pallet, but the heavy items have to be placed on a pallet. Once everything is on pallets the items can be stored in the rack with the aid of AGVs. To pick items the whole pallet has to be collected by the AGV. This brings the pallet to a sort area and here the items are sorted and dropped on a conveyor towards the consolidation area. Here the right combination of items is accomplished, a clamp truck places the heavy items on the pallet for consolidation and labour places the light/medium weighted items. Since every item is placed in the racks, accuracy is very important since distinguishes between heavy and light/medium items is not necessary anymore. Therefore a highly accurate data system is required.

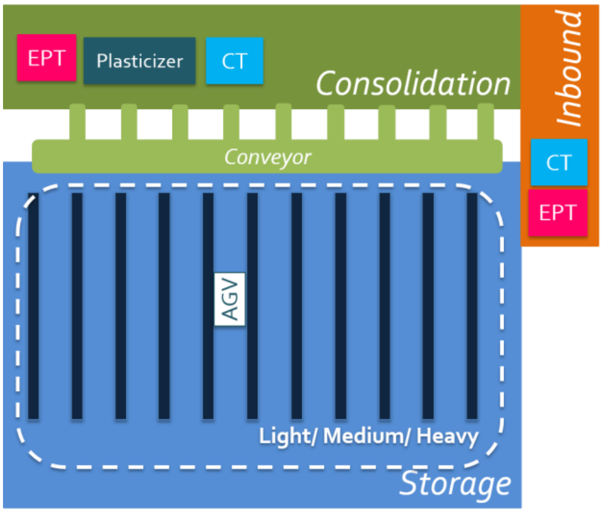


Figure 4-22. Warehouse System option 3: ASRS

b. Required MHE:

Power lift truck – Clamp truck (CT)	Unload truck with heavy items, place heavy items on pallets inbound, place heavy items on pallets outbound.
Pallet jack - Electric Pallet truck (EPT)	Unload light/medium items, transport items on pallets to storage, transport items to and from the plasticizer.
Automated guided Vehicle – Heavy Load AGVs	Store the pallets in the racks, pick pallets, replenish.
Conveyor – Sort conveyor	Transport and sort pallets from storage to consolidation area.
AutoIdentification – RFID	Store and rewrite data at the spot.

c. Benefits:

- Maximize product care: clamping reduced to a minimum (clamp = damage risk).
- Minimize error sensitivity: RFID is very accurate and improves store and pick accuracy.
- Minimize distances for labour: AGVs and conveyors cover the long distances.
- Maximize ergonomics: by using different type of trucks and AGVs lifting is reduced to an absolute minimum.
- FIFO: possible for the entire system.
- Increase automated control: human interaction for storing and picking items is reduced, increase in accuracy.
- Minimize variable costs: Labour is concentrated on the activities that require the labour flexibility, unnecessary movements and handlings by labour are reduced.

d. Drawbacks:

- Medium flexibility: although the variability in the movement is reduced, the activities that require flexibility remain (consolidation).
- Space is not minimized: stacking is a more space efficient method than racking.
- Handlings not minimized: every heavy item has to be placed on a pallet and the capacity of picking heavy items is reduced. Same amount of heavy items require more handlings.

4. ‘AS/RS’ for Light/Medium items + ‘Block Stacking’ for Heavy items.

a. Description:

The last option is to store the light/medium items with the AS/RS method and the heavy items with Block Stacking. After the items are checked the light/medium items are placed in the racks with the aid of AGVs while the heavy items are stacked with clamp trucks. The light/medium items are picked by the AGVs and brought to the sorting area and the heavy items are picked by the clamp truck. The light/medium items are placed on the conveyor and for the heavy items the choice can be made to use the conveyor or to bring the items to the consolidation area. The combination of a clamp truck with labour enables consolidation of the pallets for dispatch. Accuracy is important and an adequate system is required.

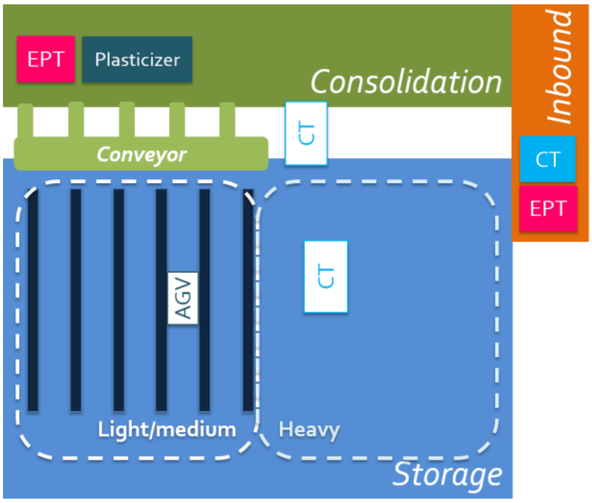


Figure 4-23. Warehouse System option 4: ASRS + BS

b. Required MHE:

Power lift truck – Clamp truck (CT)	Unload truck with heavy items, store items in the block stack area, pick items in block stack area, transport to consolidation area, compress.
Pallet jack - Electric Pallet truck (EPT)	Unload light/medium items, transport light/medium items on pallets to storage, transport items to and from the plasticizer.
Automated guided Vehicle – Heavy Load AGVs	Store the pallets in the racks, pick pallets, replenish.
Conveyor – Sort conveyor	Transport light/medium items from storage to consolidation.
AutoIdentification – RFID	Store and rewrite data at the spot.

c. Benefits:

- Minimize error sensitivity: RFID is very accurate and improves store and pick accuracy.
- Maximize ergonomics: by using different type of trucks and AGVs lifting is reduced to an absolute minimum.
- Minimize distances for labour: AGVs and conveyors cover the long distances for the light/medium items.
- Minimize handlings: every handling is reduced to the absolute minimum.
- Increase automated control: human interaction for storing and picking light/medium items is reduced, increase in accuracy.
- Minimize space usage: both the AS/RS + Block stacking increase the space utilization.
- Medium distance reduction: For the light/medium items the distance is reduced tremendously.

d. Drawbacks:

- Medium flexibility: Although the variability in the movement is reduced, the activities that require flexibility remain (consolidation).
- Medium human interaction: system is sensitive for violation by human interaction.
- FIFO/LIFO mix: due to the Block Stacking.
- Product care not maximized: clamping increases the damage risk.

Economic consideration

Before the final warehouse equipment system choice can be made, the economic aspects of the options must be calculated during the '*Economic Consideration'* path. With the aid of a business case the financial benefits can be found. For each of the options the investment costs, variable costs and productivity has to be analysed and compared. The productivity can be estimated based on data from similar systems. Once the financial picture is known, this data will be used as input, together with the non-economic benefits and the productivity, for the Multi Criteria Decision Analysis (MCDA). Finally, the output of this MCDA-model brings us to the last sub-path and sub-step of Step C, '*Select Systems*'. In this step the best option in storage equipment, material handling equipment and, as a result from that, the best fitting unit load are stated. From here, the specific equipment types and models can be determined as well as the required system numbers, which is a sub-step of Step E – Resource Dimensions.

However, the execution of the business cases is a research project in itself. Since a limited amount of time is available for this project, both the 'Economic Consideration' path as the 'System Selection' path of step C are not performed within this project.

Conclusion

Now that we have discussed all the possible equipment systems and we have explained that we will not execute the business case studies, we have arrived at the end of step C. During the subsequent step, step D, a high level overall system layout will be determined. In the next section we discuss step D and the results of the Systematic Layout Planning method.

4.1.4 Step D- Layout of the overall system

Based on the NIWD-framework (Figure 2-16), the next step for us to carry out is the layout of the overall system. During this section we discuss the results of the Activity Profiling data collection we executed in chapter 3. We will use the relationship chart we drafted (section 3.2.3 on page 56) as input for the *relationship diagram* that eventually will lead to the *block layout,* the end result of this step.

Relationship diagram

In the relationship chart we indicated the importance and closeness relationships among the different departments and zones. In the next step we convert the relationship chart into a *relationship diagram* by creating a graphical representation of the activities and their closeness relationships. First of all we draw the A-relations. Each department with an A relation gets its own department block and these blocks are connected. The maximum distance allowance between two of the A relation blocks is 2 cm. Subsequent the E-relations are in turn and these are drawn with maximum of 3 cm space between each department block. Hereafter the I-relations are displayed with 4 or more cm distance allowance. At last the O-relations can be displayed. However, not all O-relations are drawn to maintain clarity in the graphical representation. Besides, O means that ordinary distance is required, which in general is achieved, and thus are those relationships not as necessary to be shown as the former relationships. The U relationships are not displayed.

During the drawing process multiple options are encountered. Due to the large amount of departments and zones, only a small amount of relationship diagrams options are actual valid. Eventually, two diagrams passed the selection, which are displayed in Figure 4-24 and Figure 4-27 under the sub-section 'Results'.

Space requirements

To be able to convert the diagrams into block layouts, information on the required space per department is needed. The exact space requirements for all the departments of ATAG are not available yet and the numbers that are available are still confidential. However, based on the estimations the relative proportions can be determined. In Appendix A.12 an overview of this relative proportions is given. The required space for the Expedition is used as a benchmark and set to 1, from here the relative proportion of the other departments and zones is calculated, e.g. the storage area for heavy items (clamp goods) is 36 times the size of the expedition.

Block layouts

In the last step of Step D, the space requirements are applied on the relationship diagrams. By replacing the departments blocks of the relationship diagram with blocks that represent the relative proportion (and thus the required space) the block layout can be drawn. However, this activity still requires some insight because the exact location of the departments is still variable. This means that the departments still need to be positioned logically. The final results can be found below (Figure 4-25 & Figure 4-28).

Results

Option 1- Figure 4-24 displays the first relationship diagram. By converting this relationship diagram with the relative proportions into a block layout, Figure 4-25 is created. We rotate the relationship diagram with 90° (because of the first plans for the optional plot). In addition we add the laboratory and the other departments that are located in the warehouse but have no relationship with the rest of the departments. These are placed where space remains after the placing the connected departments and zones.

Legend:
1. Inbound light/medium
2. Inbound heavy
3. Return service technicians
4. Inbound spare parts/components
5. Storage light/medium
6. Storage heavy
7. Storage spare parts
8. Storage components
9. Storage Q&A
10. Sorting area
11. Consolidation shipments
12. Consolidation service technicians
13. Consolidation spare parts
14. Dispatch shipments
15. Dispatch Pick up
16. Return receipt
17. Expedition
18. Production
19. Q&A
20. Post room
21. Docks (grey dashed line)

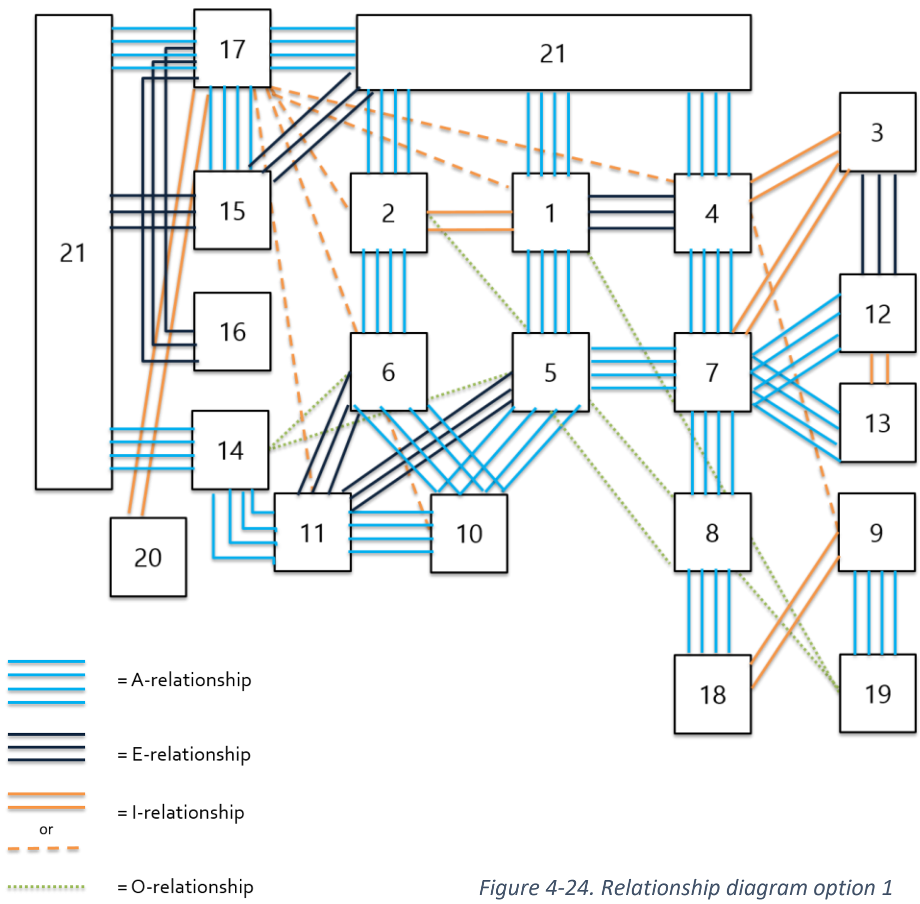


Figure 4-24. Relationship diagram option 1

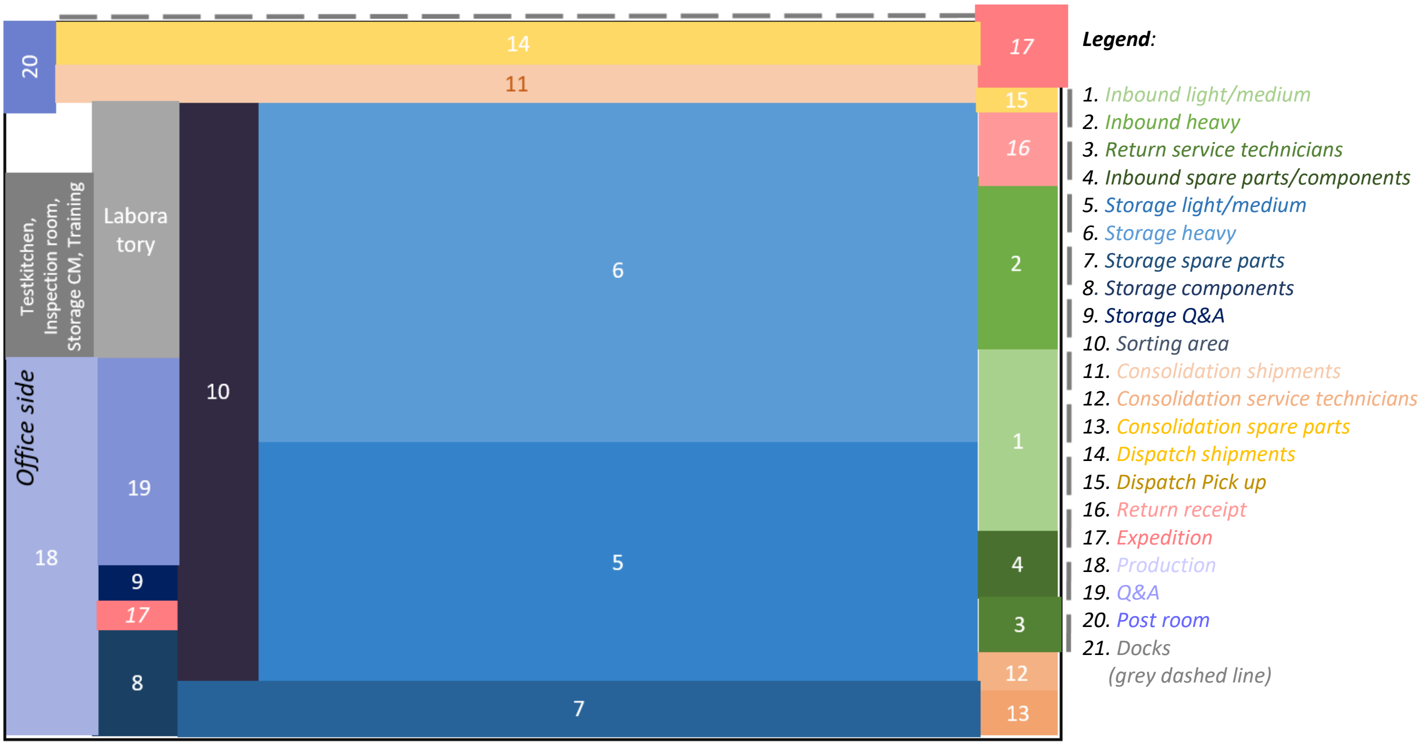


Figure 4-25. Block layout option 1 based on relationship diagram 1

In the first block layout the shipment dispatch area and the inbound area are separated with both their own docks. Production is located In the back of the warehouse together with Q&A. Far away from the docks but near the offices. The expedition is placed on the corner between the two dock sides, to have a good overview and to be able to receive the truck drivers. The post room and the remaining departments are placed near the offices because these departments have a high interaction with the office. Figure 4-26 shows the relative proportions for the first block layout.

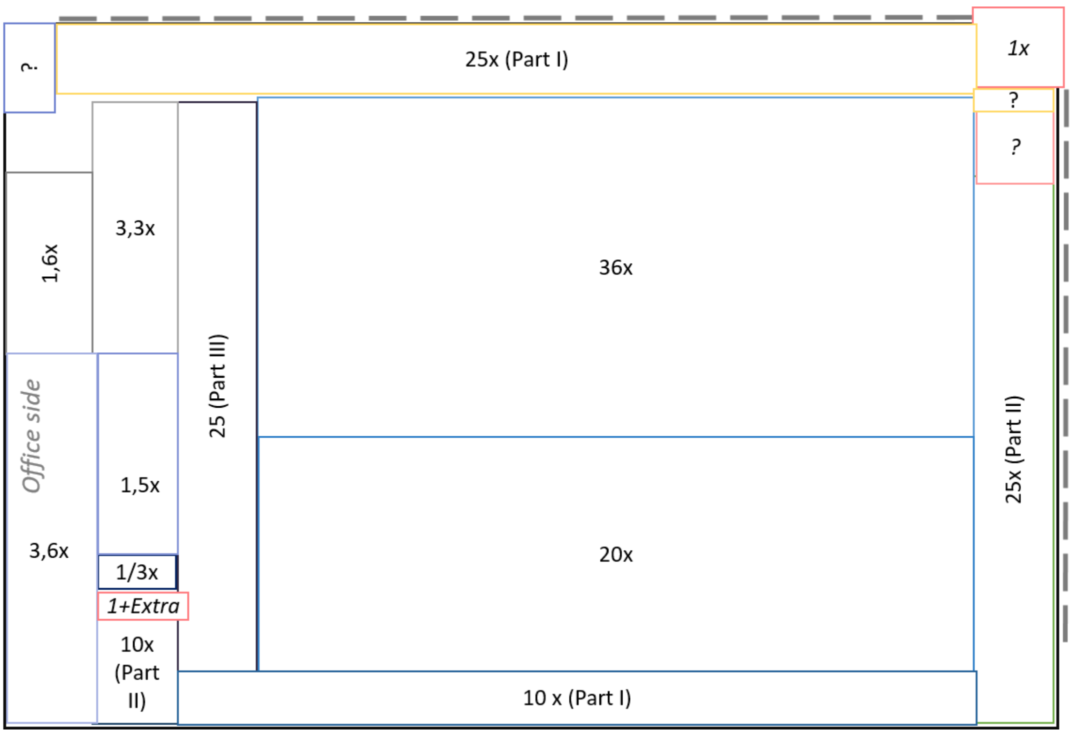


Figure 4-26. Block layout 1 with the relative proportions

Option 2- Figure 4-27 shows the second relationship diagram. Figure 4-28 is created, converting the relationship diagram with the relative proportions into a block layout. As with diagram 1 we added the laboratory and the other departments that have a location in the warehouse but are not connected with the rest of the departments.

In the second block layout, we added an extra dockside. This was necessary because the dimensions of the building would otherwise be out of proportion with a long length and a narrow width.

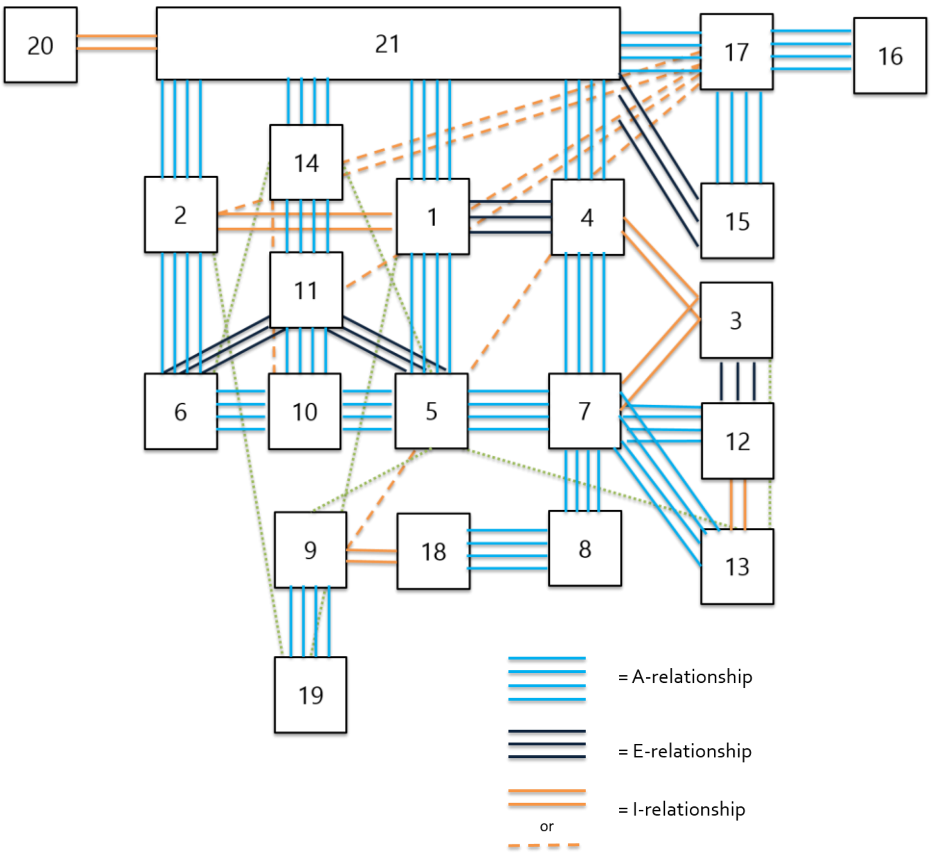


Figure 4-27. Relationship diagram option 2

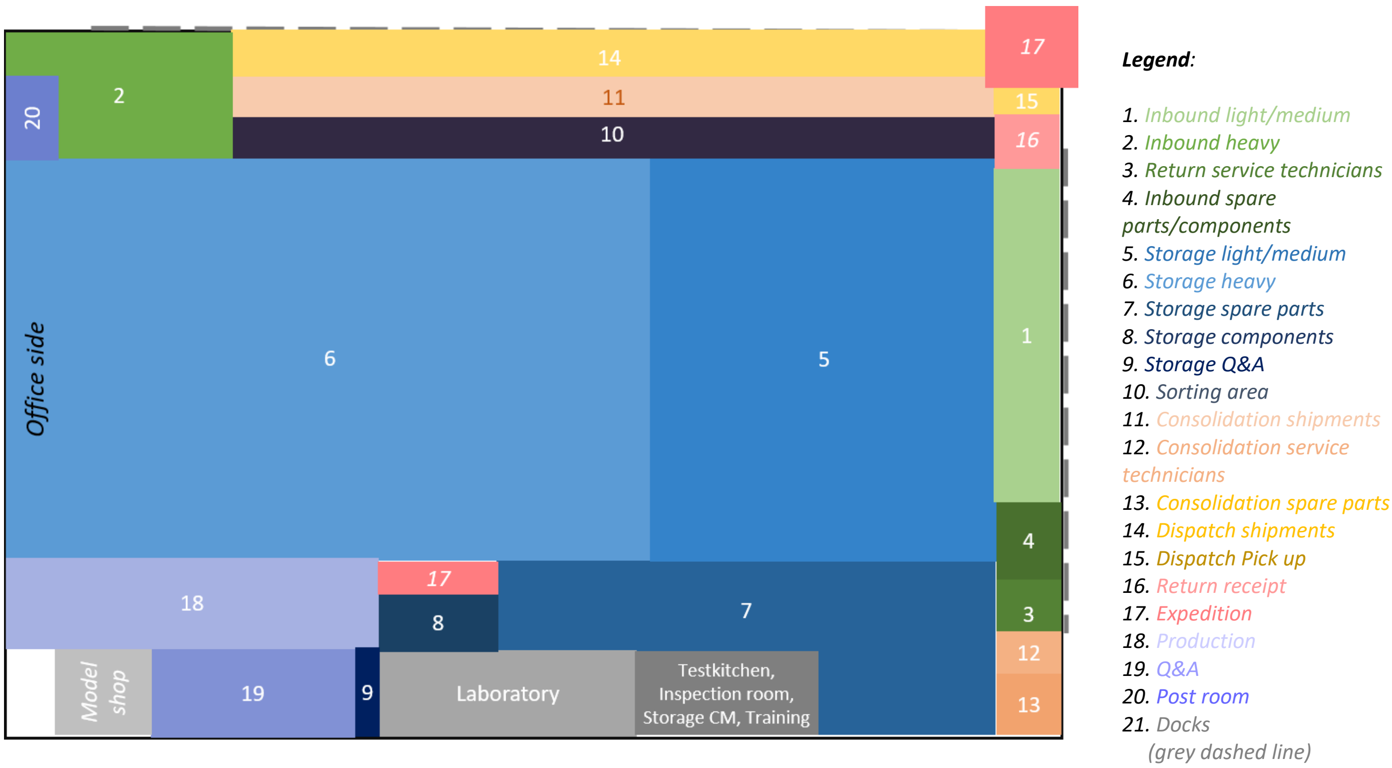


Figure 4-28. Block layout option 2 based on relationship diagram 2

The inbound area is divided among these two docksides. Again Production is located In the back of the warehouse together with Q&A and the remaining departments. Besides, the expedition is placed, as in block layout 1, on the corner between the two dock sides, to have a good overview and to be able to receive the truck drivers.

Figure 4-29 shows the relative proportions for the second block layout.

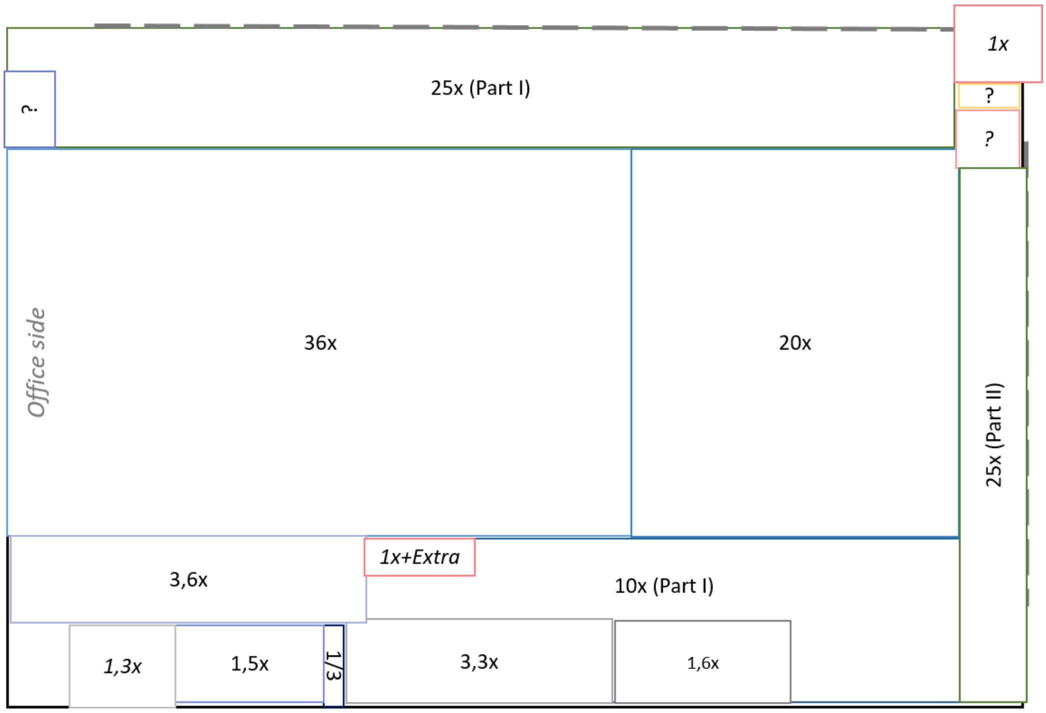


Figure 4-29. Block layout 2 with the relative proportions

Benefits and drawbacks

Step D has provided us two different layouts, both with valid closeness importance relationships. Each of the two layouts has its own benefits and drawbacks. It depends on the interests of the stakeholders and the equipment system that will be chosen, which layout fits the new warehouse of ATAG the best. In Table 4-5 the benefits and drawbacks are listed that are possible to determine on this high level with little detail. If no restrictions were in place, layout option 1 would be the best layout.

Table 4-5. Overview of the benefits and the drawbacks of the two overall layout proposals

Overall layout option 1	***Overall layout option 2***
Benefits	
- Inbound areas on the same side: *prevents confusion* - Production in the length of the building: *more possibilities to show customers* - 'Other departments' near the office: *high interaction*	- High accessibility from storage to sort/consolidation area: *decrease in distance/time* - Storage zones more concentrated: decrease in *distance/time*
Drawbacks	
- Long distance to cover from sorting area to consolidation area: *increase distance/time*	- 'Other departments' not optimally located from the office.

4.1.5 Conclusion

Now that we have insight in the direction, deep understanding of the processes, potential warehouse equipment systems and two options for the high level overall layout of the warehouse, we have to draft a concrete concept design. Without a concrete design the follow-up steps cannot be performed, since a specified warehouse equipment system and a specified overall layout are required for Step E to Step H. However, as we mentioned in the previous sections of chapter 4, a business case study is needed to find the best equipment system and the overall layout depends hereupon. In the next section, we will discuss and give advice on the best combination of alternatives for different situations.

4.2 Idealized Design for the ATAG warehouse

In the previous paragraph we have appointed four equipment warehouse systems for the distribution warehouse and two overall warehouse layouts. Besides, during the design of the process flow we collected insight in the assortment and its behaviour. Now, we will combine those data to give advice on the idealized design of the ATAG warehouse. In the next sections the possible combinations of the equipment systems (ES) and layouts are discussed. The options are ordered from high investment costs with great benefits to low investment costs with some benefits.

4.2.1 Operations and procedures

Before we discuss the best combinations, we enumerate the advices we have based on the results of Step B 'design of the process flow'. These advices will be included in the ES benefits argumentation.

- Strongly consider a 'Goods-to-picker' (GTP) method for the light/medium weighted items: as the data time measurement has shown, efficiency can be achieved at the order picking of the pallet goods. Besides, our MHE analysis has shown that the GTP has major benefits.
- Combine shipments during the pick process, thus reconsider the batch composition for both the light/medium and the heavy weighted items: the SKU and pallet density analysis data has shown that there is synergy in the SKUs and the shipments.
- Automate the store process for the light/medium weighted items and the heavy items: as the time measurement has shown, an improvement in efficiency can be achieved for both the storage of items in the racks as for the block stacking.

4.2.2 Option 1: AS/RS – Layout option 1

If ATAG decides to go for more efficiency, and they decide that automation is an important part of their mission, the 'Goods-to-Picker' *ASRS method for both the light/medium and heavy items* is the best solution. The sorting of the heavy item on pallets will require some extra time, however the store process for both item weight categories will improve tremendously. Furthermore a full-FIFO system is being realized, which improves the service level. Besides, based on the ES analysis (section 4.1.3 Warehouse system alternatives) we can state this system has the most benefits and the least drawbacks. Last, to let the system operates at its best, a RFID Auto Identification system is advised. The layout that fits this system the best is layout option 1. This layout has the most benefits and the drawback of this layout is not applicable anymore since the distance between the consolidation and the sorting area is covered with the aid of conveyors.

4.2.3 Option 2: ASRS + BS – Layout option 2

When automation and efficiency is high on the agenda, but space utilization plays an important role too, the *ASRS system in combination with block stacking* is a good outcome. For the light/medium items the efficiency is still achieved by deploying the 'Goods-to-picker' policy and the store process of this item-weight category is improved as well. For this particular part of the system, the distance for labour to travel is still reduced and this time gain can be used elsewhere. However, since the clamp truck still have to travel the entire distance from the storage area to the consolidation area, layout option 2 is advised.

4.2.4 Option 3: VNAR – Layout option 1

When the budget is insufficient for such automation and therefore the 'Goods-to-picker' method is infeasible, but FIFO and efficiency in distance and labour allocation (for the sake of minimum variable costs) are still part of the objectives, the '*VNAR for both item types*' fits ATAG best. As with the first ES option, the sorting of the heavy item on pallets will require some extra time. However, the distance to be travelled by labour is reduced by implementing conveyors. Therefore layout 1 is applicable for this equipment system. If shipments are combined, more full pallets are picked. An additional feature of this system is that during the order pick process the stacking capacity of the items has no influence on the order anymore. In the other systems the location of the items in the storage and the route of the order picker depend on the stack-order. Here the location of the items can be determined based on other, more efficient features. With this option, all the storage areas are combined in one VNAR and therefore an accurate location system of the items is a must. In case the RFID system proves to be too expensive, the barcode Auto Identification system requires improvement for the inbound and store processes.

4.2.5 Option 4: VNAR + BS – Layout option 2

Ending with the last equipment system, *VNAR with BS*, we recall that this is the ES that is used in the current situation. This 'Picker-to-goods' system is the best choice when: a semi-automatic system satisfies and there is a low budget available to invest in technical equipment. To still make an improvement in the future situation relative to the current situation, we advise to consider a RFID Auto Identification system. As we have shown in 3.3.3 Communication and information equipment, is RFID the best tool for high accuracy and a FIFO system since these two features fit the desired direction of ATAG and its logistic department. Also here applies, in case the RFID system proves to be too expensive, the barcode Auto Identification system requires improvement for the inbound and store processes. One other important thing to mention is that the current block stacking procedure is not performed correctly. Currently different batches are stored by each other on the same spot, this is very damaging for the quality accuracy and it creates a LIFO system. By changing this policy into smaller store locations with each batch having its own individual location a high accuracy improvement is made possible by enabling FIFO per lane. Since the distances from the storage areas to the dispatch area have to be travelled by both the order picker as the clamp truck, layout 2 fits the system the best.

4.2.6 Conclusion

To find the best option for ATAG among the four options discussed in the previous sections, a simulation study is advised. With the aid of this study the best option can be found, and subsequently the optimal batch formation, optimal number of workers and other system specifications can be imitated, which are important input factors for step E and F of the NIWD-framework. Once the overall design is completely devised, it has to be implemented. If possible, an even more complicated process than the design process itself, since many internal and external factors might influence the expected outcome. In the next paragraph advice on and insight in the implementation process is given.

4.3 Design of the implementation

The last phase of the Idealized design approach of Ackhoff (2001) is the 'Design of the Implementation'. During this phase who, what, when and where regarding the design implementation is discussed. Since the design is not entirely finished yet, it is difficult to specify concrete statements about the implementation process. However, advice on the steps to undertake and points of attention at the start of the process can be named.

First of all, a project team must be composed. This project team should include interested parties of several layers within the logistic department.

Secondly, the environment has to be analysed. Both the external as the internal forces have to be mapped. With the aid of a *force field analysis*, the driving and restraining forces are viewed. Then, with the aid of a *stakeholder analysis* each of the stakeholders and their attitude towards change can be made transparent. This is necessary to understand which parties have to be influenced and involved to bring the project to fruition. Lastly, the *leadership style* is very important. The project leader has to communicate bright and clear the several steps of the process. Especially for the people who are involved but are resistance to change, the attitude and actions of the leader are of great influence on their co-operation.

Finally, a project plan needs to be developed. Here the phases of the project with related actions are discussed. Besides, a contingency plan can be developed to avoid failure of the action plan. In the contingency plan, the critical points are listed with a related chance of occurrence. By creating awareness for these points, solutions can be devised and adequate responses are achieved. Moreover, by combining the project team (and the stakeholders) with the project plan, a responsibility overview can be drafted. This overview indicates the responsible actors for each of the to be undertaken actions. Another important point that should not must be forgotten is the transition phase from the current to the new warehouse. Once everything is implemented, the actual process must be moved. The facilitation of this process requires considerable amount of attention.

In conclusion, we have to emphasize the importance of communication. The key to any well-implemented plan is clear understanding and the involvement of all the stakeholders, no matter their position. Because, the greatest importance is to create unity throughout the entire process.

4.4 Conclusion

At the end of this chapter, in which we discussed the final design and the implementation, we have almost arrived at the end of this thesis and the related research project. During this chapter, we have discussed the first four steps of the New Integrated Design framework. The results of the data analyses have been presented and two options for the overall warehouse layout of ATAG have been presented together with four equipment systems for the distribution warehouse.

The next chapter, we will answer the research questions and we will give recommendations on:

- The further course the design process for the warehouse of ATAG.
- Future research regarding the New Integrated Warehouse Design framework.

5. Conclusion and recommendations

To conclude this thesis, the research questions of section 1.4.1 are answered and we make recommendations for ATAG Benelux BV and future research.

5.1 Answers to the research questions

In this thesis we have achieved the research objective *"Develop an integrated warehouse design framework, to support the design of a new warehouse that takes into account strategic, tactical and operational aspects on different description detail"* by answering three main research questions;

1. *What warehouse (design) models and frameworks are available and how can these be integrated into a comprehensive warehouse design framework?*

   By critically reviewing the available literature on warehouse design and by answering the three sub-questions, we have established a New Warehouse Design framework (see section 2.7) in which the available models and frameworks are integrated. The framework is developed to be useful for organizations without investments in expensive software and decision programs.

   The framework includes the following steps:

   Strategic level:

A. ***Determine the direction of the organization***: determination of vision, mission, success requirements, guiding lines and the evidence of success.

B. ***Design the process flow***: designing the processes with Value Stream Mapping, analyse the item behaviour with Activity Profiling and the chart the department dependencies with Activity Relationship Charting.

Tactical level:

C. ***Select the warehouse system***: select storage equipment and material handling equipment based on requirements, objectives, performance indicators and functions.

D. ***Draw the overall system layout***: convert the relationships chart to a relationship diagram and create block layouts based on the space requirements.

E. ***Determine the resource dimensions****:* concretize the overall warehouse layout in detailed level by combining it with the equipment system.

F. ***Set organizational issues*:** complete the detailed layout with decisions on the storage and picking process.

Operational level:

G. ***Determine storage policies***: assign item locations and docks.

H. ***Determine order picking policies***: assign labour.

Research question 2 and 3 focus on ATAG Benelux BV, since the problem of the organization has served as study object for the application of the New Integrated Warehouse Design framework. Research question 2 comprises the application of the New Integrated Warehouse Design framework:

2. *How can the integrated comprehensive warehouse design framework be applied at the current warehouse of ATAG Benelux BV for a new warehouse redesign?*

   The current situation at ATAG came to light by applying the second step of the framework. With the aid of the Value stream Map method, Activity Profiling and the Activity Relationship Charting, we indicated the obstacles in the processes, we mapped the SKU behaviour and we displayed the department interdependency. Combining these insights we found the gaps in relation to the desired situation. Furthermore led this question to the knowledge needs in the current available storage, material handling and information and communication equipment. The collected information showed the possibilities for ATAG and provided a scope for the selection of a comprehensive equipment system. The gained knowledge in both the current situation at ATAG and the currently available equipment, functioned as a good foundation for the design of the new warehouse. With the aid of Step A to Step D of the framework we established, four potential layout and equipment combinations for the new warehouse of ATAG (section 4.2).

To finally devise and select the best design, some subsequent steps have to be executed. Research question 3 deals with those steps:

3. *What follow-up (redesign) steps are required for an adequate warehouse design for ATAG Benelux BV?*

   First of all, a high level design must be chosen. Besides a financial calculation through a business case study, a simulation can be executed that indicates the productivity of the system. If not at hand, operational information from similar systems can be used, e.g. efficiency data from system suppliers. Comparing the four options based on both the financial and the productivity the most efficient solution is picked. As soon as the high level layout is chosen, step E to step H can be applied. With the aid of these steps the overall layout is filled with as end result a new warehouse design that includes the number of systems, exact location of items, policies for all the logistic processes and a well-appointed labour division. Once the final warehouse design is confirmed, the implementation process is started. Before or at the start of the implementation process a project team must be composed, the environment must be analysed and a project plan drafted.

5.2 Recommendations ATAG Benelux BV

The execution of the first four steps of the framework has created insight in the current situation of the distribution warehouse at ATAG and laid a foundation for the desired situation of the distribution warehouse at ATAG. However, the time frame of the project was limited and therefore some recommendations on the follow-up of the project can be made.

- *Execute a business case study and a simulation study for the four equipment systems and apply step E-H:* this balances the financial aspects with the efficiency benefits and results in the best choice. This requires some time (and extra investments), but it gives insight in what is really the best option for ATAG. Especially given the mission of ATAG and the related objectives a well-considered decision in this area of choice can cause great differences. Subsequently, step E – H can be performed with the final choice in layout and system as foundation.
- *Create future state Value Stream Maps and pursue standardisation:* in the current situation the several teams conduct the process similarly in the main lines, however on detailed level various operation methods occur. To enable the interchangeability of labour and human

capacity, standardisation is a pre. In fact, in an environment with increased automation this is a requirement.

- *Apply step B 'Design of the process flow' and step C 'Selection of a warehouse system' for the service and production warehouse:* during this research project step A (Determine direction) and D (Layout for the overall system) has been applied on both the service as the distribution warehouse, since these steps are general applicable. However, Step B (Design of the process flow) and Step C (Selection of warehouse systems) we only executed for the distribution warehouse. Therefore we strongly advise to execute Step B and Step C for the Service warehouse. The input for the Value Stream Maps for the Service warehouse and (a part of) the production warehouse have been prepared and can be found in Appendix A.5.
- *Find new batches in which multiple shipments on a day are compared during the pick process:* our data analysis during the Activity Profiling step has shown that potential efficiency improvements can be made by combining multiple shipments on a day for the picking process. This data analysis has been executed for the light/medium weighted items that are currently stored on pallets in racks. With the aid of the simulation study we mention in recommendation 1 the optimal batch size can be found.
- *Involve people from the 'work floor' in the improvement process:* currently, multiple employees that work 'on the floor' feel they are not involved in the improvement processes and that their ideas are not taken seriously. Besides that this way of thinking does not increase the motivation, it can cause major difficulties during the implementation process of the new warehouse. We strongly recommend to ask the employees: "who wants to be involved in the redesign process?" and communicate and clarify when their ideas are not included or why certain choices have been made.
- *Improve communicate within and between departments:* During our analysis we discovered that the major cause of problems is miscommunication. Agreements are not clear for all involved and this leads to incorrect assumptions. Create regular consultation moments and give, during this moments, follow ups on topics discussed previously. Especially, now in the new situation all the departments and technical zones are integrated in one building, the importance of minimum friction and ambiguity has increased.

5.3 Future research

As mentioned in the introduction of this thesis, the lack in academic literature of an integrated framework that facilitates the overall redesign process, required the creation of a comprehensive framework. During this research project we tried to design a comprehensive framework that bridges the gap in the literature a bit. The framework is generally applicable and needs no additional investments in other (software) programs. The following topics might be interesting to further investigate:

- *The generalizability of Step E to Step H:* As we appointed in section 2.6, the variation in possible methods for Step E, Step F, Step G and Step H is large and therefore a standardized roadmap for these steps, which can be applied on multiple warehouses, is difficult to develop. Therefore, more research for those specific steps and their generalisability might be interesting to consider.
- *The computerized framework:* As we indicate multiple times throughout the research project, we attempted to design a framework that is applicable by organizations without investments in extensive software programs that support decision processes or that facilitate layout design. However, in the academic literature a large amount of information is available on the computerized models. In future research a framework that combines the computerized decision models with the manual models can be investigated.

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Appendices

A.1 Action and Knowledge Problems

Overview of the detailed knowledge problems that enables us to gap the action problems presented in section 1.3.1.

Action Problems	Knowledge Problems
Department/Division Placement	**What steps are required for finding a suitable division and allocation of departments?** - What models are available, which one should be applied and what related steps should be executed? ***ATAG -case:*** - *What departments are crucial for the performance of the ATAG warehouse?*
Shape & Zones	**How can zones and shapes be determined and how is this division established?** - What zone compositions are possible and when to apply what? - What are the shape possibilities and how to find a fit? ***ATAG -case:*** - *What is the assortment of ATAG?*
Storage Equipment	**What steps should be executed to select the right storage equipment that fits the assortment?** - What are available storage techniques? - What criteria should be taken into consideration? ***ATAG -case:*** - *Which internal flows are present at ATAG?* - *What storage techniques are applicable for ATAG Benelux BV based on the several characteristics?*
Transport Equipment	**What steps should be executed to select the right transport system that fits the assortment?** - What transport techniques are on the market? ***ATAG -case:*** - *What type of transport system would fit the ATAG assortment for internal flow transportations?*
Product Data Management	**What operating management techniques related to data processing are on the market?** ***ATAG-case:*** - Which data processing technique fits ATAG best based on the selected transport systems and storage equipment?
Picking Strategy	*Based on the operating system, equipment and operating management, what picking technique is applicable e.g. to reduce empty movements?* - *How can task-interleaving be applied?*

A.2 Literature Comparison and Additional Information Tables

A2.1 Warehouse design steps overview by Baker and Canessa (2009)

The table below displays the comparison made by Baker and Canessa (2009) of warehouse design models. For each article included in the comparison the steps and sub-steps are shown. The steps of the several models are clustered in the same row when some overlap exists.

Table A. 1. Overview of the warehouse design model comparison made by Baker and Canessa (2009)

Rouwenhorst, et al. (2000)	Rowley (2000)	Rushton, et al. (2000)	Bodner, et al. (2002)	Hassan (2002)	Waters (2003)	Rushton, et al. (2006)
Define concept	Define system requirements and design constraints	Define system requirements and design constraints		Specify type and purpose of warehouse		Define business requirements and design constraints
Acquire data	- Define and obtain relevant data - Analyse data	- Define and obtain data - Analyse data	- Assemble data - Undertake data profiling	- Forecast and analyse expected demand - Establish operating policies - Determine inventory levels	- Estimate future demand - Forecast movements through warehouse	- Define and obtain data - Formulate a planning base - Define the operational Principles
Produce functional specification	Postulate the operating procedures	Postulate basic operations and methods	Determine high-level functionalities	Form classes of products	Compare available handling equipment	Evaluate equipment types
Produce technical specification	Consider equipment types and characteristics	Consider possible equipment types	Produce high-level specification	Departmentalize into areas and establish general layout	Calculate the space needed for storage and movement	Prepare internal and external layouts
Select the means and equipment	- Calculate equipment quantities - Define other facilities and services	- Calculate equipment quantities - Calculate staffing levels		-Partition into storage areas -Design MH, Storage and sortation systems	Identify which materials should be close to each other	-Draw up high-level procedures and IS requirements -Evaluate design flexibility
Develop layout	Draft possible layouts	Prepare possible building and site layouts		Design Aisles	Develop outline plans	-Calculate equipment quantities -Calculate staffing levels
Select planning and control policies	-Select preferred design -Evaluate and assess expected performance - Conduct computer simulations	-Evaluate the design against requirements -Identify preferred design	-Undertake detailed system specification/ optimization -Reiterate above steps	-Determine space requirements -Determine input/output points - Determine docks - Determine the storage arrangement - Form picking zones	Finalise plan	-Calculate capital and operating costs - Evaluate design against requirements - Finalise preferred design

A2.2 Equipment classes summary selected by expert systems and analytical procedures

The table below (Table A. 2) displays the comparison made by Hassan (2015) of equipment system selection models. For each article included in the comparison the type of approach is presented. In the table stands 'A' for Analytical approach and ES for Expert System approach. Furthermore the equipment classes present in each of the articles are shown.

Table A. 2. Overview of the comparison table showing Equipment classes summary for several articles - Hassan (2015)

	Class of equipment										
Reference	Type of approach	Truck	Conveyor	Crane	AGV	Monorail	Manual	AS/RS	Rack	Robot	Positioner
Hassan, et al. (1985)	A	X	X	X							
Fisher, et al. (1988)	ES	X	X	X	X	X	X				
Matson, et al. (1992)	ES	X	X	X	X	X	X				X
Welgama and Gibson (1995)	ES + A	X	X	X							
Park(1996)	ES	X	X	X	X	X		X	X	X	
Chittratanawat and Noble (1999)	A	X	X	X							
Chan, et al. (2001)	ES	X	X	X	X			X	X	X	
Fonseca, et al. (2004)	ES		X								
Kulak (2005)	ES	X	X	X	X			X	X	X	
Cho and Egbelu (2005)	ES	X	X	X	X	X		X	X		X
Mirhosseyni and Webb (2009)	ES +A	X	X	X	X		X				

A2.3 Requirement classification for the MH Equipment Selection Method

Preliminary design phase - Suggested prioritization of requirements for trucks, conveyors, racks & STO

Once a class has been selected with the aid of the equipment selection framework of Hassan (2015) (see section 2.4.3), a specific equipment type can be selected. Table A. 3 to Table A. 6 show requirement tables that support the decision process of selecting a specific equipment type. First the truck types are discussed, then the Conveyor types, subsequent Rack types and finally two Goods-to-Picker variants. Each of the questions to answer when searching a specific equipment type are presented in order of priority.

Table A. 3. Truck - Preliminary design phase requirement table - Source: Hassan (2015)

Priority	Requirement	Classification	Type of truck
1	Weight of load	Light ≥ Medium	Walking truck- use priority 2 Riding truck – use priority 2
2	2.1 Stacking 2.2 Move pallet 2.3 Various load shapes	- Yes - No - Yes - No	Walking stacker Use requirement 2.2 Pallet jack Use requirement 2.3 Hand trucks – carts
3	3.1 Lifting 3.2 Move Pallets 3.3 Large volume, various shapes	- Yes - No - Yes - No	Counter balance truck Use requirement 3.2 Platform pallet truck Use requirement 3.3 Tractor trailer

Table A. 4. Conveyor - Preliminary design phase requirement table - Source: Hassan (2015)

Priority	Requirement	Classification	Type of Conveyor
1	Weight of part/load	Light ≥ Medium Overhead movement Floor movement	Use priority 2 Power and free Tow
2	Shape of part/load	Regular Irregular	Use priority 3 Belt
3	Size of part/load	Small Medium Large	Belt Roller – slat – belt Roller

Table A. 5. Racks - Preliminary design phase requirement table - Source: Hassan (2015)

Priority	Requirement	Classification	Type of Rack
1	Storage density	Low High	Single or double rack Use priority 2
2	Accessibility	Low High	Mobile racks Use priority 3
3	Throughput	Low High	Drive in/through racks Pallet flow – push racks

Table A. 6. STO - Preliminary design phase requirement table - Source: Hassan (2015)

Priority	Requirement	Classification	Type of Stock to Operator (STO)
1	Security	Low High	Horizontal carousel Use Priority 2
2	Maintenance	Low High	Vertical carousel AS/RS

A2.4 Material Handling Equipment – Classification List

Table A. 7 shows an overview of nine equipment categories; *Pallet truck, Industrial hand truck, Automated guided vehicle systems, Lifting devices, Continuous material handling, Elevators, Self-propelling trucks, tractors and stackers*. For each of these categories the classes and the related equipment types are shown. This table can be used for the system selection phase explained in section 2.4.3 and is used as input for step C- Selection of warehouse systems in section 4.1.3.

Table A. 7. New Classification of Material Handling Equipment (Source: Bouh & Riopel, 2015)

Category	Class - *Type*
Pallet Truck	**Pallet Jack** *- Hand pallet truck* *- Power operated pallet truck* **High lift pallet truck** *- Electric scissor lift pallet truck* *- Hand high lift pallet truck* **Platform truck** *- Hand operated stillage truck* *- Power-driven platform truck*
Industrial hand truck	*- Basket-truck* *–Beam type truck* *- Cage cart* *–Dolly* *–Fit-in truck* *- Metal wheelbarrow* *- Platform truck with upright sides* *- Rack truck* *- Roll-container* *–Service cart* *- Specialised truck* *–Stock picking truck* *- Tilt truck* *- Tipper truck* *- Towable truck* *- Trolley for carrying boards* ***Platform truck*** *- Folding platform truck* *- Low lift platform truck* *- Narrow aisle cart* *- Tilt platform truck* ***Two wheel hand truck*** *- Appliance truck* *- Barrel truck* *- Convertible two-wheel hand truck* *- Dual cylinder truck* *- Dual directional hand truck* *- Folding two-wheel hand truck* *- Lift two-wheel hand truck* *- Luggage cart* *- Multiple-cylinder truck* *- Single-cylinder truck* *- Stair climbing hand truck*
Automated guided vehicle systems (AGVS)	**Automated Guided Vehicle (AGV)** *- Heavy load Automated guided vehicle* *- Light load automated guided vehicle* *- Medium load Automated guided vehicle*

Category	Class - *Type*
Lifting devices	**Hoist** *- Hand hoist* *- Powered hoist* **Winch** *- Hand winch* *- Motor-winch* **Jack** *- Manual jack* **Lifting cylinder** *- Manual cylinder* *- Motorized jack* **Monorail** *- Automated electrified monorail* *- Manual monorail* **Jib crane** *- Articulated beam jib crane* *- Floor-mounted jib crane* *- Hand rotated jib crane* *- Jib crane with powered slewing* *- Pillar jib crane* *- Wall jib crane* **Gantry crane** *- Cantilever gantry crane* *- Cross aisle tie* *- Fixed gantry crane* *- Hand-operated gantry crane* *- Radial gantry crane* *- Self-propelling gantry crane* *- Single-girder gantry crane* *- Travelling gantry crane* *- Twin-girder gantry crane* **Bridge crane** *- Automatic overhead crane* *- Cab operated bridge crane* *- Double-girder crane* *- Flameproof overhead travelling crane* *- Manually operated crane* *- Overhead travelling stacking crane* *- Single-girder crane* *- Top-running bridge crane* *- Underhung bridge crane* **Semi-gantry crane** *- Motorized semi-gantry crane* **Portable crane**
Continuous material handling	*- Ball table* **Conveyor** *- Automatic baggage conveyor* *- Belt conveyor* *- Chain conveyor* *- Chute conveyor* *- Mesh band conveyor* *- Overhead conveyor towing floor truck* *- Overhead monorail chain conveyor* *- Overhead power and free chain* *- Roller conveyor* *- Single strand floor truck conveyor* *- Skatewheel conveyor* *- Sort conveyor* *- Steel band conveyor*

Category	Class - Type
Elevators	*- Freight elevator* *- Material hoist* *- Scissor lift* *- Work assist vehicle* **Step ladder** *- Rolling service extension ladder* **Lift table** *- Constant-level table* *- Manual mobile scissor lift table* **Boom lift** *- Articulating boom lift Self-propelled boom lift* *- Telescopic boom lift* *- Towable boom lift*
Self-propelling trucks	*- Burden carrier* *- Straddle carrier* **Power lift truck** *- All-wheel drive multidirectional forklift* *- Articulated frame lift truck* *- Counterbalanced lift truck* *- Forklift truck Order-picking truck* *- Reach forklift truck* *- Rotating cabin lift truck* *- Rough terrain lift truck* *- Telescopic handler*
Tractors	*- Industrial trailer* **Industrial tow trailer** *- Electric tow tractor* *- Internal combustion powered tow tractor* *- Powered rider tow tractor* *- Walkie tow tractor*
Stackers	**Manual stacker** *- Manual hand stacker* *- Manual hydraulic stacker* *- Semi-electric stacker* **Power operated stacker truck** *- Electric stacker* *- Reach stacker* *- Weighing stacker*

A2.5 Material Handling Equipment – Attributes list

Table A. 8 displays attributes that can be used as input for the technical capabilities path of step C-selection of warehouse systems. For determining the material handling equipment characteristics regarding the unit load, movements, built in specifications and environment aspects the table below is of added value (see section 2.4.3). We have used the attribute table within our research project to set up the requirement table (Table 4-3) presented in section 4.1.3.

Table A. 8. Attributes of Material Handling Equipment (Source: Bouh & Riopel, 2015)

Family	Attributes	Family	Attributes
***Unit load:** Single handled item*	**Bottom surface**: rigid or not, flat or not **Easy to clean**: plastic container, metal container **Height**: short, medium, high **Length**: short, medium, high **Nature**: fragile, robust, compact, granular, block (bulk) **Production trend**: increase, increase sharply, regression, strong regression, stable, **Quantity to handle**: low, medium, high **Shape**: regular, irregular **Size** : regular, irregular, small, medium, large **Temperature** : °C **Type** : container, pallet, individual, tray handling, bar, bulk, reusable or not **Volume** : m3 **Warehousing properties**: nestable and stackable **Weight**: light, medium, heavy **Width**: short, medium, high	***Equipment:** Built-in characteristics*	**Accumulation**: permitted or no **Acquisition cost**: low, medium, high **Bearing strength**: newton **Design of the loading platform**: roller, skatewheel, stationary lifting **Engine type**: diesel, gasoline, other **Equipment battery**: low, medium, high **Equipment Compatibility with others**: yes or no **Equipment profile complexity**: straight line, composed, simple (continuous handling) **External energy required**: yes or no **Gripping equipment**: platform, skate, pallet fork, tractor, trailer etc. **Lifting/ loading/unloading speed**: low, medium, high **Loading capacity**: Kg **Mode**: manual, semi-programmable, programmable **Operation control**: alone, manual, automatic, yes or no **Operation cost**: uniform, variable, irregular **Operator**: accompanying, standing, sitting **Power source**: gravity, electrical **Primary function**: movement, warehousing, manipulating, transportation **Product protection**: yes or no **Transportation method**: carry, tow **Wheel type**: demountable tire, bonded tire, etc.
***Movement:** Desired transfer*	**Aisle length**: meter **Aisle width**: meter **Available height**: meter **Obstacle**: yes or no **Automation level**: manual, semi-automatic, automatic, required or not **Coverage area:** point to point, confined to variable, fixed, variable, linear, 2D, 3D **Cross traffic**: present or absent **Direction/plan**: descent, horizontal / angled, vertical (up / decreasing) **Distance**: short, medium, long **Flow**: controlled or not **Frequency** : fixed, continuous, intermittent **Handled load/time unit**: uniform, variable, combination **Interface handling equipment type**: manual, semi-programmable, programmable **Lifting height :** meter **Loading nature**: simple, double or other **Loading/unloading**: alone, controlled or not **Location**: indoor, outdoor, Mixed **Loop**: open, closed **Management mode**: FIFO, LIFO **Movement configuration**: continuous, intermittent **Nature**: transfer, rotate, capture, distribution, stacking, loading, unloading, conveying, transportation, lifting, wrenching, fixing, inserage, orientation, dock, order preparation, handling assets, outdoor handling	***Movement:** Desired transfer*	**Operation accuracy:** low, medium, high **Operator lift height**: low, high **Origin/destination**: fixed, variable, racks **Output**: low, medium, high **Path**: straight, curve, right angle **Path variability**: fix, variable Route : fixed point to fixed point, fixed point to variable point, variable point to variable point **Sequence**: fix, variable **Speed**: low, medium, fast, uniform, irregular, variable **Tilt**: degree **Transaction data processing**: manual, semi-automatic, automatic (barcode) **Type**: horizontal (above ground, overhead), inclined, rotational Unloading places : one place, several places at equal intervals, different places at unequal intervals **Working level**: ground, breast height, raised (horizontally, vertically, inclined) **Workstation types**: one lane or two-way
		***Environment:** Workplace characteristics*	**Depth of the rack:** simple, double **Floor space:** available or no **Floor space nature:** smooth, rough **Slope**: degree **Space between column**: m2 **Warehousing:** floor, pallet rack, automatic warehouse system **Working condition:** noise, exhaust, dirt, debris, etc.

A.3 Value Stream Map Data Collection Form (Sample)

For step B – Design of the process flow, a data collection activity has to be executed. For the value stream mapping method a form for recording the process data has been developed. Below this form is presented for the first two sub step. For each process the following information has to be denoted:

- The value stream map name
- Product group
- Frequency of the process
- Special process conditions
- The trigger for the process
- The boundaries for the process
- The first and last step

Subsequently, for each sub step of the process the activity blocks have to be filled. This require:

- The number of the step
- The activity
- Function of the employee executing the step
- o)= number of employees executing the step
- IT and documents required for the step
- PL = Process time
- LT= Lead time
- The barriers interrupting this particular step.

Furthermore, if present, the WIP (work in progress), the location of the WIP, the duration of the storage of the WIP and the character (push or pull inventory) of the WIP has to be determined.

Value stream map:	**Conditions:**	**Trigger:**
Product group:	**First Step:**	**Boundaries:**
Frequency/Demand:	**Last Step:**	

Step	1
Activity	
Function	
o)	
IT/DOC	
PT	
LT	
Barriers	

Step	2
Activity	
Function	
o)	
IT/DOC	
PT	
LT	
Barriers	

Type WIP	
Location	
Duration	
Push or Pull	

Type WIP	
Location	
Duration	
Push or Pull	

A.4 Work Sampling Recording form (Sample)

For step B – Design of the process flow a data collection activity has to be executed. For the value stream mapping method a form to denote the time measurement data has been developed. Below this form is presented. On the vertical axis the activities and on the horizontal axis the employees are presented. By tallying their activities a time insight can be accomplished (see 2.3.1 page 22)

Table A. 9. Example of a work sampling recording form

	Activity	Man 1 (*Name*)	Man 2 (*Name*)	Man 3 (*Name*)	Man 4 (*Name*)	Man 5 (*Name*)
Activity 1 (Inbound – Pallet)	Sub step 1 – (*Unload*)					
	Sub step 2 – (*Sort/prepare*)					
Activity 2 (*Put away – Pallet*)	Sub step 3 – (*Transport*)					
	Sub step 4 – (*Store*)					
Activity 3 *(Inbound – Bulk)*	Sub step 5 – (*Unload*)					
	Sub step 6 (*Transport/store*)					
	Sub step 7 (*Sort/prepare*)					
Activity 4 (*Order picking – Pallet*)	Sub step 8 (*Collect*)					
	Sub step 9 (*Position unload*)					
Activity 5 (*Order picking – Bulk*)	Sub step 10 (*Collect*)					
	Sub step 11 (*Position unload*)					
Activity 6 (*Dispatch Mix*)	Sub step 12 (*Consolidate*)					
	Sub step 13 (*Prepare ship*)					

A.5 Value Stream Maps Data Collection Forms – Filled

During step B -Design of the process flow – we executed the value stream mapping method. We filled the recording forms of Appendix A3 and A.4 for each of the processes and collected the results, which we present in this section. Below an quick overview of the filled A3 recording forms, of which the results can be found in Appendix A.5, are presented with related page number.

Subsequently we converted these recording forms into visual maps. These can be found under Appendix A.6. As mentioned in section 3.2.1 we applied a scope which includes merely the distribution warehouse.

Appendix A.5 Index:

Distribution warehouse:

Service warehouse:

Production warehouse:

Support activities:

Appendix A.6 Index:

Distribution warehouse:

A5.1 VSM – Inbound + Put away trailer – Pallet goods

Value stream map: Inbound Trailer or Container + Put-away
Product group: Pallet goods
Frequency/Demand: 4 trailers per day depending on complexity (sometimes 2)
Conditions: Mixed or non-mixed
First Step: Collect Discharge list
Last Step: Drop Discharge list
Trigger: Arrival truck
Boundaries: Available time (arrival on appointment) & available space
Average total duration:

Step	1
Activity	Receive Info/Unload: *Request Discharge list, Unloading truck & Unpack*
Function	WW Inbound - Pallet (Electric Pallet Truck "Hondje")
o)	2
IT/DOC	Discharge List + Product Stickers - SAP
PT	10-15 min
LT	
Barriers	- Inaccessible resources - Discharge list not always available/ready > Result = Inaccuracy: manually location note - Space limits > Result = inefficient execution

Type WIP	(Mixed) OEM on pallets
Location	Floor, inbound - Hall B
Duration	1 hour 45 min
Push or Pull	Push

Step	2
Activity	Sort/Check: *Check quantities, sort quality items*
Function	WW Inbound - Pallet
o)	1 (2 - *when potential post control*)
IT/DOC	Discharge list + product stickers + Quality stickers
PT	10-30 min (depends on mix)
LT	
Barriers	- Quality items not reduced on the stickers > Result: Inaccuracy

Type WIP	Items for quality check (QA goods)
Location	Pallet, QM collection place – Hall B/Hall D
Duration	
Push or Pull	Push

Step	3
Activity	Prepare Stock: *Repack (if needed), paste product stickers & taping*
Function	WW Inbound - Pallet (Pallets)
o)	1 (2)
IT/DOC	Product stickers
PT	15-20 min
LT	
Barriers	- Space limits > Result = Time loss: higher distance to cover, due to lack of space for pallets(with repacked items) therefore can't be placed next to original pallet

Type WIP	Sorted OEM on pallets
Location	Floor, inbound - Hall B
Duration	1 hour 15 min
Push or Pull	Pull

Step	4
Activity	Transport: *Move to racks*
Function	WW Inbound - Pallet (Electric Pallet truck)
o)	1
IT/DOC	
PT	
LT	
Barriers	- Space limits > Result = Downtime: The movements towards racks have to wait, till previous pallets are stored or full pallets are moved

Type WIP	Sorted OEM on pallets
Location	Floor Rack end, Storage - Hall B/Hall C
Duration	1 hour 25 min
Push or Pull	Push

Step	*5 (Bottleneck)*
Activity	Store: *In rack placement*
Function	WW Inbound - Pallet (High rise truck)
o)	1 (2 depending on complexity)
IT/DOC	Product Stickers + Location stickers + Scanner - SAP
PT	1,5 min/pallets (40 pallets per hour per person)
LT	2,4 min/pallet (25 per hour per person)
Barriers	- Inefficient allocation procedure - Only places deeper down the aisle considered (*) > Result = increase in distance. - Space limits - Order picker usages same aisle > Result = Down time

Type WIP	Sorted OEM on pallets in rack
Location	Rack, Storage - Hall B/Hall C
Duration	50 days
Push or Pull	Pull

Step	6
Activity	Report: *Discharge list check (when changes are applicable) & drop at Expedition*
Function	WW Inbound - Pallet
o)	1
IT/DOC	Discharge List – SAP WMS
PT	
LT	
Barriers	- Modify changes manually on discharge list > Result = Inaccuracy

Type WIP	NO WIP

A5.2 VSM – Inbound + Put away trailer – Clamp goods

Value stream map: Inbound trailer + Put away
Product group: Clamp
Frequency/Demand:

Conditions:
First Step: Collect discharge list
Last Step: Drop discharge list

Trigger: Arrival truck
Boundaries: Available time (when arrival on other timespan than planned)

Step	1
Activity	**Unload** *Request Discharge list, Unloading truck, Unpack, Sort & Check*
Function	WW inbound - Clamp (Clamp Truck)
o)	2
IT/DOC	Discharge list (2x) + quality stickers - SAP
PT	
LT	30 min
Barriers	

Type WIP	(mixed) OEM Clamp items
Location	Floor, inbound - hall D/hall E (Hall A)
Duration	45 min
Push or Pull	Push

Step	2
Activity	**Check/Transport/Store**: *Check, move & place*
Function	WW inbound - Clamp (Clamp truck)
o)	1
IT/DOC	Discharge list
PT	
LT	35 min
Barriers	- Different locations – Buffer and pick inventory > Result = extra movements

Type WIP	Sorted OEM clamp items & Items for quality check
Location	Floor blockstack, Storage - hall D/Hall E/Hall A
Duration	35 min
Push or Pull	Pull

Step	2b
Activity	**Report**: *Discharge list check (when changes are applicable), Confirm unloading & drop at Expedition*
Function	WW inbound - Clamp
o)	
IT/DOC	Discharge List - SAP
PT	
LT	35 min
Barriers	- Modify changes manually on discharge list > Result = Inaccuracy

Type WIP	X
Location	X
Duration	X
Push or Pull	X

A5.3 VSM - Inbound + Put away trailer – Pallet goods + clamp goods

Value stream map: Inbound trailer + Put away (1/2)
Product group: Clamp + Pallet
Frequency/Demand:

Conditions:
First Step: Collect discharge list
Last Step: Drop discharge list

Trigger: Arrival truck
Boundaries: Available time (when arrival on other timespan than planned)

Step	1
Activity	**Unload**: *Request Discharge list, Unloading truck & Unpack*
Function	WW Inbound - clamp
o)	2
IT/DOC	Discharge list Pallet + Discharge list clamp + quality stickers + product stickers - SAP
PT	
LT	
Barriers	

Type WIP	Clamp & Pallet goods & Quality check items
Location	Floor, inbound – Hall D
Duration	
Push or Pull	Push

Step	2
Activity	**Check/Sort**: *Check quantities & sort quality item & Repack (if needed)*
Function	WW Inbound – Clamp
o)	2
IT/DOC	Discharge list pallet + Product stickers + Quality stickers
PT	
LT	
Barriers	

Type WIP	Items for quality check
Location	QM collection, Inbound – Hall D
Duration	
Push or Pull	Push

Step	3
Activity	**Prepare Stock**: *paste product stickers & taping*
Function	WW Inbound - Clamp (Pallets)
o)	1 (2)
IT/DOC	Product stickers
PT	15-20 min
LT	
Barriers	

Type WIP	Sorted OEM on pallets
Location	Floor, Inbound - Hall B
Duration	
Push or Pull	Push

Step	4a
Activity	**Transport:** *Move pallets to Rack storage*
Function	WW Inbound - Clamp (Electric Pallet truck)
o)	1
IT/DOC	Product stickers
PT	
LT	
Barriers	- Space limits > Result = Downtime: The movements towards racks have to wait, till previous pallets are stored or full pallets are moved

Type WIP	Sorted OEM on pallets
Location	Floor front Rack-End, Storage - Hall B/Hall C
Duration	
Push or Pull	Push

Step	4b
Activity	**Transport/Store**: *Move clamp goods to storage place*
Function	WW inbound - Clamp (Clamp truck)
o)	1
IT/DOC	Discharge list
PT	
LT	
Barriers	Different locations – Buffer and pick inventory > Result = extra movements - Locations not always clearly marked > Result = wrong storage location – difficulties by picking

Type WIP	Sorted OEM clamp items & Items for quality check
Location	Floor, blockstack Storage - hall D/hall E/Hall A
Duration	35 min
Push or Pull	Pull

Step	5
Activity	**Report**: *Discharge list check (when changes are applicable), Confirm unloading & drop at Expedition*
Function	WW inbound - Clamp
o)	1
IT/DOC	Discharge List - SAP
PT	
LT	
Barriers	- Modify changes manually on discharge list > Result = Inaccuracy

Type WIP	X
Location	X
Duration	X
Push or Pull	X

A5.4 VSM - Order picking Dispatch - Pallet goods + clamp goods

Value stream map: Order picking
Product group: Pallet
Frequency/Demand: 90 colli per hour

Conditions: Normal or Special client request (Post NL) **Trigger:** Delivery scheduling order
First Step: Collect picklist
Last Step: Drop full pallet
Boundaries: Available floor space dispatch area
Average time duration:

Step	1
Activity	**Receive:** *Collect pallet picklist & Collect Pallet*
Function	WW Outbound - Order picker Pallet (Orderpicker)
o)	1
IT/DOC	Pallet pick list + Pallet stickers - SAP
PT	
LT	
Barriers	- Different pallets for different clients

Type WIP	Pallet
Location	Orderpicker, Storage – Hall A/Hall D
Duration	
Push or Pull	Push

Step	2
Activity	**Collect/Load:** *Collect items & paste pallet stickers*
Function	WW Outbound – Order picker Pallet (Orderpicker)
o)	1
IT/DOC	Pallet picklist + Colli stickers
PT	
LT	
Barriers	

Type WIP	Pallets with mixed OEM items
Location	Orderpicker – Hall B/Hall C
Duration	
Push or Pull	Push

Step	3
Activity	**Position/Unload:** *Place items pending consolidation (Repeat Step 2 & Step 3), Drop picklist and note (if applicable) changes*
Function	WW Outbound – Order picker Pallet (Orderpicker)
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Pallets with mixed collected OEM items
Location	Floor, outbound– Hall A/Hall D
Duration	
Push or Pull	Push

Step	
Activity	
Function	
o)	
IT/DOC	
PT	
LT	
Barriers	

Type WIP	
Location	
Duration	
Push or Pull	

Step	
Activity	
Function	
o)	
IT/DOC	
PT	
LT	
Barriers	

Type WIP	
Location	
Duration	
Push or Pull	

Step	
Activity	
Function	
o)	
IT/DOC	
PT	
LT	
Barriers	

Type WIP	
Location	
Duration	
Push or Pull	

Value stream map: Consolidation + dispatch ride (1/2)
Product group: Pallet + Bulk
Frequency/Demand: 150 pallets per 3 man per day

Conditions: Specific requirements per client (Coolblue, Bruynzeel, PostNL)
First Step: Collect ride information
Last Step: Place dispatch pallets at final destination

Trigger: Pallet with mixed collected OEM Items
Boundaries: Available floor space outbound area
Average time duration:

Step	1
Activity	Receive info: *Collect ride information & Place pallets*
Function	WW Outbound – Consolidation (Electric Pallet Truck)
o)	1
IT/DOC	Picklist clamp + Picklist pallet + Heavy pallet + full pallet picklist + Colli stickers + Consolidation list + Dispatch stickers - SAP
PT	
LT	
Obstacles	- Space limits > Result = not optimal space utilization – maximum of 8 pallets currently possible

Type WIP	Pallets
Location	Floor, Consolidation – Hall A/Hall D
Duration	
Push or Pull	Push

Step	2
Activity	Consolidate: *Place clamp goods*
Function	WW Outbound – Orderpicker Clamp (Clamp truck)
o)	1
IT/DOC	Picklist clamp
PT	
LT	
Obstacles	

Type WIP	Clamp
Location	Pallet, consolidation– Hall A/Hall D
Duration	
Push or Pull	Push

Step	3
Activity	Consolidate: *Check clamp goods, paste colli stickers, Place pallet goods*
Function	WW Outbound - Consolidation
o)	1
IT/DOC	Consolidation list + Pallet stickers
PT	
LT	
Obstacles	

Type WIP	Clamp + Palletgoods
Location	Floor, Consolidation – Hall A/Hall D
Duration	
Push or Pull	Push

Step	4
Activity	Check: *Check overall pallet + paste dispatch stickers*
Function	WW Outbound - Consolidation
o)	1
IT/DOC	Pallet stickers + Dispatch stickers + Scanner - SAP
PT	
LT	
Obstacles	- Heavy and full pallets might miss > Result = Inefficient execution – downtime for picking. - Not all products have a scannable barcode > Result = inaccuracy – no 100% check

Type WIP	Clamp + Pallet goods
Location	Pallet, Consolidation - Hall A/Hall D
Duration	
Push or Pull	Push

Step	5
Activity	Consolidate: *Collect heavy and full pallets, consolidate & Check*
Function	WW Outbound – Consolidation (Electric Pallet Truck)
o)	1
IT/DOC	Heavy picklist + consolidation list + Dispatch sticker + palletstickers + product sticker + Scanner - SAP
PT	
LT	
Obstacles	- Exact location of heavy and full pallets not always exactly know. > Result = Time Loss: for searching articles - Restructure of already consolidated pallet > Result = Time loss

Type WIP	Clamp + Pallet + Heavy goods
Location	Floor, Consolidation area – Hall A/D
Duration	
Push or Pull	Push

Step	6
Activity	Prepare Shipment: *Sealing of pallets*
Function	WW Outbound – Dispatch (Electric Pallet Truck)
o)	1
IT/DOC	
PT	
LT	
Obstacles	

Type WIP	Dispatch pallet
Location	Plasticizer, consolidation – Hall A/Hall D
Duration	
Push or Pull	Push

Value stream map: Consolidation + dispatch ride (2/2)
Product group: Pallet + Bulk
Frequency/Demand: 150 pallets per 3 man per day

Conditions: Specific requirements per client (Coolblue, Bruynzeel, PostNL)
First Step: Collect Ride information
Last Step: Place dispatch pallets at final destination

Trigger: Pallet with mixed collected OEM Items
Boundaries: Available floor space outbound area
Average time duration:

Step	7
Activity	Position/Load: *Place goods for dispatch + note changes and dispatch info*
Function	WW Outbound – Dispatch (Electric Pallet Truck)
o)	1
IT/DOC	Consolidation list - SAP
PT	
LT	
Obstacles	- Space limits > results = Time loss & distance increase – inefficient placement of dispatch ride

Type WIP	Dispatch pallets
Location	Truck/floor, temporarily outbound – Hall A/ Hall D
Duration	
Push or Pull	Pull

A5.5 VSM – Order picking Dispatch Delivery – Pallet goods + clamp goods

Value stream map: Dispatch Delivery & Pick up
Product group: Pallet + Bulk
Frequency/Demand: Daily

Conditions:
First Step:
Last Step:

Trigger: Arrival of order
Boundaries:

Step	1
Activity	Receive info: *Receive order* *1. Create take-away order & invoice & print* *2. Create appointment with clients*
Function	Expedition worker
o)	1
IT/DOC	Take-away/Courier order picklist + Invoice + Dispatch sticker– SAP WM Vision
PT	
LT	
Barriers	

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	2
Activity	Collect: *Collect items & paste dispatch sticker*
Function	WW Outbound – Order picker Pallet (Orderpicker)
o)	1
IT/DOC	Take-away order picklist – SAP WM Vision
PT	
LT	
Barriers	

Type WIP	Pallets with mixed OEM items
Location	Orderpicker – Hall B/Hall C
Duration	
Push or Pull	Push

Step	3
Activity	Position/Unload: *Place items pending take-away/courier shipment and Drop take-away picklist*
Function	WW Outbound – Order picker Pallet (Orderpicker)
o)	1
IT/DOC	Invoice
PT	
LT	
Barriers	

Type WIP	Pallets with mixed collected OEM items
Location	Floor, outbound take-away – Hall C
Duration	
Push or Pull	Push

A5.6 VSM – Replenishment & Compress – Pallet goods + clamp goods

Value stream map: Replenishment
Product group: Pallet
Frequency/Demand: 2,5 per day – 20-30 pallets per hour

Conditions:
First Step: Collect empty pallets
Last Step: Placement of pallet

Trigger: Free time in the planning
Boundaries: Time limitations
Average time duration:

Step	1
Activity	**Receive info:** *Read system, Pick up empty pallets at bins and drop at storage location*
Function	WW Inbound - full pallets (High rise truck)
o)	1
IT/DOC	Scanner - SAP
PT	
LT	
Barriers	

Type WIP	Empty pallets
Location	Floor, Empty pallet storage – Hall A/Hall D
Duration	
Push or Pull	Pull

Step	2
Activity	**Move/Collect/Load:** *Move to inventory bin & pick up pallet*
Function	WW inbound – full pallets (high rise truck)
o)	1
IT/DOC	Scanner - SAP
PT	
LT	
Barriers	- Different location - Sometimes goods are stored at the wrong place > Result = Time waste - Search for right goods + count inventory

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	3
Activity	**Position/Unload/Report:** *Move to destination, place pallet & confirm*
Function	WW inbound – full pallets (high rise truck)
o)	1
IT/DOC	Scanner - SAP
PT	
LT	
Barriers	

Type WIP	Pallet goods
Location	Rack, storage - Hall C/Hall D
Duration	
Push or Pull	Pull

XX

Value stream map: Compress
Product group: Bulk
Frequency/Demand: Daily

Conditions:
First Step: Receive compress info
Last Step: Report compress info

Trigger: Lack of space for incoming goods or too great distance
Boundaries:

Step	1
Activity	**Receive info:** *Request compress-list*
Function	WW Inventory Management Planning
o)	1
IT/DOC	Compress list – SAP
PT	
LT	
Obstacles	

Type WIP	Compress-list
Location	Expedition
Duration	
Push or Pull	Push

Step	2
Activity	**Collect/Position:** *Collect items, move to new location position and unload items*
Function	WW Inbound - Clamp (Clamp Truck)
o)	1
IT/DOC	Compress-List
PT	
LT	
Obstacles	

Type WIP	Sorted OEM clamp items
Location	Floor, blockstack storage - hall D/hall E/hall A
Duration	
Push or Pull	Pull

Step	3
Activity	**Report:** *Compress list check, Confirm movements & drop at Expedition*
Function	WW Inbound - Clamp
o)	1
IT/DOC	Compress list – SAP
PT	
LT	
Obstacles	

Type WIP	X
Location	X
Duration	X
Push or Pull	X

A5.7 VSM – Return processes – Pallet goods + clamp goods

Value stream map: Customer & quality return
Product group: Clamp + Pallet
Frequency/Demand: Daily (Return goods), weekly (QA), biweekly

Conditions: Items not accepted by clients or returned from QA
First Step: Collect receipt goods
Last Step: Bring products to store location

Trigger: Incoming return goods
Boundaries: Not always aware of number of arrivals beforehand
Average time duration:

Step	1
Activity	**Unload**: *Pick up goods & report undeclared goods (return goods, QA goods & damaged goods)*
Function	WW Return
o)	1
IT/DOC	
PT	
LT	
Barriers	-Inaccessible resources - QA items not always present > Result = Inefficient execution – everything is delivered at once

Type WIP	Return goods, QA goods & Damaged goods
Location	Floor, Service workshop – Hall C
Duration	
Push or Pull	Push

Step	2
Activity	**Check:** *Return reference number on correctness label with product (return goods)/check damage form (damaged goods), analyse goods, denote findings and decide on destination (return goods & Damage Goods)*
Function	WW Return
o)	1 a 2
IT/DOC	Insert data - SAP WMS
PT	
LT	
Barriers	- Not always entered in system & incorrect label > Result = Time waste for sort situation & extra movements - Products are not scanned > Result = Inaccuracy: No FIFO and shortage in data management

Type WIP	NO WIP

Step	3
Activity	**Repack**: *Create "Impact" or rebook, decide on location, post goods (return goods & QA goods) & place items on pallet*
Function	WW Return
o)	1
IT/DOC	Process Data - SAP WMS
PT	
LT	
Barriers	- Some of the virtual locations are used by others too > Result = no overview of 'own' goods – Sorting takes time – Not efficient. - System location availability = not accurate compared to real-life > Result = Time waste & unnecessary movement - Sometimes no location in system due to no current inventory stored. > Result = Takes more time to process

Type WIP	A-choice & QA goods on pallet B-choice goods on pallet & C-choice goods
Location	Floor, service workshop or scrap bin – Hall C
Duration	
Push or Pull	Push

Step	4
Activity	**Prepare stock/Report**: *A-choice & QA goods: Print discharge list, Paste stickers, remove sticker residue* *B-choice: Print label + insert in system and create 1 order* *C-choice: Write off*
Function	WW Return
o)	1
IT/DOC	A-choice & QA: Product sticker + discharge list - SAP B-choice: Order list + Label – SAP C-choice: SAP
PT	
LT	
Barriers	
Type WIP	No WIP

Step	5
Activity	**Store**: *Seal, label & store B-choice products*
Function	WW Return
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	B-choice goods on pallets
Location	Rack, Storage - hall C
Duration	
Push or Pull	Push

Step	6
Activity	**Move/Store**: *Move c-choice goods from scrap bin to scrap container*
Function	WW Return
o)	1
IT/DOC	
PT	
LT	
Barriers	- Scrap container is relatively far away from return workshop

Type WIP	No WIP

A5.8 VSM – Inbound + Put away – Spare parts

Value stream map: Inbound supplier shipments + Put away
Product group: Spare Parts
Frequency/Demand: Daily

Conditions:
First Step: Pick up pallet
Last Step: Store items + stickers in racks

Trigger: Arrival of pallets at lift
Boundaries:

Step	1
Activity	**Unload**: *Pick up pallets & deliver QA pallet*
Function	WW Inbound - Spare Parts
o)	1
IT/DOC	Discharge list – SAP WM vision
PT	
LT	
Barriers	

Type WIP	Pallet with boxes
Location	Floor, Inbound - Hall G or QA rack, inbound – Hall H
Duration	
Push or Pull	Push

Step	2
Activity	**Check/Prepare stock**: *Check discharge list with system, paste product sticker (if needed: create location – also bulk), print invoice*
Function	WW Inbound - Spare Parts
o)	1
IT/DOC	Discharge list, product stickers - Invoice – SAP WM vision
PT	
LT	
Barriers	

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	3
Activity	**Check/Prepare stock**: *Check in articles from hall A, B, C & D*
Function	WW Inbound - Spare Parts
o)	1
IT/DOC	Insert Data - SAP WM Vision
PT	
LT	
Barriers	

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	4
Activity	**Check**: *Check other items and inform final recipient*
Function	WW Inbound - Spare Parts
o)	1
IT/DOC	Email - Outlook
PT	
LT	
Barriers	

Type WIP	Other items
Location	Floor near door, inbound – Hall G
Duration	
Push or Pull	Push

Step	5
Activity	**Collect/load**: *Place items in trolley*
Function	WW Inbound - Spare Parts
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Single spare part items
Location	Trolley, Inbound - Hall G
Duration	
Push or Pull	Push

Step	6
Activity	**Store**: *Place items + product stickers in racks*
Function	WW Inbound - Spare Parts (Reach truck)
o)	1
IT/DOC	Set of stickers product – SAP WM vision
PT	
LT	
Barriers	

Type WIP	Spare Part Stock
Location	Pick Racks & Bulk Racks, Storage – Hall G
Duration	
Push or Pull	Pull

Value stream map: Inbound return boxes service technicians + Put away
Product group: Spare Parts
Frequency/Demand: Daily

Conditions:
First Step: Pick up pallets
Last Step: Place items in racks

Trigger: Delivering of returned service boxes
Boundaries:

Step	1
Activity	**Collect:** *Collect service technicians boxes*
Function	WW Inbound - Return Service boxes
o)	2
IT/DOC	
PT	
LT	
Obstacles	

Type WIP	Service Technicians
Location	Floor, Inbound service boxes - Hall G
Duration	2 hours
Push or Pull	Push

Step	2
Activity	**Unload:** *Unpacking boxes, Scan box/insert technician number, Scan return articles, Paste product stickers*
Function	WW Inbound - Return Service Boxes
o)	2
IT/DOC	Scanner + SAP WM Vision
PT	5 min per box
LT	
Obstacles	

Type WIP	Single Spare Parts
Location	Table, Inbound – Hall G
Duration	2,5 min
Push or Pull	Push

Step	3
Activity	**Collect/Load:** *place in trolley (sort)*
Function	WW Inbound - Return Service Boxes
o)	2 (sometimes 3)
IT/DOC	Product stickers – SAP WM Vision
PT	2,5 min
LT	
Obstacles	

Type WIP	Single Spare Parts
Location	Trolleys, Inbound service boxes – Hall G
Duration	
Push or Pull	Push

Step	4
Activity	**Store:** *Store Spare Parts in Racks*
Function	WW Inbound - Return Service Boxes
o)	1
IT/DOC	
PT	
LT	
Obstacles	

Type WIP	Spare Parts Stock
Location	Pick racks, Storage – Hall G
Duration	
Push or Pull	Pull

A5.9 VSM - Put-away + Order picking elevator – Spare parts

Value stream map: Put away Elevator
Product group: Spare parts
Frequency/Demand:

Conditions:
First Step: Pick up items at inbound
Last Step: Place item in Elevator

Trigger: Inbound activities are completed
Boundaries:

Step	1
Activity	**Collect/Load:** *Pick up items at inbound*
Function	WW Elevator Service
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Boxes with mixed Spare Part items
Location	Floor, Elevator Area – Hall G
Duration	
Push or Pull	Push

Step	2
Activity	**Collect/Load:** *Start system & Sort items in order of elevator drawers per shaft*
Function	WW Elevator Service
o)	1
IT/DOC	Kardex – Power Picker
PT	
LT	
Barriers	- While picking up goods it is possible to enter new items > Result = Inefficient execution - Systems gives order for certain item, while still at inbound table

Type WIP	Spare Part Stock
Location	Elevator Kardex – Hall G
Duration	
Push or Pull	Pull

Step	3
Activity	**Store:** *Place items in elevator*
Function	WW Elevator Service
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Spare Parts Stock
Location	Drawer, Kardes – Hall G
Duration	
Push or Pull	Pull

Value stream map: Order picking Elevator
Product group: Spare Parts
Frequency/Demand:

Conditions:
First Step: Start system
Last Step: Place items on trolley

Trigger: Receive pick list from Orderpicker Customer/Orderpicker Technicians
Boundaries:

Step	1
Activity	**Receive Info:** *Start System*
Function	WW Elevator Service
o)	1
IT/DOC	Kardex - Powerpick
PT	
LT	
Obstacles	

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	2
Activity	**Collect:** *Collect items, write down Service Technician number/order number, place in box/on trolley*
Function	WW Elevator Service
o)	1
IT/DOC	Kardex - Powerpick
PT	
LT	
Obstacles	- Picking and put away can be combined, but overview gets lost > Result = Time waste

Type WIP	Single spare part items
Location	Trolley, Elevator Area – Hall G
Duration	
Push or Pull	Push

Step	3
Activity	**Position/load:** *Place items in Service Technician Boxes*
Function	WW Elevator Service
o)	1
IT/DOC	
PT	
LT	
Obstacles	

Type WIP	Sorted Spare Part Items
Location	Service Technicians Boxes, Outbound – Hall G
Duration	
Push or Pull	Push

A5.10 VSM – Order picking + Dispatch customer – Spare parts

Value stream map: Order picking + Dispatch
Product group: Spare Parts Customer
Frequency/Demand: # per day

Conditions:
First Step: Start up system
Last Step: Place mail trolleys in shipping portal

Trigger: Start of new day
Boundaries:

Step	1
Activity	**Collect/Receive info**: *Collect mail trolley, Boot system, retrieving orders, mail erroneous orders, print, check and rip stickers & print pick list lift*
Function	WW Orderpicker - Customer
o)	1
IT/DOC	Dispatch stickers + Customer pick list lift - SAP WM Vision
PT	
LT	
Barriers	- Different location - Item not always present - Different location - Stickers not always present > Result = Time waste printing/searching/login 3 a 4 times per route – each time 3 a 4 min - Defect products > Result = Time waste for extra check (5 min)

Type WIP	Empty Mail Trolley
Location	Floor, Outbound area – Hall G
Duration	
Push or Pull	Push

Step	2
Activity	**Move**: *Sort dispatch tickers and bring pick list to lift*
Function	WW Orderpicker - Customer
o)	1
IT/DOC	Dispatch stickers + Customer pick list lift – SAP WM vision & PowerPick
PT	
LT	
Barriers	

Type WIP	X

Step	3
Activity	**Collect/Load**: *Collect items, paste product stickers, & scan dispatch + product stickers*
Function	WW Orderpicker - Customer
o)	2 (or more when necessary)
IT/DOC	Product sticker + Scanner – SAP WM Vision
PT	
LT	
Barriers	- Refreshing is necessary for second picker > Result = possible inconsistency – inefficient - Larger size products do not always fit trolley > Result = Distance increase - Extra pick round for bigger items

Type WIP	Sorted Single Spare Part items
Location	Trolley, outbound area – Hall G
Duration	
Push or Pull	Push

Step	5
Activity	**Consolidate**: *Collect and sort lift items, second picker items & place 'accumulate customers' items in accompanying box*
Function	WW Orderpicker - Customer
o)	2
IT/DOC	Dispatch stickers – SAP WM Vision
PT	
LT	
Barriers	

Type WIP	Sorted Single Spare Part items
Location	Trolley & aggregate boxes, outbound area – Hall G
Duration	
Push or Pull	Push (trolley) Pull (aggregrate boxes)

Step	6
Activity	**Check**: *Check delivery, scan product stickers and dispatch sticker (Order dispatch form print), Collect Order Dispatch Forms & add to shipment*
Function	WW Wrapper - Customer
o)	2
IT/DOC	Product sticker + Dispatch sticker + Order dispatch forms– SAP WM Vision + Post NL stickers
PT	
LT	
Barriers	- Sometimes connection loss > Result = Time waste due waiting

Type WIP	X

Step	7
Activity	**Prepare shipment:** *Remove supplier brand stickers, pack goods, paste dispatch stickers, place on mail trolley (NL or EU) or place for pick up reception*
Function	WW Wrapper Customer
o)	2
IT/DOC	Dispatch sticker + waybill
PT	
LT	
Obstacles	

Type WIP	Dispatch packages
Location	Mail trolley Floor door, Outbound - Hall G
Duration	
Push or Pull	Push

Step	8
Activity	**Position/Unload**: *Seal mail trolley & place for dispatch*
Function	WW Wrapper Customer
o)	1/2
IT/DOC	
PT	
LT	
Obstacles	

Type WIP	Mail Trolley
Location	Floor, Shipping portal - Hall E
Duration	1 hour
Push or Pull	Push

A5.11 VSM – Order picking + Dispatch 'great clients' – Spare parts

Value stream map: Dispatch 'Accumulate clients'
Product group: Spare Parts
Frequency/Demand: Weekly

Conditions:
First Step: Collect dispatch forms
Last Step: Place pending for shipment

Step	1
Activity	**Collect**: *Collect all dispatch forms for specific customer, collect all items, place all in pallet box & close*
Function	WW Wrapper - Customer
o)	1
IT/DOC	Dispatch Forms
PT	
LT	
Barriers	

Type WIP	Pallet box with collected orders for great clients
Location	Pallet, outbound floor – Hall G
Duration	
Push or Pull	Push

Step	2
Activity	**Position/Unload**: *Move box to outbound area & Place in outbound area – Hall A/Hall D*
Function	WW Wrapper - Customers
o)	1
IT/DOC	
PT	
LT	
Barriers	- Time costly activity

Type WIP	Pallet Box
Location	Floor, outbound area – Hall A/Hall D
Duration	
Push or Pull	Push

A5.12 VSM – Order picking + Dispatch Service technicians – Spare parts

Value stream map: Order picking + dispatch
Product group: Spare parts Service Technicians
Frequency/Demand: # per day

Conditions:
First Step: Start up the system
Last Step: Place items for dispatch

Trigger: Start of the day (07:45)
Boundaries: Boundary conditions service order has to be sufficient

Step	1
Activity	**Receive Info:** *Set up Service Technicians specific day, Boot system (before 10:00 Standard inventory, after 10:00 specific inventory), print pick lists & shipping advice, Print & Paste box sticker*
Function	WW Orderpicker - Service Technicians
o)	1
IT/DOC	Email – Outlook & SAP WM Vision
PT	
LT	
Barriers	

Type WIP	Service Technician Boxes
Location	Table, Service Technicians Outbound – Hall G
Duration	
Push or Pull	Push

Step	2
Activity	**Collect/Load**: *Collect items, Paste product sticker & note Service Technician number*
Function	WW Orderpicker - Service Technicians
o)	2
IT/DOC	Picklist Spare Parts Service Technicians
PT	
LT	
Barriers	

Type WIP	Single Spare Parts Items
Location	Pick Trolley, Storage – Hall G
Duration	
Push or Pull	Push

Step	3
Activity	**Consolidate**: *Place items in Service Technician Boxes*
Function	WW Orderpicker - Service Technicians
o)	2
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Sorted Spare Part Items
Location	Service Technician Boxes, Outbound – Hall G
Duration	
Push or Pull	Push

Step	4
Activity	**Prepare Shipment:** *Create and paste colli stickers, denote # of collis per technician & place collis in dispatch boxes*
Function	WW Orderpicker - Service Technicians
o)	2
IT/DOC	Collli Stickers - SAP WM vision
PT	
LT	
Barriers	

Type WIP	Dispatch ready collis
Location	Dispatch colli boxes, Outbound – Hall G
Duration	
Push or Pull	Push

Step	5
Activity	**Repeat:** *Restart system and repeat step 4, 5, 6*
Function	WW Orderpicker - Service Technicians
o)	2
IT/DOC	
PT	
LT	
Barriers	

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	6a
Activity	**Prepare Shipment:** *Send colli stickers info, box stickers info and to Hellman*
Function	WW Orderpicker service Technicians
o)	1
IT/DOC	StaringTex
PT	
LT	
Barriers	

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	6b
Activity	**Position/Unload:** *Shut down (4:00), prepare and close boxes for shipment, place on pallet, seal and place in Shipment portal*
Function	WW Orderpicker - Service Technicians
o)	2 (3 a 4)
IT/DOC	SAP WM Vision
PT	
LT	
Obstacles	

Type WIP	Boxes on Dispatch Pallets
Location	Floor, Shipment Portal – Hall E
Duration	
Push or Pull	Push

A5.13 VSM – Dispatch Bulk Service technicians - OEMs

Value stream map: Dispatch
Product group: OEMs
Frequency/Demand: Daily

Conditions:
First Step: Check colli situation for today
Last Step: Dispatch collis

Trigger: Arrival OEMs from distribution warehouse
Boundaries:

Step	1
Activity	**Receive info**: *Check mail for colli's, Set up Colli Technician Excel list, Print Colli stickers*
Function	WW Orderpicker - Service Technicians
o)	1
IT/DOC	Collisticker – StaringTex + SAP + Excel + Outlook
PT	
LT	
Barriers	

Type WIP	Colli Stickers
Location	Table, Service Technicians outbound – Hall G
Duration	X
Push or Pull	Push

Step	2
Activity	**Consolidate/Prepare shipment:** *Paste collisticker, Place on pallet & seal pallet*
Function	WW Orderpicker - Service Technicians
o)	1
IT/DOC	Collistickers
PT	
LT	
Barriers	

Type WIP	OEMs on pallet
Location	Floor, Service Technicians outbound – Hall G
Duration	
Push or Pull	Push

Step	3
Activity	**Position/unload:** *Place pallets in Shipment Portal*
Function	WW Orderpicker - Service Technicians
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Dispatch Pallets
Location	Floor, Shipment Portal – Hall E
Duration	
Push or Pull	Push

A5.14 VSM – Replenishment + Deduplications – Spare parts

Value stream map: Replenishment
Product group: Spare parts
Frequency/Demand: Weekly

Conditions:
First Step: Search for article location
Last Step: Insert information in system

Trigger: Free time in the planning
Boundaries: Time limitations, therefore the process is not executed enough

Step	1	***Step***	2	***Step***	3
Activity	**Receive info**: List with to replenish items and locations	***Activity***	**Collect/Load:** Collect pallet, collect items, past sticker	***Activity***	**Move/Position/Report:** Move to new location, place items, Insert new location & quantities in system
Function	WW Spare parts	***Function***	WW Spare parts (any function)	***Function***	WW Spare Parts (any function) (Reach Truck)
o)	1	***o)***	1	***o)***	1
IT/DOC	SAP WM Vision	***IT/DOC***		***IT/DOC***	Insert data – SAP WM Vision
PT		***PT***		***PT***	
LT		***LT***		***LT***	
Obstacles		***Obstacles***		***Obstacles***	

Type WIP	X	***Type WIP***	Spare parts pallet	***Type WIP***	Spare parts stock
Location	X	***Location***	Reach truck – Hall G	***Location***	Pick Racks, storage – Hall G
Duration	X	***Duration***		***Duration***	
Push or Pull	X	***Push or Pull***	Push	***Push or Pull***	Pull

Value stream map: De-duplication
Product group: Spare Parts
Frequency/Demand:

Conditions:
First Step: Find specific items
Last Step: Follow up upon findings

Trigger: Email from purchasing
Boundaries:

Step	1	***Step***	2	***Step***	3
Activity	**Receive info**: *Search for locations in system and collect items*	***Activity***	**Check:** *Email findings, rebook article, print new sticker*	***Activity***	**Collect & store:** *Move articles to correct location*
Function	WW Inbound - Spare Parts	***Function***	WW Inbound - Spare Parts	***Function***	WW Inbound - Spare Parts
o)		***o)***	1	***o)***	1
IT/DOC	Email - Outlook + SAP WM Vision + Nice-LabelPrint	***IT/DOC***	Email + SAP WM Vision	***IT/DOC***	
PT		***PT***		***PT***	
LT		***LT***		***LT***	
Barriers	- Not 1 system to search for locations > Inefficient execution & time waste	***Barriers***	- Purchasing employee does not always believe results. Result = Waste of time convincing	***Barriers***	

Type WIP	Single Spare Parts	***Type WIP***	X	***Type WIP***	Spare Parts Stock
Location	Table, Inbound Service Workshop- Hall G	***Location***	X	***Location***	Pick racks & Bulk racks, Storage – Hall G
Duration		***Duration***	X	***Duration***	
Push or Pull	Push	***Push or Pull***	x	***Push or Pull***	Pull

A5.15 VSM – Inbound + Put away – components

Value stream map:	Inbound + Put-away	**Conditions:**		**Trigger:**	Arrival of products
Product group:	Production Components	**First Step:**	Receive incoming goods	**Boundaries:**	
Frequency/Demand:	Daily	**Last Step:**	Store products		

Step	1
Activity	**Receive info/unload/check**: *Receive inbound number, inbound list, check numbers or send packaging list to purchasing*
Function	WW Inbound - Production
o)	1
IT/DOC	Email – Outlook & Scan – Printer
PT	
LT	
Barriers	

Type WIP	New components
Location	Floor, Inbound production – Hall G
Duration	
Push or Pull	Push

Step	2
Activity	**Prepare stock**: Print productstickers + recalculation + note inbound number, paste product sticker, email changes
Function	WW Inbound - Production
o)	1
IT/DOC	Product Stickers – SAP + Email - Outlook
PT	
LT	
Barriers	- Inaccuracy: Sometimes the number is not correct > Result = Inefficient execution (extra handling) Cumbersome process

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	3
Activity	**Collect/load**: Scan number/insert number, determine location
Function	WW Inbound – Production
o)	1
IT/DOC	Product stickers + Scanner – SAP
PT	
LT	
Barriers	- Locations are not always up to date > Result = Time waste searching for correct one - Only empty locations are considered > Result = Inefficient space utilization

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	4
Activity	**Store**: store products on location & Scan location
Function	
o)	
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Component stock
Location	Rack, Storage – Hall H
Duration	
Push or Pull	Pull

A5.16 VSM – Order picking – components

Value stream map: Order picking
Product group: Production Components
Frequency/Demand: Daily

Conditions:
First Step: Receive planning list
Last Step: Drop Components

Trigger: Planning
Boundaries: Not everything on stock/stock in system is incorrect

Step	1
Activity	**Receive info:** *Receive planning list & production orderlist, search production order and date*
Function	WW Order picker - Production
o)	1
IT/DOC	SAP
PT	
LT	
Barriers	- Scan doesn't work correct > Result = Time waste for searching in system

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	2
Activity	**Collect/Load:** *Start with large items, search location in scanner, transfer virtually, pick pallet with Electric Pump Truck*
Function	WW Order Picker – Production (Electric Pump Truck)
o)	1
IT/DOC	Scanner – SAP
PT	
LT	
Barriers	- Piece list is incorrect > Result = inaccuracy in inventory – sometimes extra pick – Time waste - Slow Electric Pump Truck

Type WIP	Components - Large
Location	Electric Pump Truck
Duration	X
Push or Pull	Push

Step	3
Activity	**Transport:** *Bring to P002,*
Function	WW Order Picker – Production
o)	1
IT/DOC	
PT	
LT	
Barriers	- Components are reduced in SAP after whole product is produced > Result = Inaccuracy inventory – system thinks component is still on stock

Type WIP	X
Location	X
Duration	X
Push or Pull	X

Step	4
Activity	**Store:** *store products on pick location P002*
Function	WW Order Picker – Production
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Component Stock
Location	Floor, Production – Hall H
Duration	
Push or Pull	Pull

Step	5
Activity	**Collect/Load:** *Subsequently search location in scanner for small components, transfer virtually, pick and put on trolley*
Function	WW Order Picker - Production
o)	1
IT/DOC	Scanner - SAP
PT	
LT	
Barriers	- Extra materials miss in the Requirementslist > Result = Inefficient execution – extra pick round needed

Type WIP	Components - Small
Location	Trolley
Duration	X
Push or Pull	Push

Step	6
Activity	**Transport & Store:** *Store the products on pick location P002*
Function	WW Order Picker – Production
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Component Stock
Location	Rack, Production – Hall H
Duration	
Push or Pull	Pull

A5.17 VSM – Shuttling – Finished goods & Quality goods

Value stream map: Shuttling
Product group: Pallet or Bulk
Frequency/Demand:

Trigger: Confirmation Ready Production
First Step: Collect items
Last Step: Place items in other building

Step	1
Activity	**Collect, Load & Move**: *After check in is created, collect items from production hall H*
Function	WW Shuttle Driver
o)	1
IT/DOC	"Impact" - SAP
PT	
LT	
Barriers	- Resource inaccessible > Result = Distance increase – Extra rides

Type WIP	Finished goods
Location	Shuttle Truck
Duration	
Push or Pull	Push

Step	2
Activity	**Position/unload:** *Place items at inbound Hall B*
Function	WW Shuttle Driver
o)	1
IT/DOC	
PT	
LT	
Barriers	

Type WIP	Finished goods
Location	Floor, Inbound – Hall B
Duration	
Push or Pull	

Value stream map: Inbound checked QA
Product group: Pallet + Bulk
Frequency/Demand: Daily

Conditions:
First Step: Place items in Elevator
Last Step: Deliver items at Service Workshop

Trigger: Space limit max reached
Boundaries: Not clear who places articles for pick

Step	1
Activity	**Collect/Load**: *Place pallets and items in elevator*
Function	WW Service dispatch
o)	1
IT/DOC	
PT	
LT	
Barriers	- Miss communication concerning responsibilities > Result = Inefficient execution & Downtime

Type WIP	Quality controlled items
Location	Floor, next to Elevator – Hall E
Duration	
Push or Pull	Push

Step	2
Activity	**Move**: *Transfer items from one building to the other*
Function	WW Shuttle Driver
o)	1
IT/DOC	
PT	
LT	
Barriers	

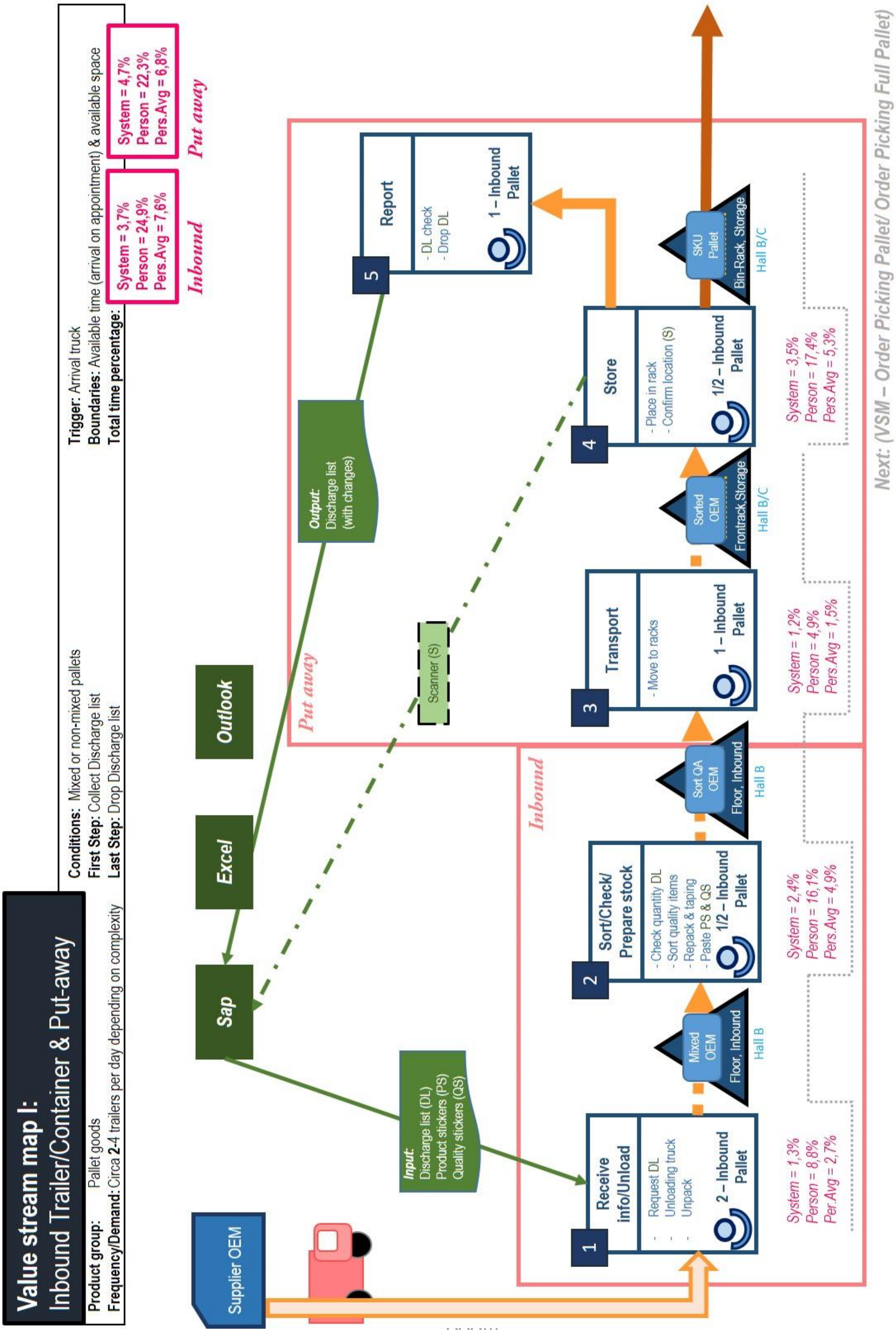
Type WIP	Quality controlled items
Location	Truck
Duration	
Push or Pull	Push

Step	3
Activity	**Position/Unload**: *Place items at Service Workshop*
Function	WW Shuttle Driver
o)	1
IT/DOC	
PT	
LT	
Barriers	

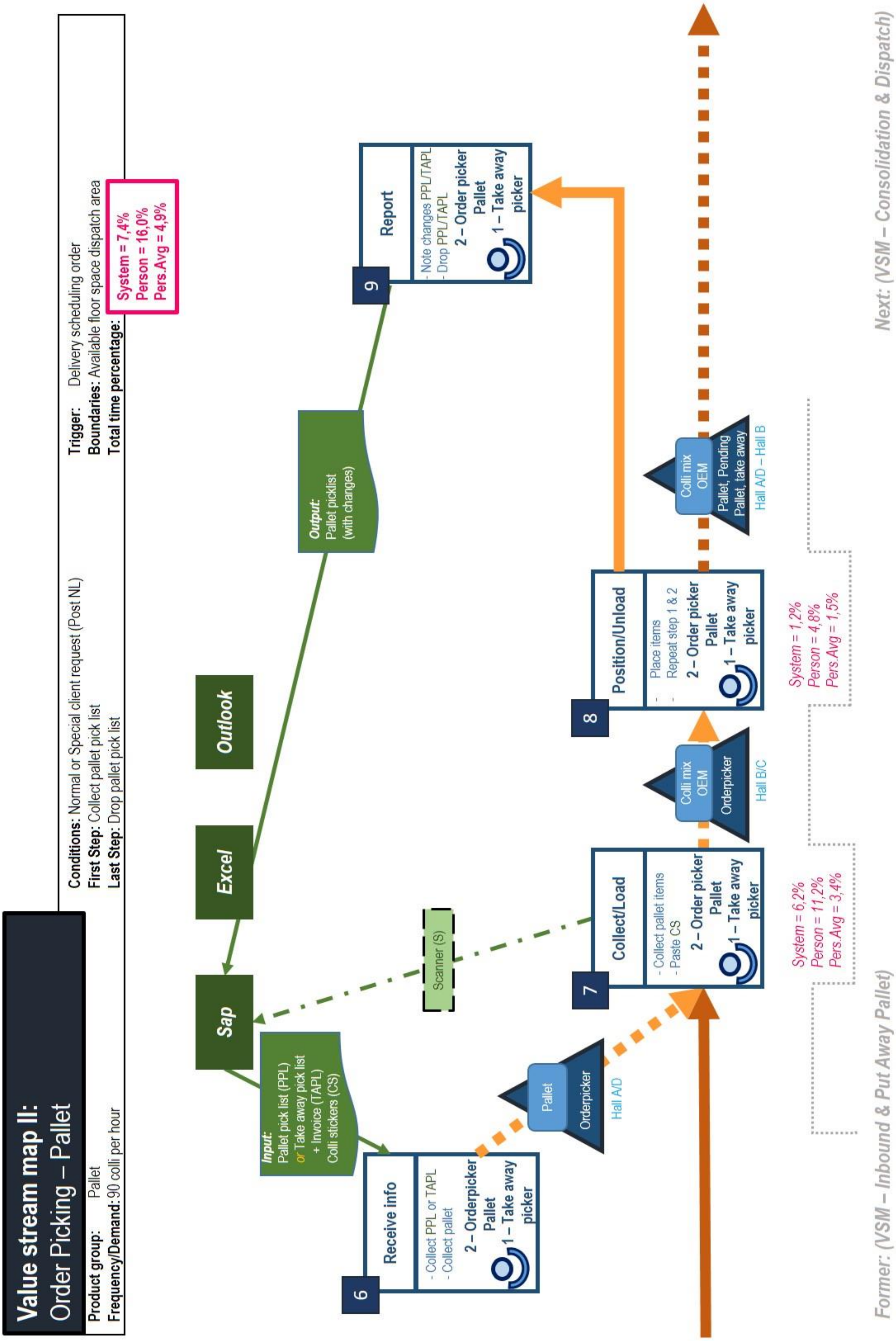
Type WIP	QA Goods
Location	Floor, Inbound Service Workshop – Hall G
Duration	
Push or Pull	Push

A.6Value Stream Maps on detailed level – Distribution warehouse

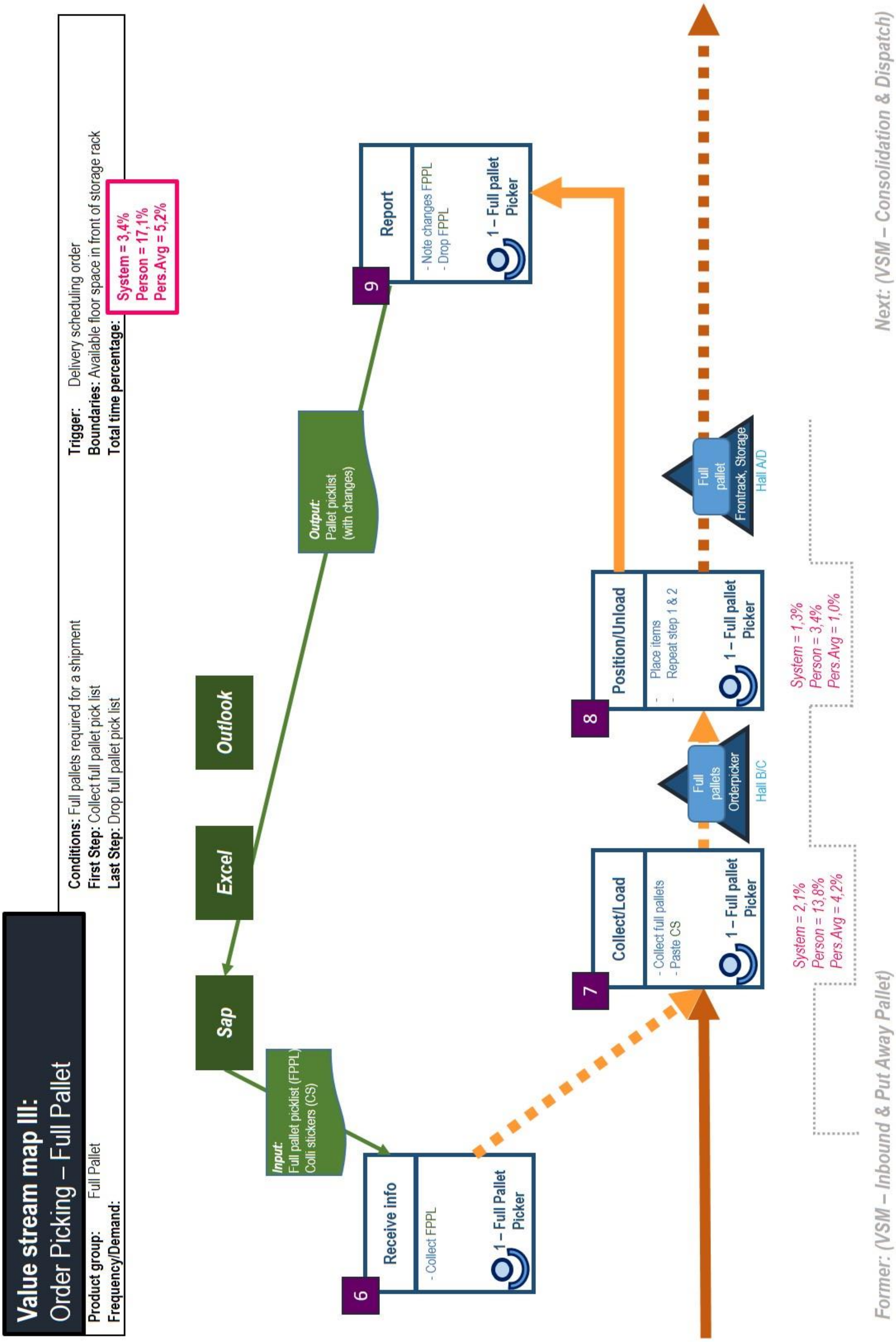
A6.1 VSM-I Inbound & Put away – Pallet goods



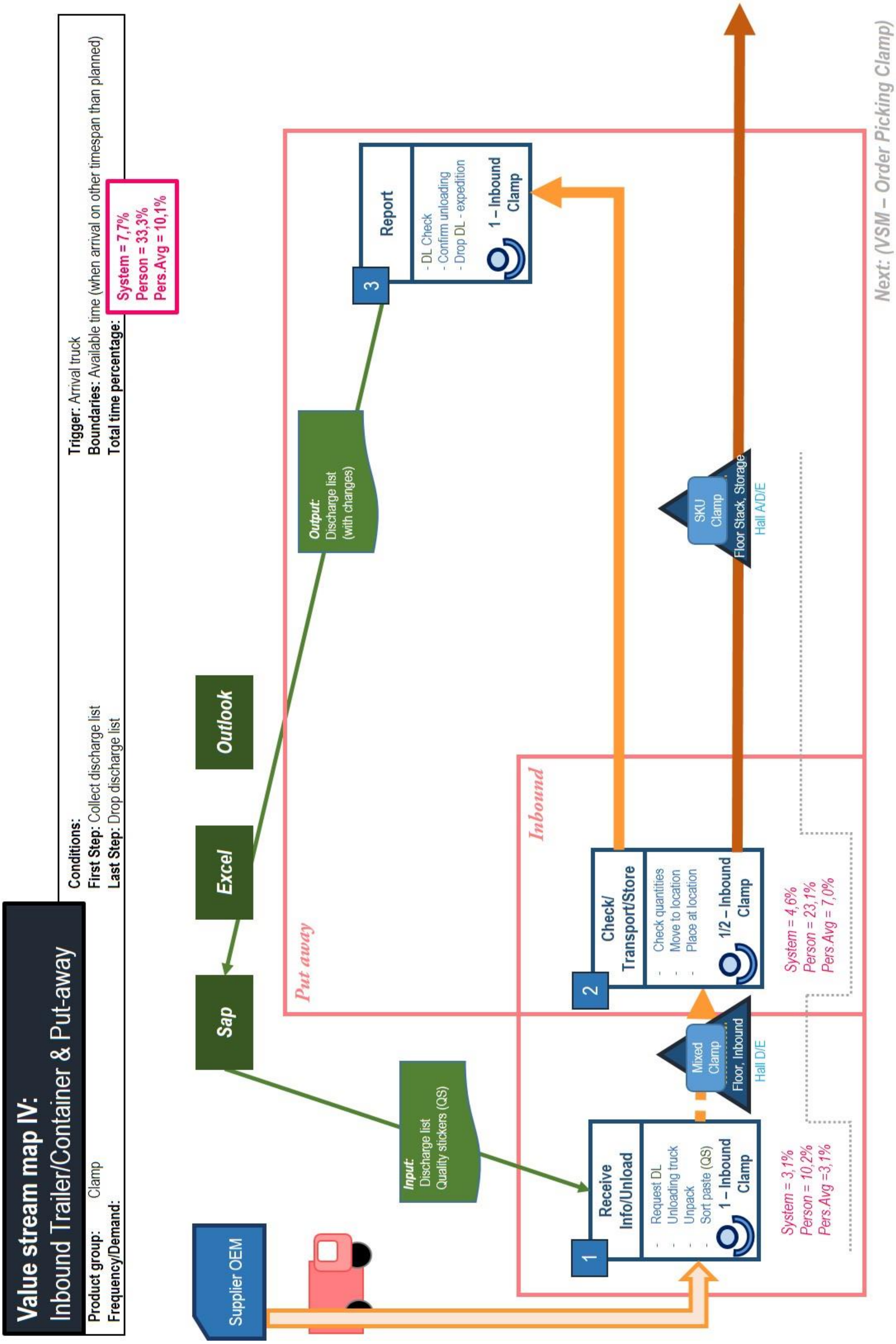
A6.2 VSM-II Order picking – Pallet goods



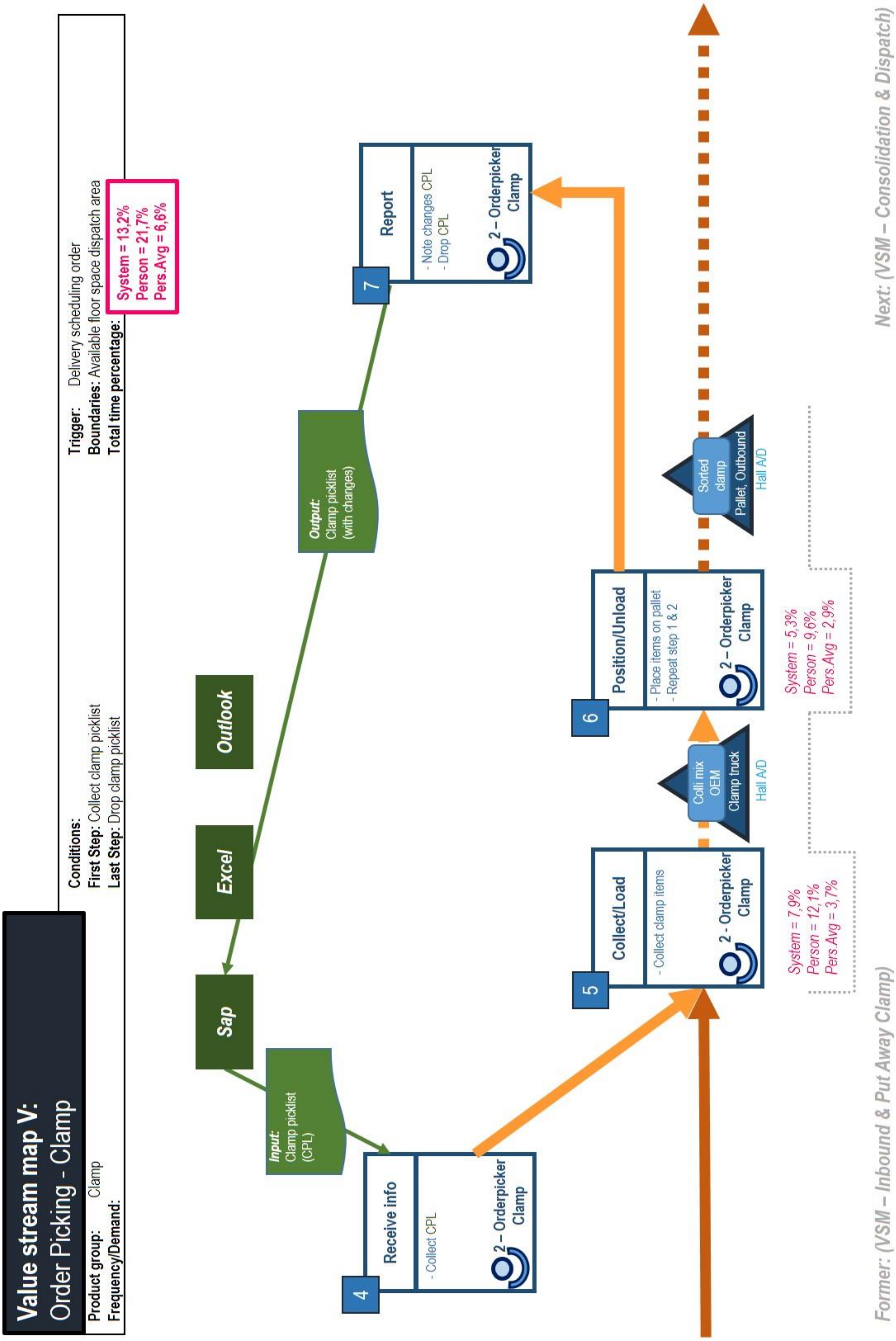
A6.3 VSM-III Order picking – Full pallets



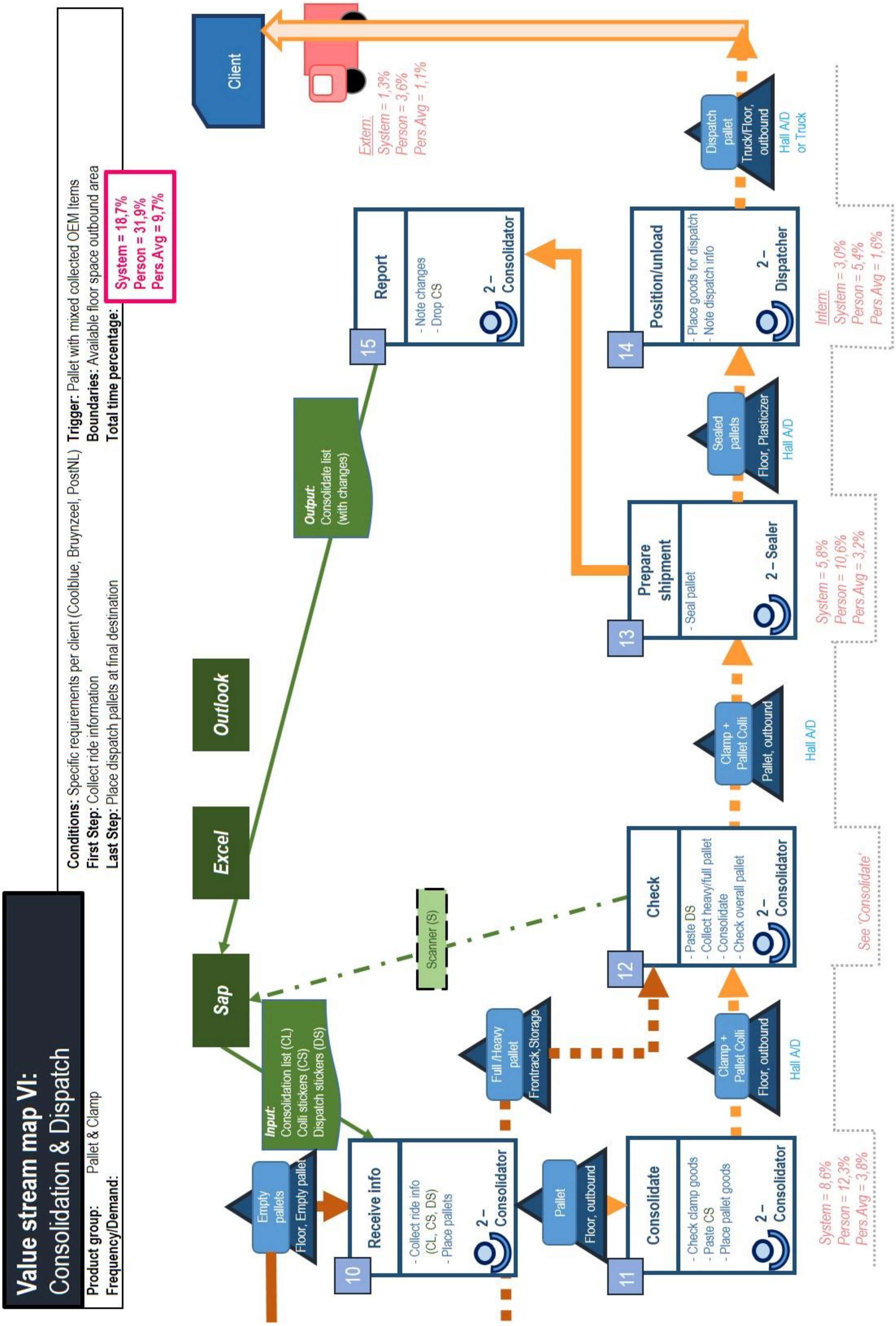
A6.4 VSM-IV Inbound & Put away – Clamp goods



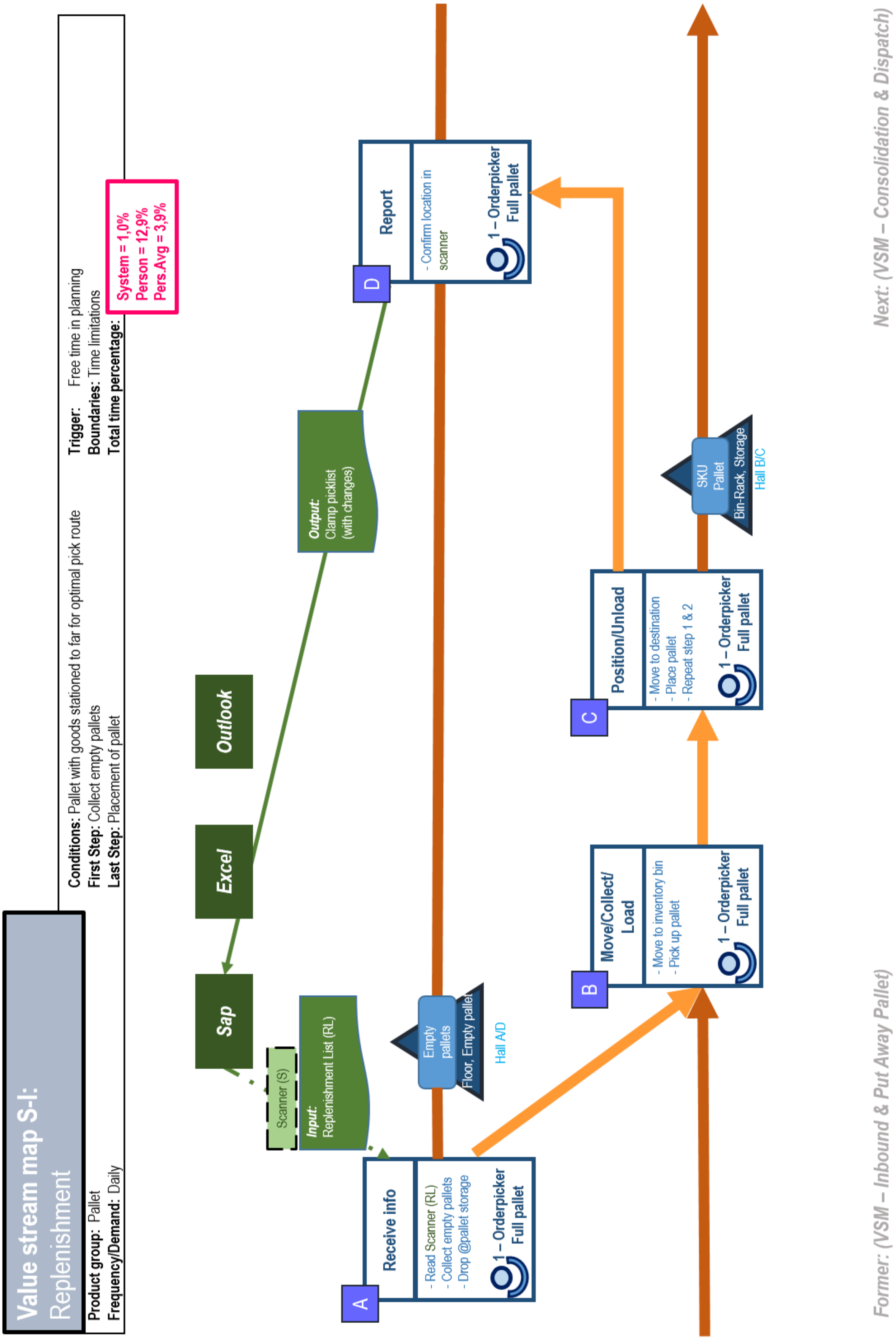
A6.5 VSM-V Order picking – Clamp goods



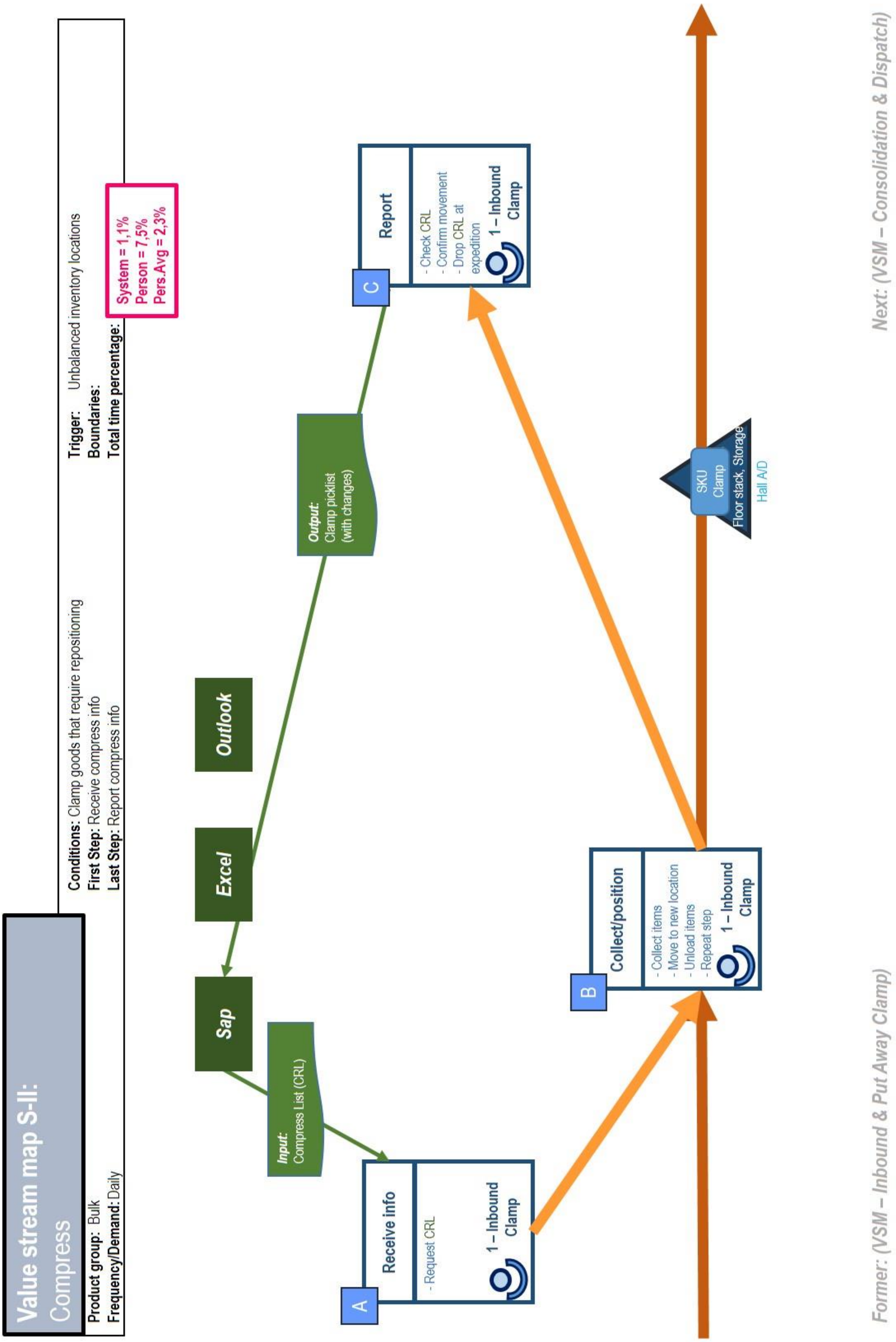
A6.6 VSM-VI Consolidation & Dispatch – Pallet & clamp goods



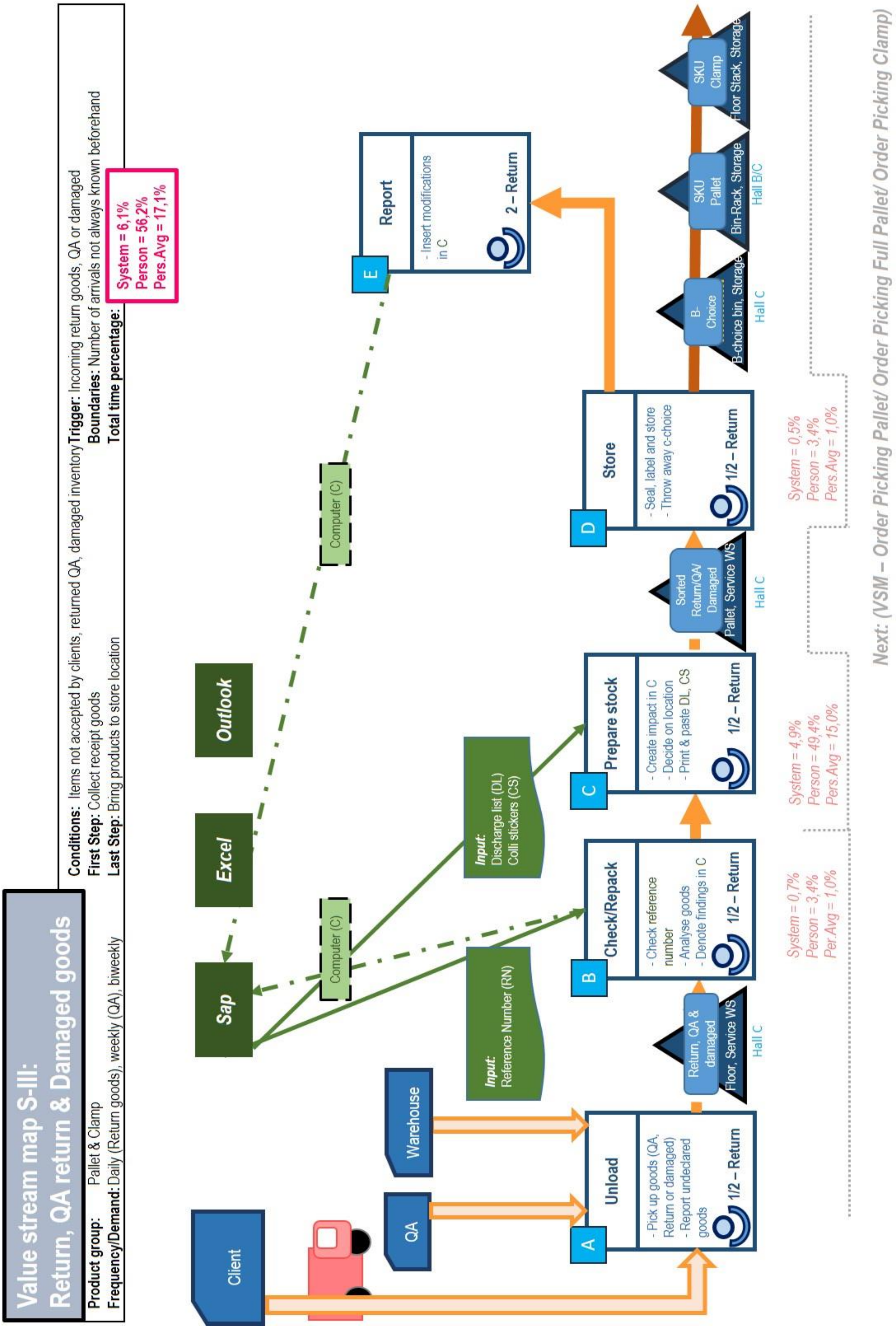
A6.7 VSM-SI Replenishment – Pallet goods



A6.8 VSM-SII Compress – Clamp goods



A6.9 VSM-SIII Return – Pallet & clamp goods, QA goods and damaged goods



A.7 Work Sampling Recording Form – ATAG Application

Below we display the recording form we used to collect the time measurement data as explained in section 3.2.1. On the vertical axis the activities are shown and on the horizontal axis the different employees are displayed.

	Activity	Man 1	Man 2	Man 3	Man 4	Man 5	Man 6	Man 7	Man 8	Man 9	Man 10	Man 11	Man 12	Man 13
Pre-pick	Shuttle													
	Transport													
Inbound - Pallet	Unload													
	Sort/prepare													
Putaway - Pallet	Transport													
	Store													
Inbound - Clamp	Unload													
	Transport/store													
	Sort/prepare													
Order picking - Full Pallet	Collect													
	Transport													
Order picking - Pallet	Collect													
	Position unload													
Order picking - Clamp	Collect													
	Position unload													
Dispatch Mix	Consolidate													
	Prepare ship													
	Position Intern													
	Position Extern													
Collect Report info	Receive													
	Report													
Shuttle	Production													
	QA													
	Service													
Replenishment	Transport													
Compress	Transport													
Return process	Unload/provide													
	Check & Prepare													
	Store													
Waiting	Waiting - Lack													
Others	Clean up/Wipe													
	Collect/movement pallets													
	Stock movements/empty pallet collection													
	Planning													
NP	Not in sight													
NP	Break/toilet													

A.8 Relationship Chart Form (Sample)

The form that is used to record the closeness relationships chart is shown in Figure A. 1. The filled relationship chart can be found in section 3.2.3.

Serial Num ber	Name of department
1	Name
2	Name
3	Name
4	Name
5	Name
6	Name
7	Name
8	Name
9	Name
10	Name
11	Name
12	Name
13	Name
14	Name
15	Name
16	Name
17	Name
18	Name
19	Name
20	Name

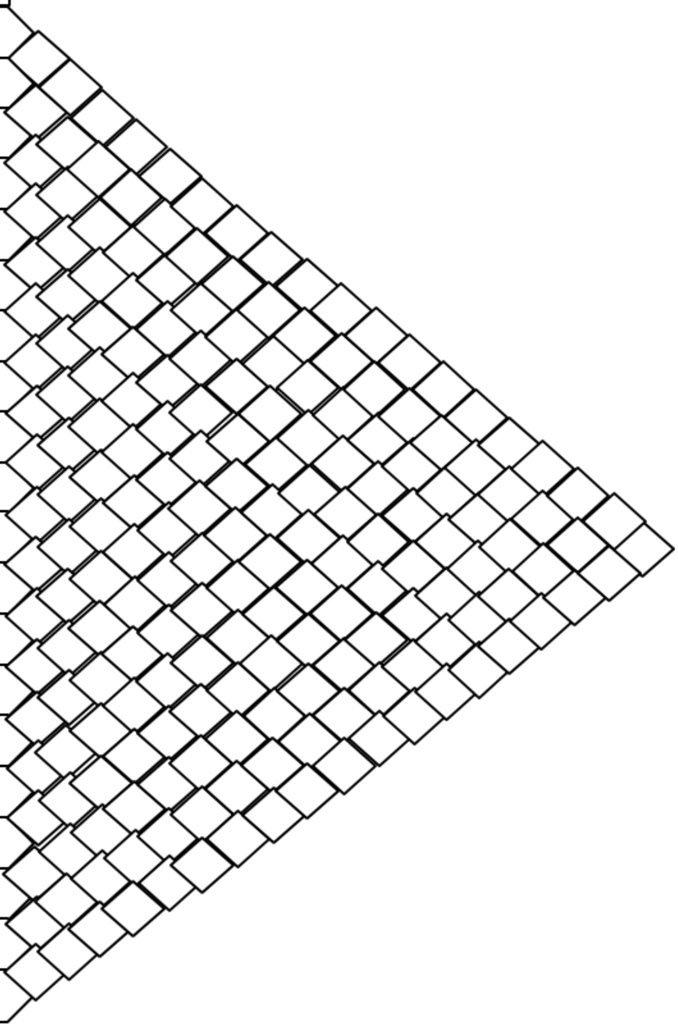


Figure A. 1. Relationship chart form

A.9 Pictures of Goods-To-Picker MHEs

Figure A. 3 to Figure A. 8 show pictures of Good to Picker material handling equipment described in section 3.3.2.

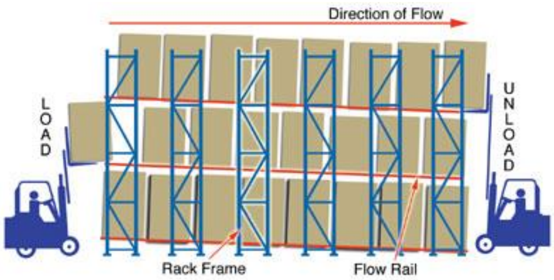


Figure A. 3. Pallet Flow System graphical view

Figure A. 2. Pallet Flow System picture

Figure A. 4. Horizontal Industrial Carousel

Figure A. 5. Vertical Industrial Carousel

Figure A. 7 .Mini-load ASRS System

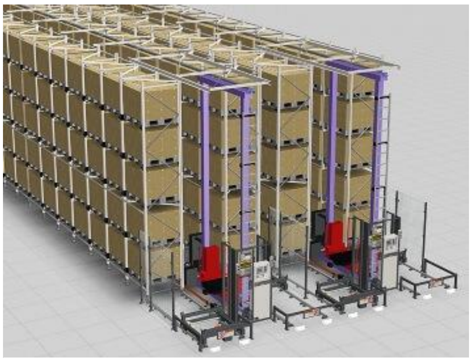


Figure A. 8. Unit-Load ASRS System

Figure A. 6. Robot Picking System

A.10 Labour and Storage capacity indication

Table A. 10 gives a generalized approximation for the labour capacity per activity, whereas Figure A. 9 and Figure A. 10 display the capacity for several storage methods based on the unit load dimensions.

Labour

Table A. 10. Approximation of warehouse functions and picking types (source: Stone, 2014)

Picking type	Pick/Man-Hour
Unloading floor-stacked trailers; sort to pallets	120 Cartons
Unload floor-stacked pallet onto takeaway conveyor	640 Cartons
Put away a full pallet into a pallet rack storage position	32 Pallets
Piece pick from carton flow rack into totes (paper pick tickets in use)	184 Lines
Piece pick from carton flow rack (pick-to-light)	260 Lines
Piece pick from horizontal carousels (pod of 3 approx.; light tree used) into totes	300 Lines
Full case picking using forklift; picking from pallet rack floor level onto pallet	29 Cases
Full case picking using man-up order picker truck and picking from all pallet rack levels onto pallets	134 Cases
Full case picking from pallet flow rack onto takeaway powered conveyor (paper pick tickets)	525 Cases
Full case picking from pallet flow rack onto takeaway powered conveyor (voice recognition)	600 Lines
Full pallet picking using counterbalance truck from bulk floor storage	50 Pallets
Full pallet picking using counterbalance truck from pallet rack	65 Pallets

Storage

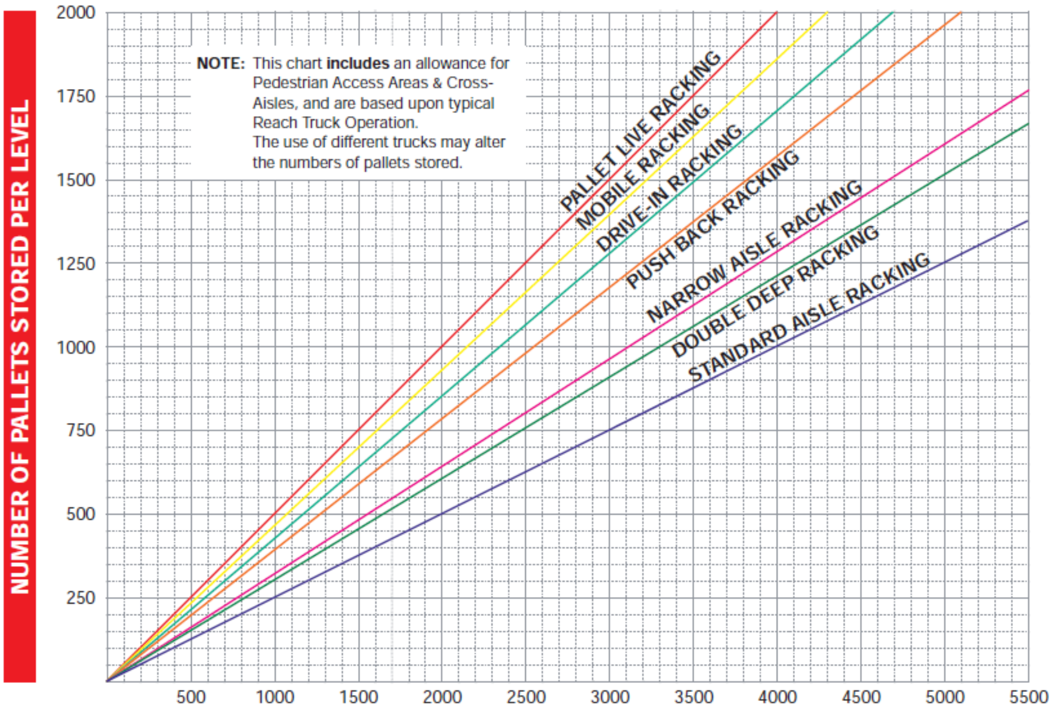


Figure A. 9. Indication overview of number of pallets positions available for given space for a certain storage method (Pallet size 1200-1100 mm) (Source: Link51, 2017)

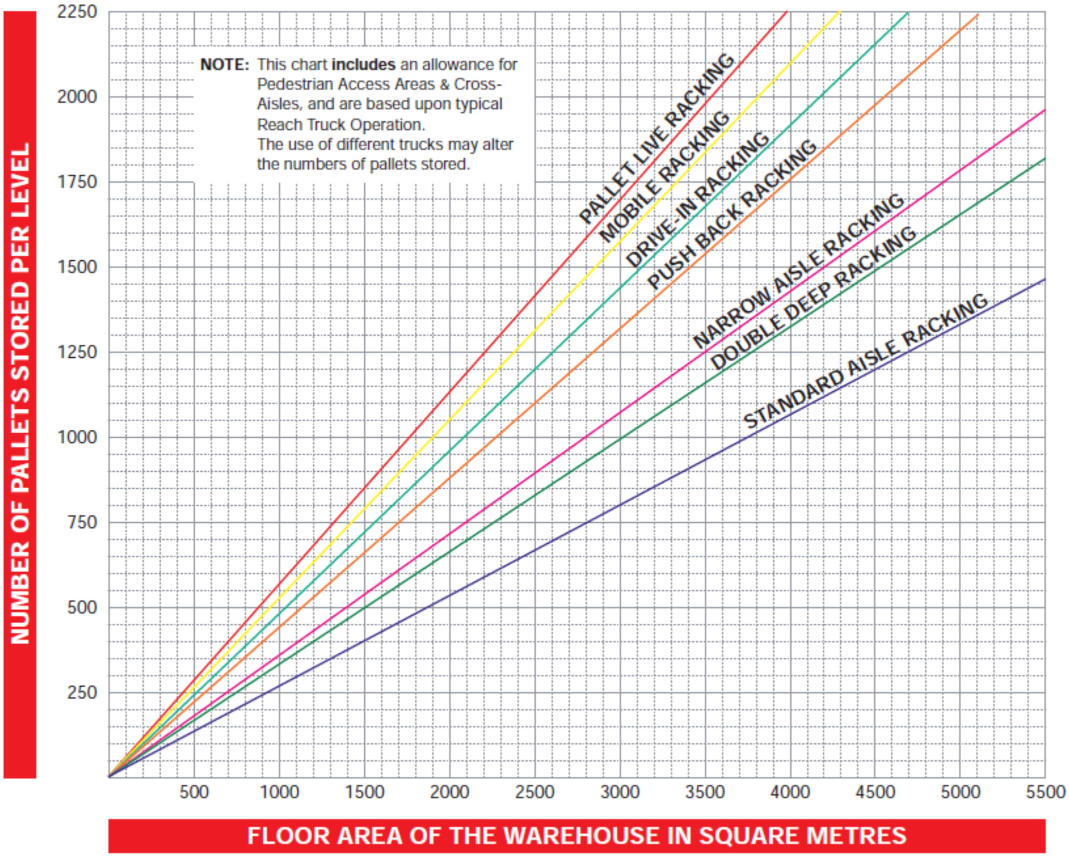


Figure A. 10. Indication overview of number of pallets positions available for given space for a certain storage method (Pallet size 1200-800 mm) (Source: Link51, 2017)

A.11 Work Sampling Recording Results

Table A10. shows the time division per activity of the logistic department at ATAG, which we obtained with the work sampling method explained in section 3.2.1.

Table A. 11. Filled recording form for the work sampling executed at ATAG

Activity		Observations	% spend in the system to activity		Observations	
		Total	Detail activity %	High level activity %	# of man	Average in observations
Pre-pick/Shuttle	Shuttle outside	21	0,6%	1,1%	4	5
	Transport intern	18	0,5%		7	3
Inbound - Pallet	Unload	46	1,3%	3,7%	3	15
	Sort/prepare	84	2,4%		3	28
Putaway - Pallet	Transport	43	1,2%	4,7%	5	9
	Store	121	3,5%		4	30
Inbound - Clamp	Unload	107	3,1%	7,7%	6	18
	Transport/store	161	4,6%		4	40
	Sort/prepare	0	0,0%		0	0
Order picking - Full Pallet	Collect	72	2,1%	3,4%	3	24
	Transport	47	1,3%		8	6
Order picking - Pallet	Collect	215	6,2%	7,4%	11	20
	Position unload	42	1,2%		5	8
Order picking - Clamp	Collect	275	7,9%	13,2%	13	21
	Position unload	184	5,3%		11	17
Dispatch Mix	Consolidate	301	8,6%	18,7%	14	22
	Prepare ship	203	5,8%		11	18
	Position Intern	103	3,0%		11	9
	Position Extern	44	1,3%		7	6
Collect Report info	Receive	124	3,6%	4,8%	18	7
	Report	44	1,3%		15	3
Shuttle	Production	1	0,0%	0,3%	1	1
	QA	5	0,1%		3	2
	Service	4	0,1%		3	1
Replenishment	Stock movements/empty pallet collection	25	0,7%	1,0%	2	13
	Intern Transport	10	0,3%		1	10
Compress	Transport	39	1,1%	1,1%	3	13
Return process	Unload/provide	24	0,7%	6,1%	4	6
	Check & Prepare	172	4,9%		2	86
	Store	18	0,5%		3	6
Waiting	Waiting - Lack	20	0,6%	0,6%	9	2
Leftover	Clean up/Wipe	17	0,5%	0,5%	6	3
	Collect/movement pallets	79	2,3%	2,3%	13	6
	Planning	68	2,0%	2,0%	2	34
NP	Not in sight	103	3,0%	17,6%	13	8
	Break/toilet	511	14,7%		18	28
	Travel	134	4%	3,8%	3	45
Total		3485	100%	100,0%		573
		174				

A.12 Space requirements for the ATAG departments

The table below shows the space requirements in relative proportions of each of the departments and technical zones. Due to confidentiality the exact SQM are not shown.

Table A. 12. Overview of the space requirements and its relative proportions per department/technical zone

Department/Technical zone	Reciprocal proportions
Inbound Pallet	
Inbound Clamp	
Sorting Area	
Consolidation Shipment	
Dispatch Shipments	25
Inbound spare parts/components	
Consolidation Spare Parts	
Consolidation area Service Technicians	
Storage Pallet	20
Storage Clamp	36
Storage Spare Parts	10
Storage Components	
Storage QA	1/3
Return Service Technicians	
Dispatch Pick-Up	
Return Receipt	
Expedition	1
Production	3,6
QA	1,5
Post Room	
Laboratory	3,3
Testkitchen, Inspection room, Storage CM, Training	1,6
Modelshop	1,3