Delft University of Technology

Nedcargo

Master Thesis Project - May 2018

K. Silvius - 4062795

Integration or Separation of E-fulfilment in the Order Pick System of an existing Logistic Service Provider

This page is initially left blank

This page is initially left blank

Implementing E-fulfilment in the Order Pick System of an existing Logistic Service Provider

Using a simulation model to design a time-efficient order pick system
for fulfilling e-commerce orders at Nedcargo Logistics B.V. in Waddinxveen

K. (Kirsten) Silvius
Student number: 4062795
Report number: 2018.TIL.8231

Master thesis for MSc. in Transport, Infrastructure & Logistics
Delft University of Technology

Graduation committee:

Prof. dr. R.R. Negenborn	Transport Engineering and Logistics, Faculty of 3mE
Dr. Ir. H.P.M. Veeke	Transport Engineering and Logistics, Faculty of 3mE
Dr. B. Wiegmans	Transport & Planning, Faculty of CEG
H. Grandia	Nedcargo Logistics B.V.
H. Neef	Nedcargo Logistics B.V.

Cover photos (from top to bottom): https://www.motraclinde.nl/producten/opslag/reachtrucks, https://www.abelwomack.com/someone-order-pick-faces-blog/, http://alternativetec.com/products/storage-rack-shelving/

This page is initially left blank

MANAGEMENT SUMMARY

The World Wide Web has facilitate the introduction of the phenomenon e-commerce. As a result of e-commerce, e-fulfilment services and centres as arising. Producers of food and beverage products cope with the problem that their retailer have too much power in the supply chain. Retailers can decide which products they want to sell or not. As a countermovement, producers are launching their own webshops to sell their products. An side issues is that these products bought on in the webshop have to be brought to the customer. For that a producers needs a fulfilment company. Since many of these producers let the warehousing and distribution of the products for the retail done by a logistic service provider (LSP), the producers are asking their LSPs to also perform the e-fulfilment services. Nedcargo is such an LSP, who gets repeatedly asked by customer to implement e-fulfilment. To be able to grow and cope with these future changes, Nedcargo wants to add e-fulfilment to their business.

In this research the e-fulfilment customer, the order pick system (OPS) design, the company of Nedcargo and Nedcargo's order pick system have been analysed to get the answer to the research question:

"How does an order pick system need to be designed in order to fulfil orders generated by e-commerce at an existing logistic service provider?'

The e-fulfilment customer is a customer which loyalty is harder to obtain than the retail customer. These difference is also notable in the demands and preference of the e-fulfilment customer. The accuracy is in both parties of importance, but since with e-fulfilment the products are send directly to the end-consumer, it has an even higher dependency in customer satisfaction. Also, the lead-time of the orders is an aspect on which the pressure from the customer is increasing, it is almost common to order on one day and get delivered the next day.

The fulfilment of the orders is executed in an order pick systems (OPS). Order pick systems are designed on a strategic level in which multiple strategy decisions have to be made before building and implementing the system. These strategies are: *order pick methods, storage strategies, zoning strategies, picking strategies, sorting strategies* and *routing methods.* For each of the strategies, multiple attributes can be selected. These attributes are outlined in this research and this information used throughout the whole research in decision making.

Since the e-fulfilment OPS is designed for an existing LSP, the company and its processes are of importance for the outcome of the research. The company of Nedcargo has a strong mission and vision in which it is clear that they want to perform their activities in a responsible way and to the satisfaction of the clients. The reduction of waste in food, time, money, transport, environment and talent, together with the safety of their personnel and others is on their top priority. Furthermore, they want clients to rate the service level of Nedcargo with a 9 out of 10.

The current order pick system of Nedcargo is completely designed for the handling of pallets, full pallet orders and case pick orders transported on pallets. Since the customer's demand are mainly focussed on accuracy and lead-time, the OPS of Nedcargo is analysed with these two aspects in mind. The result of this analysis shows that the OPS is limited in the reduction of lead-time and cannot ensure a 100% accuracy level, as required. Furthermore, the effects of integrating e-fulfilment in the current OPS are not in line with the mission and vision of Nedcargo. For these reason, it is decided that the e-fulfilment system can better be separated from the current order pick system of Nedcargo. The strategies that mostly influences the limitations and challenges of the integration and have the largest effect on the system performance are the picking strategy, the storage strategy and the routing method applied.

Since the research question drafted at the beginning of this research is partly answered by this conclusion and a more specified research is conducted further on, the new research question is:

'Which picking strategy, storage strategy and routing method should be applied,
to ensure an order pick system for e-fulfilment that can cope with the e-fulfilment customers' demand
and the objectives of the LSP ?'

To further develop this research and find out what solution design is suitable for an e-fulfilment OPS, the system requirements and the order profile of the case clients, Moet Hennessy, are defined. The requirements led to the conclusion that there are five important aspects, namely: the future, i.e. how is the system handling growth and order configuration changes, the lead-time, i.e. can orders be delivered the next day if ordered before 22:00h, the accuracy, i.e. 100% the correct products and the correct amount of products, the environment and the product type, i.e. low risk of breakage and spillage including a first-expired-first-out policy. The orders taken into account for the e-fulfilment system are orders that consist of maximum five cases and/or of items. Also these parts of the orders within an order consisting of also full pallets will be fulfilled in the e-fulfilment OPS.

According to the requirements and the order profile of Moet Hennessy, a few decisions on the OPS are made. These are the use of flowracks since they can provide the first-expired-first-out policy, the fact that during picking orders are placed in the box in which they are transported and the implementation of scanning by picking a product and a weight control of the order at the end of the picking process, to guarantee a 100% accuracy. With these decision, three out of five requirements have been met, while the lead-time and the future still have to be evaluated.

This evaluation is executed by a simulation model. In this model attributes of the picking strategy, the storage strategy and the routing method compose the design alternatives. These alternatives are evaluated based on the time in the storage system, i.e. the actual picking time including the walking time between picks. Furthermore, the time in the picking system, i.e. the time in the storage system including the activities that contribute to the picking process, the time in the total system from the batching process and the total time in the system, including the batching process are evaluated.

The attributes of the picking strategy are *batch picking based on order entry* and *batch picking based on turnover category*. The attributes of the storage system are *randomized storage*, *class-based storage on turnover category, class-based storage on product type* and *class-based storage on turnover category and product typ*e. And, the attributes of the routing method are the *transversal* routing, the *return* routing and the *combined* routing. Since this e-fulfilment order pick system is designed for order consisting of five or less cases and/ or of items, two unit loads are handled. Therefore, all alternatives are variated on performing one-pick round in which both unit loads are picked, or performing two pick rounds in which first the cases are picked and secondly the items.

The analysis of the simulation results have given four general conclusions. Mainly the higher the volume, the least specific the storage strategy must be. In other words, the more *randomized* storage is performing better. Also an increase in the share of items, contributes to the increase of the performance since items take less time to pick than cases. With the *class-based storage on product type* this is also valid, until a share of 75% items, from 90% on the performance of these alternatives is decreasing also because of congestion at the item flowrack sections. Furthermore, *batching on turnover category* does always outperform the respective alternative with *batching on order entry*. And lastly, the higher the volume the better a more simple routing methods performs, i.e. *transversal* routing.

Alternative specific, the results have shown that the alternatives, in which *one pick round* is performed, a *class-based storage on turnover category* is combined with the *batching on turnover category* strategy and a *return or combined* routing method, is performing the best considering the time in the storage system, i.e. the actual picking time. When the volume is increasing to 400% and more, congestion on the links and at the flowracks is causing a reduction in time and a reduction in the performance of these alternatives. The alternatives in which the storage strategy is also based on product type, so *class-based storage on turnover category and product type,* are still performing well with a volume of 400%. However, when the volume is increasing to 800% the congestion is getting too much, making these alternatives not the best performing alternatives anymore. The alternatives with *randomized* storage and a *transversal* routing are then performing better than the other alternatives.

Due to the limitations of the system, the fact that many other possible solutions can be brought up to reduce the congestion at the flowrack sections, the likeliness of the situation in the experiments to occur and that this alternative still perform good compared to the best performing alternative, the alternative 1-C-ABC(B) has been selected as best solution design. This is the alternative with *one*-pick round, a *combined* routing method, *class-based storage on turnover category* and a *batching strategy based on turnover category.* It must be said that the alternative 1-C-ABC-CI(B) is performing better but with the current volume it is n less efficient since a double replenishment has to be executed with this experiment. When the volume has increased to around 400%, a new analysis of the order configuration should take place and based on those results it can be decided to implement 1-C-ABC-CI(B). However for now it is recommended to implement 1-C-ABC(B) to get the best results and to research further how a reduction in congestion can take place when the volume increases.

CONTENT

List of Figures

LIST OF TABLES

Definitions

The definitions stated in this section are the correct interpreted definitions for this research. In a different context, the definitions might be less specific or described otherwise.

E-fulfilment:	Fulfilling of orders generated by e-commerce.
Logistic service provider (LSP):	A company specialized in the storage and distribution of products.
Retailer:	A business entity that sells products to the end-consumer in a physical store.
E-tailer:	A business entity that sells products to the end-consumer via internet.
Manufacturer:	A business entity that produces products.
External distributor:	A business entity that distributes orders commissioned by another business entity.
Business-to-consumer (B2C):	Selling or shipping products to an individual, the end-consumer.
Business-to-business (B2B):	Selling or shipping products to another company or business entity.
Customer:	The customer of the client, i.e. the entity Nedcargo is delivering the products of the client.
Client:	The customer of Nedcargo, mostly a producer or manufacturer.
Order:	A request of one entity to another to buy the goods or services the other party is offering
Full pallet order:	An order consisting of full pallets, transported on pallets
Case pick order:	An order consisting of cases containing items, transported on pallets
Item pick order:	An order consisting of loose items, transported in boxes
Order accuracy:	The correctness of the order in products, number and status.
Lead-time:	The time between order placement and order delivery.
Order pick system (OPS):	The system in which orders are fulfilled and made ready for shipment.
Order picker:	The employee who picks the products ordered and fulfils the orders.
Order configuration:	The determination of the unit loads of the order.
Turnover category:	The category in which a product type is placed, based on the times the Product type has been ordered.
Order profile:	The order data of a specific clients or year analysed based on certain characteristics.
Order size:	The amount of products and product types an order consist of.
Stock-keeping-unit (SKU):	A product type.
Unit load:	The form in which the products are stored and ordered.
Inbound:	The processes which are involved in the receiving of the products.
Outbound:	The processes which are involved in the shipping of the products.

Replenishment:	Increasing the stock level of a product type in a specific unit load.
Pick order:	A list consisting products in a specific sequence which need to be picked by the order picker in that sequence.
Pick round:	All activities an order picker performs from start to finish during the completion of a pick order.
Pick route:	The walked route during the completing of a pick order.
Pick aisle:	The aisle between shelves from which the products are picked.
Pick face:	The side of the shelf from which the picking takes place.
Design variable:	The three subjects varied in the design alternative: picking strategy, storage strategy and routing method
Design attribute:	The different attributes a design variable can have. *(Single-order picking, batch-picking on order entry and batch-picking on turnover category)*
Experiment variable:	The two subject varied in the experiments: order volume and order configuration
Experiment attribute:	The different attributes an experiment variable can have. *(100% volume,| 200% volume, 400% volume, etc.)*

1. INTRODUCTION

The logistics department of Nedcargo International B.V initiated a research on a fulfilment system of e-commerce orders within their warehouse in Waddinxveen. The motivation for this research from academic perspective and from the perspective of a logistic service provider is described in section 1. Before commencing with a research, the problem description, the objectives and research questions and the scope of the research need to be defined, section 1.2, 1.3 and 1.4 respectively outline these subjects. The research follows a methodology on which the structure of the report is based. The methodology is outlined in section 1.5 and the report structure in section 1.6.

1.1 Motivation for the research

The motivation for this research can be derived from the development of e-commerce. The World Wide Web, the Internet, is an everyday technology that allows the emergence of a new competitive environment. In this environment, firms can develop or extend their business processes to deal with customers from all around the world (Kunesova & Micik, 2015). This has led to the development of electronic business, electronic commerce (e-commerce) and electronic shops (webshops). 'Gunasekaran' describes e-commerce as the second Internet revolution (Gunasekaran, Marri, McGaughey, & Nebhwani, 2002). E-commerce implies transactions related to online buying and selling of products and services (Mohapatra, 2013). To be able to handle e-commerce, e-fulfilment needs to take place, which entails fulfilling orders placed by customers on the Internet (Jain, Shah, Gajjar, & Sadh, 2015).

In the past, retailers had the power in the supply chain. Having power implies that the retailer consists of resources that other entities in the chain do not have (Reimann & Ketcher Jr., 2017). Retailers were the only ones in direct contact with the customer and often had information about their preferences (van der Veen & Robben, 1997). The internationalization of the market resulted in an increase in competitiveness of products and brands, which made that producers needed to fight for a spot on the shelves of the retailers. They needed to improve and renew their products continuously to be in favour of the consumers (van der Veen & Robben, 1997). Internet and e-commerce have made it possible to shift the power in the supply chain. It provides a new business environment where sellers and buyers have a powerful communication channel. Two parties can more easily get in contact with each other via the Internet (Kunesova & Micik, 2015). Producers are starting a new business, named the 'direct selling'-business, in which the producer directly sells his products to the customer (van der Veen & Robben, 1997). The trend for producers to open their own online store or selling their products through an internet platform is seen more often (Agatz, van Nunen, & Fleischmann, 2007).

Another driver of the increasing market of e-commerce is the price offered on the Internet. This price is often lower than when bought in a physical store (Ricker & Kalakota, 1999). Business-to-consumer (B2C) e-commerce has proved its convenience and its ability to offer a quick response to requests. The amount of products and services available on the Internet is still increasing. Also for business entities it brings advantages. E-commerce reduces the intermediaries in the supply chain, which can save time, money and costs of administrative tasks and labour (Kunesova & Micik, 2015).

Motivation for a logistic service provider
The logistic service provider Nedcargo Logistics B.V., noticed these changes in the search for new clients and keeping existing clients satisfied. Most clients and potential clients ask three types of services of their logistic service provider or any combination of these three types (Joong-Kun Cho, 2008).

- Fulfilment of full pallet orders
- Fulfilment of case pick orders, consisting of one or multiple product types, transported on pallets
- Fulfilment of item pick orders (generated by e-commerce): e-fulfilment orders, transported in boxes

Nowadays, producers outsource their logistic activities of full pallets and case pick orders to companies like Nedcargo, and their logistic activities for item pick orders to an e-fulfilment centre. While having one partner executing all three is preferred.

Implementing e-fulfilment can give a logistic service provider a unique position in the market of logistics. Especially for Nedcargo, since there are almost no companies who offer the three services mentioned in the food and beverage industry. Even though quite some development in the fulfilment industry is noticed, Nedcargo can be one of the first to offer this wide range of services. With this expansion, a logistic service provider like Nedcargo will broaden its target group and customer diversity. Specific target groups for the fulfilment of e-commerce orders of food and beverage are small to middle-size companies, cafes, restaurants, hotels and end-consumers.

Nedcargo is interested in performing its activities in a responsible and environment friendly way, which also can be noticed in their company's mission statement, explained in section 2.2.1. Implementing e-fulfilment will shorten the supply chain between the producer and the end-consumer. This results in less movements of products, which lowers the risk of damaged products i.e. not ready for sale. It also decreases the time between production and consumption, which lowers the risk of products passing the sell-by date. Eventually this contributes to a reduction in the spillage of food, which is good for the environment.

1.2 Description of the problem

Nedcargo mainly focuses on retail. Her expertise lies in the handling of full pallets orders and case orders transported on pallets. Because the amount of smaller orders is increasing and the wish of clients for Nedcargo to implement e-fulfilment is known, Nedcargo wants to expand her business with this service. E-fulfilment implies a different customer with possibly other preferences and a smaller order size, which has to be known before implementing e-fulfilment. Nedcargo does lack this information and requested external expertise. For Nedcargo, small orders are orders consisting of five or less cases and of items. These orders are distributed with an external distributor since it is not financially feasible for Nedcargo to distribute these orders herself. The e-fulfilment system should be able to fulfil these order sizes.

Order picking is said to be the most labour intensive and money consuming part of the order fulfilment process. From this part, over 50% is transport time (de Koster, Le-Duc, & Roodbergen, 2006). It is expected, and analysed in this research, that the current warehouse layout, does not allow a significant reduction in transport time and the current process does not meet the e-fulfilment customers' demands. The e-fulfilment customer's demands are more focussed on lead-time and accuracy and the order sizes and configuration do not consist of pallets or multiple cases, but mainly of items or a few cases. The current warehouse processes are fully focussed on pallets. This research will provide a solution proposal for how a logistic service provider, like Nedcargo, focussing on retail can implement e-fulfilment in which orders are fulfilled consisting of five or less cases and items. The system of Nedcargo is visualised in Figure 1, in which three types of outputs are shown, the third type is representing the e-fulfilment orders.

Figure 1: Schematic system visualisation of the warehouse of Nedcargo

1.3 Objectives & research question

The objective of this research is to design an order pick system for the fulfilment of e-commerce orders at the warehouse of Nedcargo in Waddinxveen. The system has to meet the requirements of the e-fulfilment industry and may not counteract the current processes of Nedcargo. Because the beverage clients of Nedcargo have the most interest in e-fulfilment and provide Nedcargo already with small orders, the focus of the design will be on beverage products. The products and order data of Moet Hennessy will be used as case for this research. Moet Hennessy has the wish to launch a webshop and has a high share of orders consisting of five or less cases and of item, namely two third of its orders. The research question that will be answered is:

"How does an order pick system need to be designed in order to fulfil orders generated by e-commerce at an existing logistic service provider?'

This question will be answered, using multiple sub questions. The sub questions are:

Chapter 2: *'Who is the e-fulfilment customer and what are his or her preferences and demands?'*
Chapter 2: *'Based on what strategy decisions is an order pick system designed?'*
Chapter 2: *'How are the current order pick processes organised at the LSP?'*
Chapter 2: *'To what level can e-fulfilment be integrated in the OPS of the LSP?'*
Chapter 3: *'What are the system requirements and KPIs of an OPS for e-fulfilment?'*
Chapter 3: *'Which design aspects can be decided based on the requirements, which not and will therefore be varied in the design alternatives?'*
Chapter 4: *'How can a simulation model be developed to evaluate the performance of an OPS?'*
Chapter 4: *'What is the preferred design and does this design meet the requirements?'*

1.4 Scope of the research

The scope is represented by the research question, which can be split into three parts: How does **an order pick system** *(1)* has to be designed in order **to fulfil orders generated by e-commerce** *(2)* at **an existing logistic service provider** *(3)*?

(1) An order pick system: The order pick system of a logistic service provider is the system in which the products are stored and from which these products are picked if requested by the customer. In this research, the order pick systems of Nedcargo are analysed based on the processes applied in the system, the performance of the system and the strategy decisions made when designing and operating the system. These strategies are gained from literature and are an important guideline throughout the research. The order pick system is designed on a strategic level and does not include the selection of e.g. picking equipment. Since the scope is the order pick system, other processes in the warehouse are not taken into account. Also, the return logistics of the products are not in the scope of this research.

(2) To fulfil orders generated by e-commerce (e-fulfilment): As mentioned in section 1, e-fulfilment is the fulfilment of orders generated by e-commerce. This research is mainly focus on the customer of e-fulfilment and his or her preferences. These findings are used to determine the level of integration of the e-fulfilment system into the current order pick processes at Nedcargo and give insight in the requirements of an order pick system for e-fulfilment.

(3) An existing logistic service provider: The logistic service provider in this research is Nedcargo Logistics B.V. Since Nedcargo is an existing LSP, she operates already in a certain way. These operations are first analysed and based on these findings, a design is made for the order pick system for e-fulfilment. Moreover, certain decisions are based on the expertise, experience and/or preference of Nedcargo and on that account might not be valid at other logistic service providers. These decisions are, e.g. the fact that the warehouse in Waddinxveen is used and that the case client for the design is Moet Hennessy.

1.5 Research methodology

Most design related methodologies all have the same main steps, namely: define problem (or task), define design requirements, generate alternatives, evaluate alternatives and validate chosen design alternative. Take for example the seven methodologies addressed by Adams, all have these steps in their process, but put the focus on a different aspect (Adams, 2015). Morris Asimov is more focused on the process after the detailed design, while Nigel Cross breaks his problem into sub-problems and Stuart Pugh is more interested in the market and sales (Adams, 2015). In this study the focus is on the definition of the problem.

The actual problem for which a solution has to be defined is gained from the studies on the e-fulfilment customer, the order pick strategies and the current warehouse processes at Nedcargo. Integration of these three studies, provides the advantages and disadvantages of implementing e-fulfilment in the current warehouse processes of Nedcargo, and with that the problem definition. After this, the order pick system can be designed.

The research methodology for the design of an order pick system is based on the research approach of Baker and Canessa for design of a warehouse. Baker and Canessa have conducted a research on the design methodologies used for warehouse design (Baker & Canessa, 2009). They compared fourteen different methodologies used in literature and four methodologies used by different warehouse design companies, resulting in a generic framework for warehouse design. The framework is translated into a framework for order pick system design, as where in this research the scope is not the complete warehouse design but the design of an order pick system. The focus is more on the operational procedures, methods and strategy decisions then on the actual layout, entailing that the conceptual designs are not layout designs, but system designs. Also, two of the steps in the original framework are eliminated. The first is the determination of the unit loads, since these are given from the problem statement. Secondly the calculation of equipment capacities and quantities, as these are not within the scope of this research. A scheme of the approach for this research is provided in Figure 2 in which chapter 2 represents the problem definition and chapter 3 and 4 the order pick system design. The translations of the framework is given in Appendix A: Translation of the methodology.

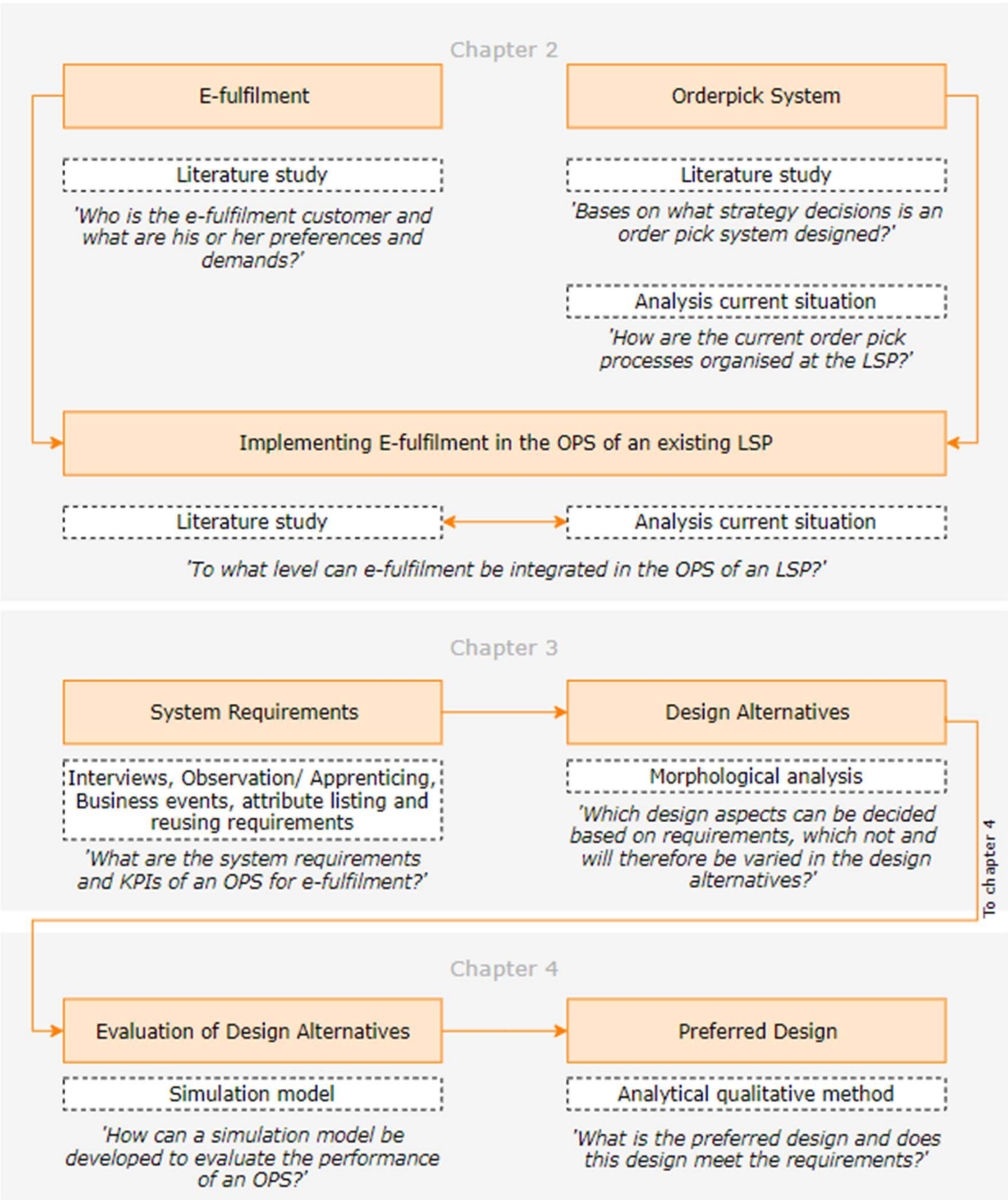


Figure 2: Scheme of approach of the research

1.6 Report structure

The structure of this report follows from the methodology that is applied. The report is divided into five chapters of which chapter 1, is the introduction and has just been read. Each chapter starts with a theory part in with the theory on certain topics or on methods that are applied in the chapter is given.

In chapter 2, the actual problem is defined, the objective of this chapter is to research the level of integration of e-fulfilment in the order pick system of Nedcargo. The chapter commences with a section in which the theory on e-fulfilment and order pick systems is described. The e-fulfilment theory is mainly focussed on the customer and customer's demand. The theory on order pick systems describe the design strategies that can be applied in order pick systems. The following section in chapter 2 describes the company Nedcargo and its order pick system. First a general description of the company is given, followed by an analysis on the order pick systems applied at Nedcargo. The analysis is executed with the information on e-fulfilment and order pick systems in mind. Next, the implementation of e-fulfilment in an order pick system of an existing LSP is described. It combines the practical aspects described in the previous two sections with theory on the implementation. The chapter concludes with the answer on the level of integration of e-fulfilment in an order pick system.

Chapter 3 describes the generation of the design alternatives of the to-be-designed system, defined in the chapter 2. The chapter commences with the theory on methods for defining system requirements and the generation of alternatives. Following is the execution of these methods, with as first subject the definition of the requirements. From the definition of the requirements, the key performance indicators on which the system will be evaluated are gained. This section is followed by a data analysis of the orders of Moet Hennessy in 2016, as this client will be used as case client. After defining the order profile of Moet Hennessy and the system requirements, some strategic decisions can already be made for the design. The decisions that yet cannot be made will be variated in the design alternatives which are described in the closing section of the chapter.

The evaluation of the design alternatives is described in chapter 0. Again, this chapter commences with theory on how the evaluation and validation of design alternatives can be executed and which methods are applied in this research. Because a simulation model is built for the evaluation, this model is then explained, verified and validated. Following, is the explanation of the experiments on which the evaluation of the design alternatives is based. After interpreting the results of these experiments, the best solution design is selected, concluding this chapter.

Chapter 5 concludes the research, and provides a discussion on the findings. In this chapter, also the recommendations for Nedcargo and further research are given.

2. E-FULFILMENT & ORDER PICK SYSTEMS

Whether or not e-fulfilment can be integrated in an order pick system of an existing logistic service provider and to what level, is dependent on the layout, processes and performance of the order pick system of this LSP.

First knowledge must be gained on e-fulfilment and order pick systems itself. For this, a literature study is performed which is explained in section 2. After the theory, the company Nedcargo and its order pick system are analysed, this analysis is given in section 2.2. In section 2.3, the implementation of e-fulfilment in an OPS is described, accompanied by the advantages and disadvantages of this integration. Section 2.4, concludes this chapter with the answer on the level of integration of e-fulfilment in an OPS of an existing LSP.

2.1 Theory: E-fulfilment & order pick systems

To gain knowledge on how an e-fulfilment OPS should be operating and what it should manage to do, the e-fulfilment customer is researched, this research is described in section 2.1.1. Since an order pick system is a complex system with many design decision, a study is performed on the strategy decisions that are made during the design of the system and that influence the operational performance. This theory is described in section 2.1.2.

2.1.1 E-fulfilment

The term 'e-fulfilment' is a relatively new term and only became familiar after the growth of e-commerce in the beginning of the twenty-first century. For the design and implementation of e-fulfilment, it is important to know the e-fulfilment customer and his or her preferences. In this chapter, the following sub question will be answered: *'Who is the e-fulfilment customer and what are his or her preferences and demands?'*

As mentioned in the introduction, e-commerce is a growing phenomenon. An e-commerce customer can easily switch to other e-tailers due to the negligible switching cost and the minimal effort it takes. For an e-tailer it is a major challenge to retain customers (Jain, Gajjar, Shah, & Sadh, 2017). In online retailing, customers and e-tailers encounter each other only through e-fulfilment and therefore e-fulfilment is the key area that can offer a good shopping experience to customers (Jain, Shah, Gajjar, & Sadh, 2015).

According to Jain et al., e-fulfilment consist of five processes divided over two categories. First the category 'order procurement' in which the processes 'order capture' and 'order processing' are present. Secondly, the category 'order fulfilment', with processes 'picking and packing', 'shipping' and 'after-sales service'. (Jain, Shah, Gajjar, & Sadh, 2015), (Jain, Gajjar, Shah, & Sadh, 2017). Each category, has influential factors that determine the customer's experience and the probability of a customer returning, i.e. the loyalty of the customer. These factors are given in Figure 3, divided over the two categories, and are explained under the figure.

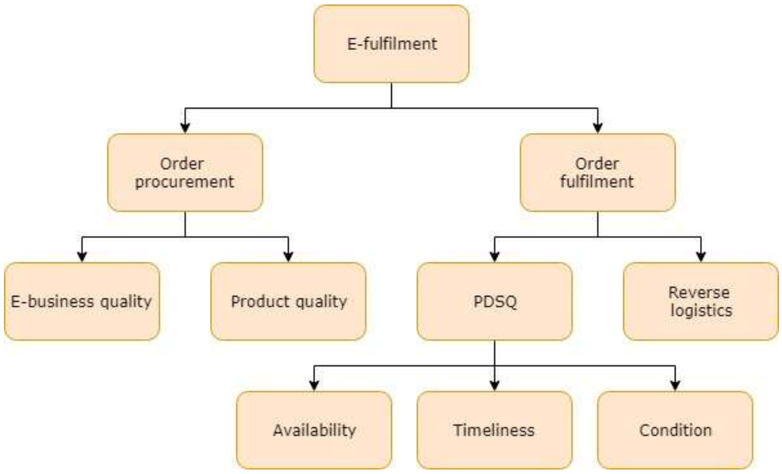


Figure 3: Factors influencing customers' experience, categorized.

E-business quality entails the quality of the webshop surrounding, this factor includes aspects as privacy and security, graphic style, ease of use and information availability. *Product quality* refers to the physical quality of the product, the assortment of products and the quality of the substitutions in case a product is not in stock. *E-business quality* and *product quality* are related in the sense that the description and information of the products on the website (e-business quality) need to represents the product itself *(product quality)* (Jain, Shah, Gajjar, & Sadh, 2015), (Jain, Gajjar, Shah, & Sadh, 2017). Both these aspects, and therefore the whole order procurement category, is the responsibility of the e-tailer selling the product and not of the LSP delivering the product.

PDSQ stands for *physical distribution service quality* and includes the picking and packing and the shipping of the products. According to Yuan Xing et. al., 'PDSQ implies the extent to which a website facilitates efficient and effective shopping, purchasing and delivery of products and services' (Yuan Xing, Grant, & McKinnon, 2010). Within these processes, three aspects of customer experience are of importance: *availability, timeliness and condition.* The customer expects that the correct product is delivered without any damage within the given time window.

- Availability: in stock, confirmations, substitute or alternative offer and tracking and tracing.
- Timeliness: speed of delivery, choice of delivery date and delivery time slot.
- Condition: order accuracy, completeness and damage.

Availability implies that the product requested is in stock and being sent to the customer, but besides only the correct product a customer gets also more satisfied when he or she can follow the product throughout the process, so when it is picked and packed, ready for shipment and shipped. If the product is not available, the customer wants to get notified and offered a substitutional product or an expected delivery time of the correct product. Moreover, the customer would like a choice in these two options, (Jain, Gajjar, Shah, & Sadh, 2017). *Timeliness* represents the order cycle performance. For the customer it is the time between order placing and order receiving (Yuan Xing, Grant, & McKinnon, 2010). Timeliness is of high importance, especially with a product bought for special occasions, since it is possible that the product is not of use any more after a certain time has passed. Therefore, delivering within the time window given by the e-tailer. In case of a different delivery time, the customer wants to get notified. Lastly, the customer is more easily satisfied when it has delivery options in location and time (Lang, 2010). Overall the pressure on a fast delivery time is increasing. Customers want their products as fast as possible, where next-day delivery is getting the standard and even same-day delivery is getting more popular. It is seen more often that customers can order until a certain time in the evening, e.g. 22:00 o'clock, and have their products next day delivered (Jain, Shah, Gajjar, & Sadh, 2015), (Jain, Gajjar, Shah, & Sadh, 2017). *Condition* implies that the products are delivered without any damage, without anything missing and with a representable 'best before'- date in case of perishable products. In some scientific articles found on e-fulfilment customer experience, the billing accuracy is also named as a satisfaction factor. This implies the correct billing of the products bought by the customer. This responsibility of this indicator lies at the party that is sending the invoices (Jain, Shah, Gajjar, & Sadh, 2015).

Another important aspect of customers' satisfaction is the reverse logistic process, especially the ease of return and the processing time of the returns (Lang, 2010). The ease of return entails the ease of bringing the products to a store or specific location and the way the retailer is handling damaged or unwanted products (Yuan Xing, Grant, & McKinnon, 2010). The processing time of the return entails the registration of the return and the repayment of the returned products. (Jain, Gajjar, Shah, & Sadh, 2017).

The indicators on which a logistic service provider has influence are the timeliness, the condition and the return (Jain, Shah, Gajjar, & Sadh, 2015). Partly on the availability, because the LSP can hold multiple storage locations and need to manage the inventory between these locations. They do not have influence on the availability throughout their whole inventory because the producers and manufacturers are pushing the finished products and a LSP cannot demand them. When the distribution is done by an external distributor the timeliness is also influenced by their performance, but still lies within the responsibility of the LSP.

2.1.2 Order pick systems

An order pick system and the way it has been designed can be analysed through strategy decisions. These decisions have influence on the layout of the storage area, on the location of the products in the storage area and on the order pick process. Six strategies have been found in literature, which are all explained in this section. The strategies are *storage strategies, order pick methods, zoning strategies, picking strategies, sorting strategies* and *routing methods.* This section provides an answer on the subquestion: *'Based on what strategy decisions is an order pick system designed?'*

Order pick methods

When deciding which order pick method to implement, the level of automation of an order pick system needs to be determined. In a warehouse and in an order pick system, three levels of automation can be distinguished (Blomqvist, 2010)

- Manual: The order picker collects the products by travelling to the storage locations
- Automated: Products are brought to a stationary picker, who picks them manually from a tote
- Automatic: Products are picked by a picking robot, there is no human activity involved.

A selection can be made in whether to employ humans, machines or both. When only employing machines, a *fully automated* order pick system is required. When employing humans and machines, a *semi-automated* order pick system is required and when employing only humans, a *manual* OPS is required. Furthermore, a *parts-to-picker* method requires a *semi-automated* OPS. For the *put-system* both, a *semi-automated* or *manual* OPS, are possible and for the *picker-to-parts* method, a *manual* OPS is applied. Still, parts of the OPS can be automated in both these methods, see Figure 4 for an overview. Because the order pick processes of Nedcargo are manual and will remain manual, only these two methods are explained more in detail.

In a *'picker-to-parts'* system, an order picker walks or drives to the location he or she has to pick the products from. After picking, he or she walks or drives further to the next location. A difference can be made in *'low-level order picking'* and *'high-level order picking'*. With *'low-level order picking'* the products are stored on a low level, e.g. on shelves, and an order picker picks the products manually, so with his or her hands. With *'high-level order picking'* the products are stored in high storage racks and the order picker needs a lifting device to collect the products (de Koster, Le-Duc, & Roodbergen, 2006).

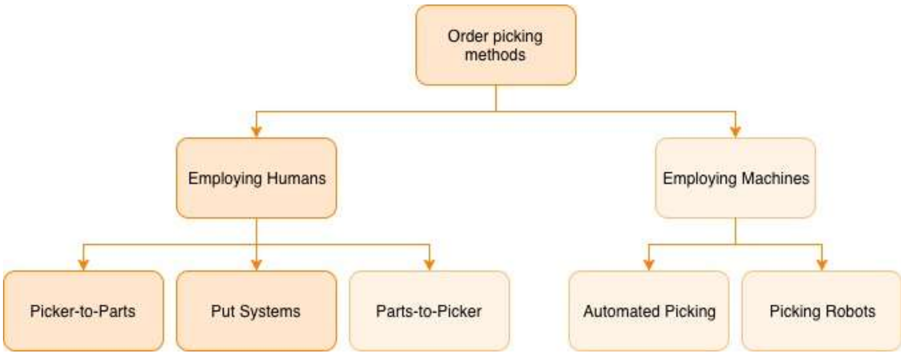


Figure 4: Order picking methods

'Put system' methods separate the retrieval of the products from the distribution of the products into individual orders. Implying that first all products of multiple orders will be picked, after which the products are distributed over the orders. The retrieval process, collecting the ordered items can be done with a *'picker-to-parts'* or *'parts-to-picker'* method. This system is mainly implemented with a limited amount of SKUs, a high volume per SKU, relatively small orders and not many products per order (de Koster, Le-Duc, & Roodbergen, 2006). A *'put system'* can be compared with a *'picker-to-parts'* system where *'batch-picking'* and *'sort-after-pick'* strategies are applied, which are explained further in this section.

Storage strategies

Products need to be stored and mostly also in different unit loads. Different unit loads are e.g. pallets, cases and items. Multiple unit loads per product type imply that there are two or three storage locations per product type. The question is where to store these different types of unit loads and as that how many storage areas to handle (de Koster, Le-Duc, & Roodbergen, 2006). A disadvantage of multiple storage areas is the replenishment of these areas and which replenishment strategies to imply. It is not said that every product type needs to be present in each storage area, this depends on the order volume of the unit load of that product type (Blomqvist, 2010).

A different storage strategy can be applied to each of these storage areas (de Koster, Le-Duc, & Roodbergen, 2006). A storage strategy indicates the sequence in which the product types are stored from the starting point. The starting point is often a depot where the picking material is present and from where the order picker starts the pick round. The four storage strategies explained are: *randomized storage, dedicated storage, family grouping* and *class-based storage.*

A *randomized storage* strategy implies that every incoming pallet or product is placed randomly in the warehouse. All empty spots have an equal probability of being selected for the placement of this inbound pallet (Glock & Grosse, 2012). The advantage of this strategy is the high utilization of storage space, as a pallet can be stored everywhere and pallet slots are not specially reserved for another product type. The disadvantage is that overall it implies more travel distance compared to other storage strategies, because it is not certain that product types with a high turnover in volume are more closely situated near the starting point (de Koster, Le-Duc, & Roodbergen, 2006), (Gu, Goetschalckx, & McGinnis, 2007), (Petersen, The impact of routing and storage policies on warehouse efficiency, 1999). A sub strategy of the *randomized storage* strategy is a *closest-open-location* strategy. The first encountered empty location will be selected for storage (Petersen, Aase, & Heiser, 2004).

The opposite of the *randomized storage* strategy is the *dedicated storage* strategy, indicating that all products have a fixed spot in the warehouse. The advantages of *dedicated storage* are that order pickers get familiar with the locations of products and products can be sorted on product type, client, or other specifications (Glock & Grosse, 2012). A disadvantage are the low space utilization since every spot stays reserved for a product and the spots needs to be large enough to hold a maximum inventory. The disadvantages are larger when applied within a large storage area, therefore *dedicated storage* is very uncommon in the pallet storage area and more common in the item pick areas (de Koster, Le-Duc, & Roodbergen, 2006).

With the storage assignment *family grouping*, the correlation in orders is taken into account. Products which are often ordered together are situated near each other. This can be dynamically updated by the system or once in a certain period of time by performing a data analysis.

Class-based storage indicates storage based on certain criteria, such as product type, size or demand. The demand can further be split in demand on *volume* or on *turnover* class (Blomqvist, 2010). Demand on *turnover* indicates the amount of times a product type has been ordered and demand on *volume* indicates the amount of products of a product type that has been ordered. The products with the highest order *volume* or *turnover* are placed in class A and mostly situated nearest to the starting point of the storage area. The second class is B and is situated a little further than A and so on (de Koster, Le-Duc, & Roodbergen, 2006).

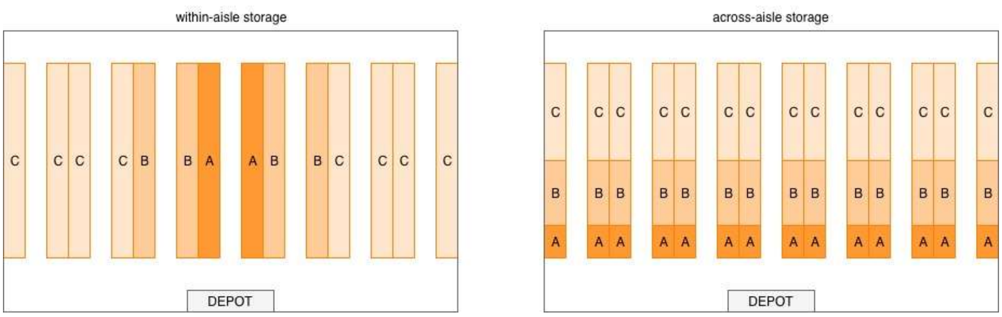


Figure 5: Layout principles demand-based storage

The advantage of class-based storage is the shorter travel distances and with that a reduction in travel time. On the other hand, congestion and unbalanced utilization can result from this strategy (Petersen, The impact of routing and storage policies on warehouse efficiency, 1999). Within *class-based storage*, two layout principles can be distinguished, the *within-aisle storage* and the *across-aisle storage*, see Figure 5. The selection of one of these layouts does affect the routing method selection. In multiple research, it has been proved that the *across-aisle storage* in combination with the routing method *combined* is close to the optimal situation gained from simulations (de Koster, Le-Duc, & Roodbergen, 2006).

Zoning strategies

In addition to implementing a strategy in storing the products, a strategy in how to zone the storage area can be applied as well. If a zoning strategy is applied, one order picker is assigned to a certain zone and will only pick products located in that specific zone. The advantages are that order pickers walk smaller areas, get easier familiar with the products and product locations and that there might be less congestion in the pick lanes. A large disadvantage is that orders need to split and later consolidated to make sure all products for one customer are shipped together. The two strategies to cope with this disadvantage are *'progressive assembly'* and *'parallel picking'* (de Koster, Le-Duc, & Roodbergen, 2006).

With the *progressive assembly* strategy, an order picker starts picking the order, places the products in a tote or box and after finishing his or her pick round, passes the box or tote to the order picker in the next zone. The order is finished after all zones from which products have to be picked are visited. Another name for this strategy is *pick-and-pass picking* (de Koster, Le-Duc, & Roodbergen, 2006). *Parallel picking'* indicates that all order pickers simultaneously pick the same order and after all order pickers are finished, the order parts are consolidated. The issue in both of the strategies is the distribution in workload over the order pickers (de Koster, Le-Duc, & Roodbergen, 2006).

Picking strategies

Depending on the order sizes, a picking strategy has to be selected. Two strategies are distinguished, namely *single-order-picking* and *batch-picking. Single-order-picking* implies that an order picker has picked one complete order after his or her pick round. The amount of pick rounds performed is similar to the amount of orders. This strategy is mainly used by large order sizes. If orders are small, *batch-picking* might be an efficient solution to reduce the pick time per order (de Koster, Le-Duc, & Roodbergen, 2006).

Batch-picking is the consolidation of multiple orders on one pick order, representing one pick round (Gu, Goetschalckx, & McGinnis, 2007). It is applied in two ways, the first is based on the proximity of its storage locations and the second is based on the time-window in which the orders are released (Marchet, Melacini, & Perotti, 2011). An advantage of *single-order-picking* over *batch-order-picking* is that the order integrity is maintained and it is easier to implement (Blomqvist, 2010).

Sorting strategies

When a *batch-picking* strategy is applied, a sorting strategy has to be implemented. The two sorting strategies are *sort-while-pick* and *sort-after-pick.* With *sort-while-pick* an order picker walks the pick round with a cart on which multiple totes or boxes are placed. Each tote or box represents on order. An order picker picks a product and places the product directly in the designated tote or box (de Koster, Le-Duc, & Roodbergen, 2006). *Sort-after-pick* entails that an order picker picks the products and places them all in one tote. When the pick round is finished, all products will be sorted to individual orders. The *sort-after-pick* strategy is mostly used when the product sizes are small and an order consist of only one or two products. When an order consists of three or more products, it is convenient to apply the *sort-while-pick* strategy (de Koster, Le-Duc, & Roodbergen, 2006).

Routing methods

A routing method is applied to guide order pickers during the pick round with an specific route and ensure an efficient and relatively short route by sequencing items on the pick order. Five heuristic routing methods exist and one optimal, gained from executing an algorithm. The methods are shown in Figure 6. With the *transversal* method, each aisle containing at least one product that has to be picked is traversed entirely (Petersen, The impact of routing and storage policies on warehouse efficiency, 1999). An order picker actually walks a s-shape figure. Therefore, the method is often referred to as the *s-shape* method. This method is seen as the simplest heuristic and mainly combined with *randomized* or *dedicated* storage (Blomqvist, 2010). Combining this route with other storage strategies, will not provide the efficiency that these storage strategies can reach.

Figure 6: Routing methods for manual order pick systems

Another simple heuristic, is the *return* method. An order picker enters solely the aisle containing a product that has to be picked, and enters and leaves every aisle at the same side. An advantage of this method over the *transversal* method is that an order picker does not have to switch between the left and correct pick face. He or she can pick from the left side on the way in and from the right side on the way out, or the other way around (Blomqvist, 2010) (de Koster, Le-Duc, & Roodbergen, 2006).

The *midpoint* method can be compared with the *return* method, only is each aisle picked from both sides and is the middle of the aisle never crossed. This method is preferred over the *transversal* method when there is only a small amount of picks per aisle (de Koster, Le-Duc, & Roodbergen, 2006). This method is mainly applied with relatively small storage area, otherwise a large distance has to be traversed since the pick route goes around the storage area which may cost a lot of time.

The *largest gap* method is similar to the *midpoint* method, only the *largest gap* in which no picks are present is searched for and does not have to be traversed. Aisles in which the *largest gap* is between two picks will be entered from both sides, while aisles where the *largest gap* is connected to the entrance of the aisle, will only be entered from the opposite side. The *largest gap* method always outperforms the *midpoint* method, but is from an implementation perspective more complicated because for each order it has to be calculated where the *largest gap* occurs. Also this routing method can only be applied in combination with the *randomized* and *dedicated* storage strategies (de Koster, Le-Duc, & Roodbergen, 2006).

With the *combined* method, or in other studies named *composite* method, aisles can be completely transferred in a *transversal* way, or be entered and exited at both sides, in a *return* way (de Koster, Le-Duc, & Roodbergen, 2006).

In most cases the heuristic methods are used, because the *optimal* method has quite some downsides. First of all, an algorithm has to be developed that needs to determine per order or pick order which route the order picker has to walk. Secondly, an optimal routing algorithm cannot take aisle congestion into account, which with some heuristics can be eliminated or reduced. And lastly, an optimal route is often illogical to the order picker, which increases the risk of this order picker taking personal decisions (Petersen, The impact of routing and storage policies on warehouse efficiency, 1999). Combined with the fact that many research has shown only a small improvement when applying the *optimal* routing method in comparison to other routing methods, the advantage of the optimal route does in most cases not compensate for the disadvantages (de Koster, Le-Duc, & Roodbergen, 2006).

2.2 Nedcargo and its order pick system

From section 2.1, knowledge is gained on the e-fulfilment customer and on OPS strategy decisions. Since this research is on implementing e-fulfilment in the OPS of Nedcargo, the company Nedcargo will be introduced and the OPS of Nedcargo analysed. In section 2.2.1 general information of Nedcargo is given to provide an overview of the type of company and its objectives. In section 2.2.2, the order pick system of Nedcargo is analysed based on processes, strategies and performance.

2.2.1 General information of Nedcargo

Nedcargo International B.V. is a logistic service provider in the food, beverage and retail industry. The company has three divisions: Logistics, Forwarding and Multimodal. This research is commissioned by the Logistics department, the analysis is focussed on this part of the company. More information on the background of Nedcargo is provided in Appendix B: Background information Nedcargo. This section describes the general information of Nedcargo including the mission and vision of Nedcargo, the layout of the warehouse in Waddinxveen, the resources, the throughput, the order types handled and the functions and flow of the warehouse.

Mission and vision

Nedcargo Logistics offers warehousing and distribution services within the Netherlands and Belgium. It provides the collection from production location, the warehousing itself, stock management and order processing as well as distribution to customers. All these services, Nedcargo wants to execute in a certain way, i.e. the mission and vision.

Nedcargo has a straightforward mission and vision, which have to be realized in 2020. As Nedcargo describes it, the logistics of food, beverage and retail is their passion and executing this in a responsible way as well. Nedcargo fulfils a big role in the food chain from producer to consumer and therefore feels to have the responsibility to be an example in responsible and efficient handling of products with respect to its environment (Nedcargo B.V., 2017).

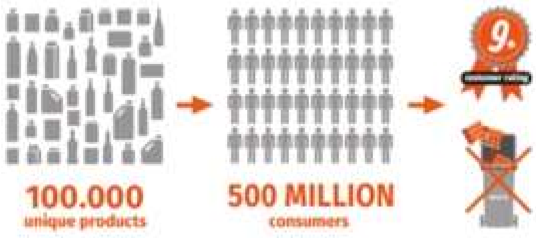


Figure 7: Mission of Nedcargo (Source: Nedcargo International B.V.)

The mission of Nedcargo consist of multiple strivings for 2020, namely:

- A logistic supply chain without waste of environment, time, money, talent, food and transport
- Handling 100.000 unique products, which will reach 500 million consumers
- Safety and quality are the leading factors within Nedcargo
- The service of Nedcargo needs to be rated with a 9+ by her customers.
- Adding value for the customer by using technologic high quality, efficient logistic solutions.

Layout

Nedcargo has six warehouses in the Netherlands and two in Belgium. This research is about their warehouse in Waddinxveen, the Netherlands. The warehouse is located near the A12 highway and covers a ground floor area of 40.000 square meters, the complete site covers an area of 64.000 square meters. Trucks and cars enter the site on the south side of the building and drive around one way to get to the exit. In Figure 8 a sketch of the situation is given.

There are 79.802 pallet slots, of which 13.235 slots are ground floor pallet locations mainly used for fulfilling case pick orders. Besides 3.513 slots are blocked for other functions, e.g. the storage of empty pallets, paths to emergency exits and disposal containers. The maximum occupancy rate is 85% resulting in a maximum capacity of 64.846 pallets euro equivalent. Euro equivalent indicates a pallet slot of the dimensions of a euro pallet. Four euro equivalent pallet slots fit between two pillars of the pallet racks. Nedcargo also has clients who use other types of pallets, of which only three pallets fit between the pillars of the pallet rack.

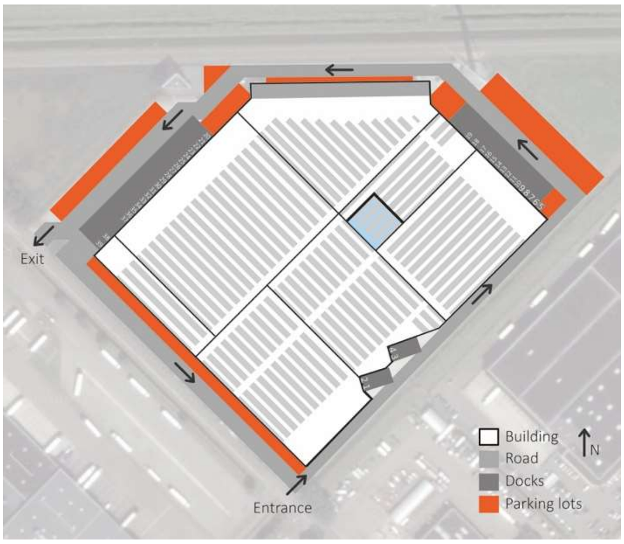


Figure 8: Situation sketch of warehouse layout and surrounding in Waddinxveen

The main aisles are at least 3,6 meters wide and the aisles are approximately 3 meters wide, leaving just enough room for two reachtruck drivers to pass one another. The warehouse has 39 docks of which 37 docks are inbound and outbound docks and 2 docks are dedicated for inbound of returned packaging materials, such as beer bottles and crates. The pallet racks are maximum 12,20 meters high, the amount of pallets in height differs per hall and can even differ per client. The client determines the configuration of the pallet; therefore some pallets have a maximum height of 1 meter, others of more than that. Pallets can also be double-stacked if that is what the client requests. The warehouse is split into eight parts, hall 1 to hall 9, with hall 7 conditioned and hall 8 not present. All the pallets of one client are located near each other, as much as possible.

Resources

The warehouse in Waddinxveen has multiple equipment types to perform all warehouse functions. All handlings are done manually, but supported by machines or mechanisms. There are no drive-in pallet racks in Waddinxveen, meaning that each pallet is reachable from the aisles. Figure 9 shows a picture of the pallet rack. The circle shows the case pick locations at ground floor level.

Figure 9: Palletracks at the warehouse in Waddinxveen

Furthermore, multiple types of trucks are used to perform the pallet movements. The trucks used the most are shown in Figure 10 and their main function is written below the picture.

Order pick truck: for picking case pick orders

Reachtruck: for picking and placing pallets on heights (full pallet picking)

Pallet truck: for loading trucks and relocating pallets

Figure 10: Trucks used in the warehouse of Nedcargo

Other equipment used are hand scanners, board computers, printers, portable printers and many other small supporting equipment. The warehouse operates 18 hours per day from Monday to Friday in two shifts. In peak periods a third shift can be added, during the night.

- Shift 1: 06:00 hr until 15:00 hr
- Shift 2: 15:00 hr until 00:00 hr
- Optional shift 3: 21:00 hr until 06:00 hr

Of these nine-hours shifts, one hour consist of breaks. Two times a break of 15 minutes and one time of 30 minutes. The amount of order pickers on reachtrucks simultaneously is 24 and on order pick trucks 40. Furthermore, multiple employees are executing functions as loading trucks, controlling orders and other tasks such as cleaning, repairing or exchanging batteries. These employees are mainly present at the docks, in the offices, on the main aisles or other designated locations, but not in the aisles where products are mostly picked.

Throughput and ordertype

The warehouse handles over 450.000 orders on an annual basis, consisting of around 1.7 million order lines. The weekly distribution of orders is given in Figure 11. Some high peaks are visible between the 10th and 21st week, due to holidays, spring season and 'Kingsday'. Also, the beginning of the summer shows a small peak and halfway of September, around week 38, peaks are present. In 2016, the month September had extremely nice weather, which can explain this peak. The last large peak is seen in the period of Christmas and New Year. The base amount of total orders is between 8000 and 9000 per week, furthermore It can be said that the amount of orders is depending on the holidays and weather conditions.

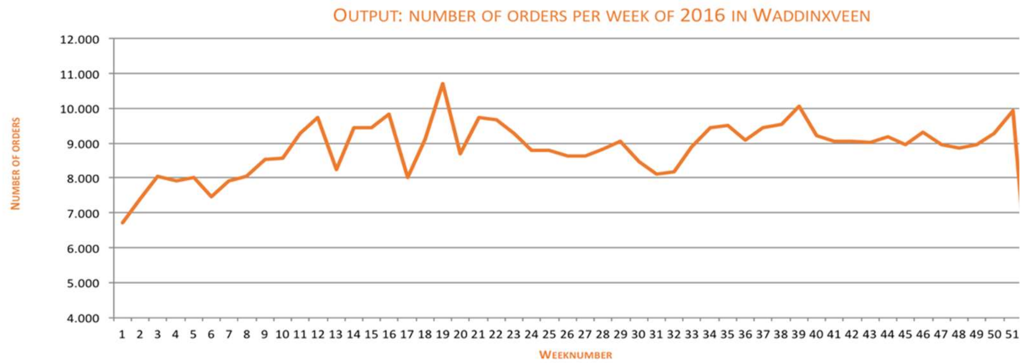


Figure 11: Amount of orders per week in Waddinxveen in 2016

The amount of products shipped to customers in 2016 was around 80,5 million. Of these, 27% is shipped in case pick orders and 73% in full pallet orders. Implying that 27% of the products is picked by hand. The products consist of food and beverage products, of which some has to be temperature controlled. Also, a lot of products consist of glass bottles, which requires careful handling of these products. All products have an expiry-date which is of influence on the process, since a product with the nearest expiry date has to be picked first. This is on itself not very difficult to register, but because some retail customers want their products to have a minimum time until the expiry-date, the process gets more complicated. Handling food and beverage products indicates that a certain policy of first-expired-first-out has to be applied when possible. Nowadays, this is only applied at pallet level since all cases on a pallet have the same expiry date.

Functions and flow

In a distribution warehouse, the type of warehouse of Nedcargo, four main functions can be distinguished, see Figure 12. The four functions aim to buffer the gap between production and consumption and to transform the unit loads in such a way the customer wants to receive them (Gu, Goetschalckx, & McGinnis, 2007).

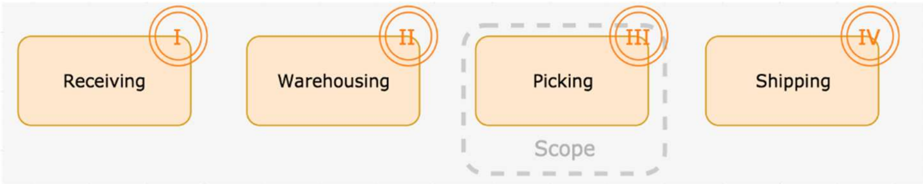


Figure 12: Main warehouse function in a distribution warehouse

First, the function 'receiving', within this function the receiving of the inbound products and the control of these products is executed. Secondly, the function 'warehousing' consists of functions as storing the products and replenishment of storage areas with a smaller unit load, the case pick pallet slots on ground floor level. Thirdly, the function 'picking' in which products are picked after receiving a customer order. Picking can be done in full pallet orders or case pick orders. Lastly, the function 'shipping' consisting of the control of the picked orders, loading the truck and distribution of the orders.

Since these four functions need to be couples into one warehouse, a warehouse flow diagram can be constructed to show the links between the functions. Figure 13 shows the warehouse flow as often analysed in research (Russell & Meller, 2003). At Nedcargo in Waddinxveen, the warehouse flow is similar to the one depicted in the figure, except for the item pick area. There is a small item pick area of one client in one of the regular aisles in the warehouse. The downside of this is that pallets are still picked in the same path, which can cause a dangerous situation. Also, the racks in which the items are stored are not made for this, which results in a messy storage area. Furthermore, the accumulation, sortation and packing step is not a separated step from the process. During picking, the orders are accumulated. Sortation is done by placing the order at the correct dock for shipping and packing is only done with case pick orders and implies sealing the pallet. Shipping at Nedcargo has three possible networks, the regular Nedcargo network with trucks, the dense Nedcargo network with small trucks and the network of an external distributor.

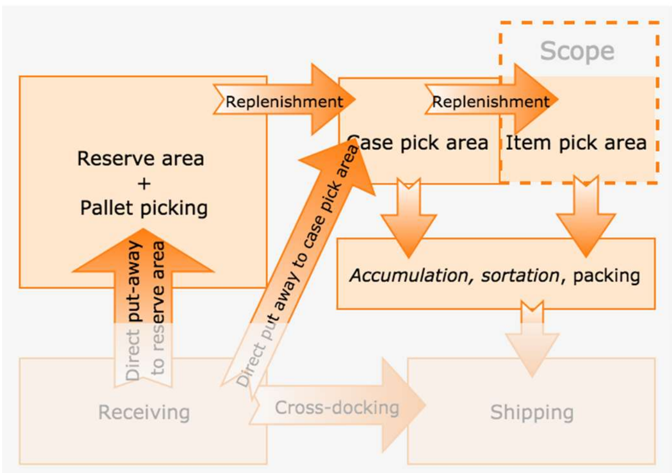


Figure 13: Warehouse flow at Nedcargo, including e-fulfilment service

Since this research is about order pick systems in which only the picking of the products is relevant, the receiving, warehousing and shipping functions of the warehouse are not taken into account in the further research. If more knowledge on these three functions is preferred, Appendix C: Receiving, Warehousing and Shipping explains the processes of these functions. Besides, the scope of this research is to design an order pick system for the handling of orders consisting of five or less cases and of items, in Figure 13 represented as the item pick area. The other two order pick systems, the pallet picking and the case picking are analysed in the following section.

2.2.2 Order pick system of Nedcargo

As mentioned in the previous section, the scope of the research is an order pick system in which the orders consisting of five or less cases and of items will be fulfilled. Since the fulfilment of these orders will be implemented at an existing logistic service provider, the current order pick processes of the LSP are of high importance in this research. This section provides an answer to the following subquestion: *'How are the current order pick processes organised at the LSP?'*. This analysis is divided over three categories, namely the process of the OPS, the performance of the OPS and the strategy decisions applied in the OPS. Since Nedcargo has actually two order pick systems, the full pallet picking and the case picking, both are analysed.

Process

The order pick system of Nedcargo consist of two main processes, the process of full pallet picking and of case picking. A case pick order consists of multiple cases of one or different SKUs. The case pick order are also transported on a pallet, no matter the size of the order.

Full pallet order consists of full pallet(s), as the name is already mentioning. It can be one pallet or multiple pallets. Full pallets are mainly stored in the upper level slots of the palletrack, with some exceptions on ground floor levels. Full pallets are always picked per pallet, by reachtruck drivers. The process of picking a full pallet is explained in Figure 14.

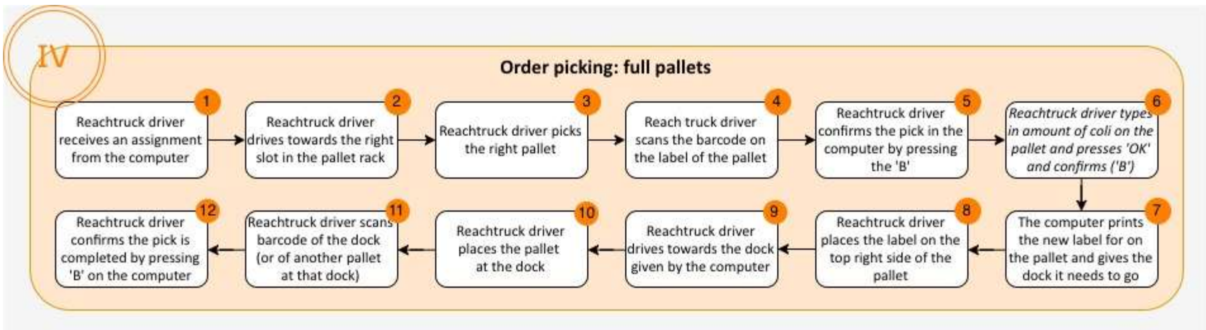


Figure 14: Process of sub function 'full pallet picking'

Every pallet that is picked is scanned, provided of a label and moved to the correct dock to get ready for shipment. The process has little room for errors. A reachtruck driver could pick the wrong pallet but after bringing the pallet to ground floor level, it will be scanned and the system will notify the mistake. Since the pallet can only be scanned when it is on ground floor level, this mistake can take up quite some time. Another inconvenience is that since food and beverage products have an expiry date, it would be logical to apply the first-expired-first-out strategy. However, this can result in a full pallet order not being picked as full pallet, but compiled from the case pick location, because these products are first expired, resulting in extra work which might have not been necessary.

The picking of case pick orders is explained in Figure 15. The cases within these orders are picked from ground floor level by an employee with an order pick truck. One order will be collected on one or more pallets, depending on the order size. Multiple orders will never be collected on the same pallet.

Figure 15: Process of sub function 'picking case pick orders'

The order pick process of case pick orders has quite some room for errors, especially pick errors. An order picker does never scan the products, but only the location of the product. This can result in the order picker scanning the correct barcode, but picking the products from the wrong location. The confusion of four barcodes between the pillars and in some cases only three pallets, as explained in 2.2.1, can increase this risk. Furthermore, the amount of products that are picked by the employee are not controlled in any way during the picking itself. Also, the way the products are stacked on a pallet, can be quite challenging, especially with products having different sizes and different weights. If a pallet is not stacked correctly, it might cause damage to the products during transport. Two time-consuming room for errors are present in the process. The first is when an order picker forgets to scan the barcode at a pick location. At the end of the pick round, the order cannot be closed because there is still a product not picked according to the system. Since the system does not shows which product still need to be picked, the order picker needs to scan each barcode again to figure out which one he or she missed. The second time-consuming aspect is the fact that for some clients the pick route is only based on location and not on product dimensions. While this is of importance with stacking. The order picker has to figure out the pick route by him- or herself. Eventually for all clients the pick routes should be based on both, i.e. the location and product dimensions.

All steps in which an order picker is scanning or typing something in the scanner or computer are registered. On the other hand, all other handlings are manually, supported by machines. The activities of the reachtruck drivers have a quite high risk of damage, since they have to pick pallets from different heights. Palletrack locations only have a few centimetres of space below and above the pallet when placing it, making it more difficult to pick and place the pallets.

Performance

The performance of the order pick system is measured by the productivity of the order pickers, in comparison to a set norm and by the lead-time of the orders from order placement to order delivery.

At this moment, Nedcargo has for most clients a lead-time from day A to day B and for some still day A to day C. Day A represents the day of order placement and day B the next day. Day C represents the day following day B. Eventually the goal is to have a lead-time of day A to day B for all clients. This lead-time entails that a customers' order should be at Nedcargo before 12:00 o'clock on day A. Than it is possible for Nedcargo to deliver the order on day B at the timeslot agreed with the customer. For day A to day C, the order should be placed on day A before 16:00 o'clock.

For the productivity performance, a time-motion study has been executed to measure the performance of the order pickers and to discover the time required per step in the process. During the study, several order pickers and reachtruck drivers were recorded by a GoPro mounted on them during their work. With the program 'V-note', the results from the videos have been analysed.

In the warehouse in Waddinxveen, a maximum of 24 reach truck drivers can work simultaneously. The set norm of the amount of assignments fulfilled per hour per person, is 21. These 21 assignments consist of the storage of inbound pallets, replenishment of the case pick slots and the picking of outbound pallets. The activities performed in order to fulfil these assignments can be categorized in five elements. '*Transport*' represents transport time from one location to another, *'Administration'* is the scanning of the pallets and the placing of the labels, '*lifting*' represents the movement of the forklifts, '*picking and placing'* is the picking of a pallet and the placing of a pallet at a certain location and *'other'* represents other activities, like throwing garbage away. In Table 1, a distribution of the total time per category is given, these are the totals of seven assignments that are analysed combined. The time distribution per assignment is given in Table 2.

Table 1: Distribution of total time of full pallet assignments

	Transport	Administration	Lifting	Picking/Placing	Other	Total
%	51,1%	10,0%	18,6%	17,4%	2,9%	100%
S	567	111	206	193	32	1109

The analysis covers 1109 seconds, which is around 18,5 minutes. In this time, seven assignments were fulfilled. The differences in duration per step over the activities are mostly caused by the distance a reachtruck driver has to travel to collect or bring a pallet and by the height of the slot where the picking and placing of the pallet takes places. An assignment takes on average 158 seconds, which is a little less than 2 minutes and 40 seconds, resulting in 22,5 assignments per hour. This does not take into account any toiletry breaks or other inconveniences. Therefore, the given 21 assignments per hour per reachtruck driver seams realistic.

The transport is the largest consumer of time, with over 50% on average, resulting in 81 seconds per assignment. In two out of five assignments, the transport is even larger than 60% of the time. An explanation for this is that in those assignments the reachtruck driver had to relocate a pallet from the first to the second level, or the other way around. In other words, the lifting and picking/placing time for those assignments is a lot lower than with the other assignments, and with that the share of transport time higher.

Table 2: Distribution of time per full pallet assignment

	Transport	Administration	Lifting	Picking/Placing	Other	Total
			Picking (level 6 to 1)			
%	54,4%	12,9%	20,7%	12,0%	0,0%	100%
S	118	28	45	26	0	217
			Storage (level 1 to 7)			
%	37,7%	14,8%	24,6%	18,3%	4,6%	100%
S	66	26	43	32	8	175
			Replenishment (level 2 to 1)			
%	60,3%	9,9%	6,6%	17,4%	5,8%	100%
S	73	12	8	21	7	121
			Storage (level 1 to 10)			
%	43,0%	6,3%	31,3%	19,4%	0,0%	100%
S	62	9	45	28	0	144
			Storage double pallet (level 1 to 4)			
%	49,0%	7,1%	11,0%	21,9%	11,0%	100%
S	76	11	17	34	17	155
			Storage (level 1 to 7)			
%	50,3%	6,6%	26,3%	16,8%	0,0%	100%
S	69	9	36	23	0	137
			Picking (level 2 to 1)			
%	64,4%	10,0%	7,5%	18,1%	0,0%	100%
S	103	16	12	29	0	160

Even though the norm is set to be 21 and from this study it shows that a productivity of 22,5 assignment is possible, the historical data shows a performance of 17 assignments per hour. This would suggest that the reachtruck order pickers do not continuously perform the assignments. From observing the order pickers and having conversations with them, it shows that many side task are also performed by these employees. These side tasks include removing empty pallets, unpacking replenishment pallets, changing the pallet type underneath the products, reporting broken products and many more.

A maximum of forty order pickers can operate simultaneously in the warehouse in Waddinxveen. The amount of cases an order picker can pick per hour is very variable. Mainly it depends on the type of order he or she has to pick. Some orders require a label on every product picked (Heineken Slow Movers). With other orders only one or two products of a certain product type are picked (Heineken Slow Movers, item pick). And another order requires repacking of the products picked (item pick). These orders result in a lower picking speed. In this analysis, the categories differ from the full pallet assignments. *'Transport'* and *'Other'* represent the same as in the full pallet assignment. *'Administration'* consists of the registration of the picked products and the scanning of the location barcodes, *'Labelling'* is the printing and placing of the label on the order. *'Picking'* represents the actual picking of a product and placing it on the pallet and *'Packing'* is the sealing of the order after finishing the pick round.

Nedcargo mentioned that with regular orders, an order picker picks around 150 coli per hour and with special orders, like the Heineken Slow Movers and the item pick orders, only fifty coli are picked per hour. Because 60% of the orders that have to be picked are in these categories (mainly in Heineken Slow Movers), the average amount of coli picked per hour in Waddinxveen is ninety coli per hour. A 'coli' is the unit load in which the product has to be picked. In most observations, this represents a case but in some it is an item. Over a time period of 11.143 seconds, approximately three hours, 254 coli were picked, which is equivalent to 85 coli per hour and approximately 5 percent lower than the set norm.

Table 3: Distribution of total time of case/item pick assignments

	Transport	Administration	Labelling	Picking	Packing	Other	Total
%	39,4%	15,3%	11,2%	14,6%	14,2%	5,3%	100%
S	4.155	1.708	1.421	1.911	1.311	637	11.143

The averages and totals of the picking of case pick orders, named in Table 3, are derived from six video analysis of the order pick activities in the warehouse in Waddinxveen. The distribution of the time of each of these videos is provided in Table 4.

Table 4: Distribution of time per case/item pick assignment

	Transport	Administration	Labelling	Picking	Packing	Other	Total
Case pick order – 61 Coli picked (Heineken Slow Movers)							
%	29,7%	14,9%	16,1%	21,9%	11,2%	6,2%	100%
S	1048	524	569	773	395	220	3.529
Case pick order – 45 Coli picked							
%	39,2%	17,4%	15,0%	17,3%	4,7%	6,4%	100%
S	594	263	227	262	72	97	1.488
Case pick order – 40 Coli picked (Heineken Slow Movers)							
%	35,6%	15,8%	13,9%	19,7%	8,3%	6,7%	100%
S	755	334	294	417	177	141	2.158
Case pick order – 44 Coli picked							
%	41,4%	17,5%	9,6%	14,3%	10,2%	7,0%	100%
S	777	328	180	269	192	132	1.878
Case pick order – 62 Coli picked							
%	49,1%	11,0%	8,8%	12,0%	17,7%	1,4%	100%
S	699	157	125	171	252	20	1.424
Item pick order – 2 Coli picked (item pick order)							
%	41,6%	15,0%	3,7%	2,8%	32,9%	4,0%	100%
S	282	102	25	19	223	27	678

Also for the case pick orders, it is clear that the transport from one place to another takes most of the time. At the Heineken Slow Mover orders, the transport has the lowest share compared to the other orders. This is because many different product types have to be picked and solely one or two products per product type. This results in a higher share of time of picking and labelling. The share of transport time of the 5th order is the highest, because just a few different product types were picked in this pick order. The packing share of the 6th order is the highest compared to other assignments, because this order consisted of two loose bottles. A box needed to be folded and taped for these two bottles and extra filling material was needed to make sure the bottles would not damage during transport. Also included in this time is the transport to and from the location where the package materials have to be collected. Excluding this part, would result in a share in transport time of more than 60%. The last order is comparable with the e-fulfilment orders for which this research is initiated. During the eleven minutes of the 6^{th} order, only two coli were picked and made ready for transport, leading to a total of less than twelve items per hour.

Strategies

As explained in section 2.1.2, order pick systems consist of multiple strategies, which have been implemented during the design of the OPS and which are still applied every day. The strategies have influence on the OPS layout, process and performance.

First of all, Nedcargo does not apply any form of automation in their warehouses. All functions and tasks are performed manually, but supported with electronic equipment and mechanizations. The order pick method applied is therefore also manual, more specific: *the picker-to-parts* method. For the picking of full pallets *'high-level picking'* is applied and the picking of case pick orders '*low-level picking'.*

The storage area in Waddinxveen is divided into two types of storages, the full pallet storage area and the case pick storage area. The full pallets are stored from the second level of the palletrack and higher and the case pick storage are the ground floor slots of the same palletracks. It occurs that full pallets are also placed on ground floor level when not all slots are required for case picking. One hall in the warehouse is a temperature controlled hall.

Multiple storage strategies are applied in these two storage areas. First of all, most pallets of one client are placed near each other. This is especially for the case pick locations, since all orders consist of products of only one client and a case pick order can consist of multiple product types. This falls in the category of *family grouping* strategy. Among clients, a *class-based* strategy is applied. Clients with a higher turnover in volume compared to other clients are placed more closely to the docks than clients with a lower turnover in volume. Furthermore, the storage of pallets happens partly *random*. If a pallet has to be stored, the system will search for the *closest open location* within the area of the client where this pallet fits. Whether it fits at a certain slot is dependent on the height of the pallet and the height of the pallet slot. An additional criterion for selecting a specific slot is whether or not there is enough free driving space in the path where the slot is located. The system takes into account whether there are already two other reachtruck drivers send to that specific path and if this is the case, it will search for another possibility. If there is no other possibility, the maximum of two reachtrucks per path is overruled. Another storage restriction is that some halls have been equipped with a sprinkler installation. Only bottled products or products in plastic can be stored here.

The zoning strategies applied differ per process. For the full pallet picking, *parallel picking* is applied. The full pallets can be picked by multiple reachtruck drivers, depending on the distance of the reachtruck driver to the pallet that need to be picked. The zones in which a reachtruck driver is, are not fixed, but depend on the location of the driver. The case pick orders, or case pick parts of orders are completely picked by one order picker, no zoning strategy is applied. Besides these case pick parts of orders, an order can consist of full pallets. These pallets can be picked by any reachtruck driver and are consolidated at the shipping dock.

Nedcargo applies only *single-order-picking*, since a reachtruck driver can only pick one pallet at the time and that pallet will always belong to one customer. Order pickers who pick the case pick parts of orders will collect all cases belonging to that order, place them on a pallet and when finished transport the pallet to the correct shipping dock. He or she will not pick multiple orders at the same time. Since no *batching* is applied, a *sorting* strategy is not necessary, therefore these are analysed in this study.

The *transversal* strategy is mainly applied at Nedcargo, even though an order picker can also turn around in a path. Due to the width of the path, turning around increases the risk of damage or collisions and is therefore not convenient. The pick route is determined based on the pick locations within a pick order. The route can be adjusted based on the characteristics of the products, since it is preferred to have lighter products on top of heavier products.

2.3 Implementing e-fulfilment in OPS of an existing LSP

In the previous sections the e-fulfilment customer and order pick system strategy decisions have been research and the description of the company Nedcargo and its order pick system are given. In this section, the combination of e-fulfilment and an order pick system of an existing LSP, in this case Nedcargo, is researched. This section starts with a small part on the theory of combining these two systems. After that, the practical challenges of implementing e-fulfilment in the order pick system of Nedcargo are given. The subquestion answered in this section is: *'To what level can e-fulfilment be integrated in the OPS of the LSP?'*

The research on e-fulfilment is of wide variety and very specific, most research all starts with distinguishing the difference of e-fulfilment from other sales and distribution services. A tremendous change is seen in the entire retail and logistics industry, due to the rise of the e-commerce business (Leung, et al., 2018). Logistic service providers must be efficient in handling e-commerce orders and combining these processes with the handling of traditional orders, retail orders. Leung et al. describes the differences between traditional orders and e-commerce orders, given in Table 5.

Table 5: Difference between traditional logistic orders and e-commerce orders

Order characteristics	Traditional logistic orders	E-orders placed by end-customers electronically
Order arrival	Regular	Irregular
Order nature	Mostly stock replenishment	Fragmented, discrete
Size per order	In bulk	In small lot-size
SKUs involved in each order	Very few or even identical	Many
Amount of orders pending for processing	Less, relatively easy to predict	More and unlimited, relatively difficult to predict
Time availability for fulfilment	Less tight	Very tight
Delivery schedule	Relatively more time buffer	Next-day or even same-day delivery

A fulfilment process consists of multiple steps, including the picking of the order. Order picking is the most labour intensive and costly process in both traditional logistics and e-fulfilment. The order pick process of e-fulfilment is initiated by the end-customer and therefore demand-driven. A demand-driven process increases the complexity of the order pick system, due to the differences mentioned in Table 5 (Leung, et al., 2018). The complexity of small order sizes, with multiple SKUs, arriving in an irregular pattern, with a tight time schedule, directly send to the end-customer, puts pressure on the performance of an order pick system. Therefore, an LSP who wants to capture the e-commerce logistic business, can no longer follow the conventional order fulfilment process to handle e-commerce orders (Leung, et al., 2018).

The main issue for an existing logistic service provider who wants to add e-fulfilment to its business is the level of integration of the two systems. Designing multi-channel systems, implies a constant trade-off, since different channels need to perform various product and service outputs (Agatz, Fleischmann, & van Nunen, 2008). Two levels of integration for an LSP can be distinguished:

- Integrated e-fulfilment facilities into existing distribution centres, that also provide the other channels
- Dedicated fulfilment facility, separate from any other channel

According to multiple articles, the integration of the inventory for retail orders and the inventory for e-fulfilment orders is not a feasible option (Agatz, Fleischmann, & van Nunen, 2008), (Xu, 2005). This is mainly because the inventory for retailers is stored in pallet racks with longer travel distances per order. Fulfilling the e-fulfilment orders in this warehouse layout implies the same amount of time for a much smaller volume (de Koster R., 2002b). For this reason, mainly dedicated fulfilment facilities are implemented for e-commerce orders. Physically, this facility can be located directly next to the existing facilities.

The analysis on the order pick system described in section 2.2.2, combined with the study on e-fulfilment in section 2.1.1, provides multiple practical challenges when implementing e-fulfilment in an order pick system of the existing LSP: Nedcargo.

Safety: First of all, if e-fulfilment is implemented in the current order pick system it implies that the amount of order pickers using the 'low-level picking' strategy will increase. This results in busier aisles and more interaction between the order pickers of full pallet picking, case picking and item picking. Since the 'low-level' order pickers have to get of their truck to pick the products, and full pallet order pickers are driving on larger and faster trucks continuously picking and placing pallets on height, the safety of the 'low-level' order pickers is harder to guaranty. This is not in line with the mission and vision of Nedcargo in which safety is an important pillar. Safety rules as not picking pallets on height when near to an order picker can prevent this, but when the amount of 'low-level' order pickers is increasing, it can counteract the process of the full-pallet picking.

Service level (accuracy): Besides safety as an important pillar, Nedcargo wants her clients to rate the service level of Nedcargo a score of 9 out of 10. This can only be realized if the client is satisfied, which depends on the satisfaction of the customer of the client. According to the research performed in section 2.1.1, a customer is satisfied when the correct product is delivered without any damage within the given time window. Since at Nedcargo the location of the product and not the product itself is scanned and the amount of products picked is not controlled during picking, the process has too many room for errors to assure the correct product is delivered at all times.

Service level (timeliness): The e-fulfilment customer has a high demand in speed of delivery. A next-day or same-day delivery policy is required for the satisfaction of the customer. At the moment, Nedcargo applies for some clients a next-day delivery policy, but the orders have to be placed before 12:00h o'clock. For e-fulfilment and especially the future of e-fulfilment this might not be fast enough, which shows that the current order pick system is not feasible for e-fulfilment.

Wasteless (time and money): Nedcargo has as mission to have a *'wasteless supply chain'*, wasteless in waste of environment, time, money, talent, food and transport. Reducing the waste of time is hard to reach when e-fulfilment is implemented in the current OPS. In the performance of case picking, the amount of coli picked is 254, of these 252 cases are picked and only in the 6th assignment 2 items are picked. The 2 items were picked in 11,3 minutes, meaning a productivity of 11 items per hour. An solution could be to improve the process of collection packaging and filling material for the item pick orders by making it more efficient and less time-consuming. Still, with a productivity similar to the case pick orders, the revenue should be divided by the amount of items in a case, making it harder to get the process financially feasible. This does not allow a reduction in time and money.

Wasteless (environment) and quality: When items are stored at the same locations as the pallets with cases, the probability of products being damaged, getting lost or completely unready for sale is higher, since loose products will be placed on the cases on the pallets. Also, the waste of the cases from which the items have been picked needs to be thrown away, but chances are high that it will be left behind, resulting in a mess at the picking slots. This is also seen at the small item pick area that is already in use, as mentioned in section 2.2.2. Another disadvantage of placing the items at the same location as the case pick storage is that the first-expired-first-out policy is harder to apply. When a replenishment takes place and there is still an open case, which will be combined with the new pallet, it can be that an order picker will open a new case for picking items, because he hasn't noticed the open case. This results in items with a longer expiry date being picked first.

Efficiency *(single-order picking)*: Since *single-order picking* is applied at Nedcargo, all e-fulfilment orders will be picked one by one and placed on a pallet at a dock or other specific location. All e-fulfilment orders are distributed with an external distributor, meaning that these orders can be combined on one pallet. However, the order picker will have to repeat its pick round and all activities required for executing a pick round for each and every single order. The smaller the order size, the less efficient this process is. The decision on whether or not to implement *batch-picking* depends on the order profile of the client.

Efficiency *(randomized storage)*: The overall storage strategies applied, namely *family-grouping*, results in all pallets of a client placed near each other and *class-based* storage, implying that customers with a higher turnover are situated near the docks can still be applied with e-fulfilment and are also of high value with e-fulfilment. The e-fulfilment orders are client-based, so products of one client should be placed near each other and situating the client with the highest demand closest to the docks helps reducing the transport time. But in each storage area of a specific client, the *randomized* storage strategy is applied and this might not be as efficient for item storage as for pallet storage. *Randomized* storage overall indicates higher transport distances, which implies a higher picking time and therefore a longer lead-time. Since the pressure on lead-time is higher with e-fulfilment than with retail orders, *randomized* storage for e-fulfilment is initially not preferred. An advantage of implementing e-fulfilment in the current order pick system and not adding another storage area, is that only one type of replenishment has to take place and the inventory level of cases is not split over two storage areas, since cases will still be stored in the current case pick storage and in the e-fulfilment storage.

Efficiency *(transversal routing)*: It is noted that a *randomized* storage is not the most suitable storage strategy for e-fulfilment. In section 2.1.2 is stated that the *transversal* routing method is less efficient with other storage strategies, than with *randomized* storage. Implying that, the probability of *transversal* routing to have a good efficiency in e-fulfilment is lower compared to other routing methods if *randomized* storage is not applied.

As seen in this section, the OPS strategies are taken into account as well. According to research, the picking strategy, storage strategy and routing method have the most influence on the performance of an order pick system (Petersen, Aase, & Heiser, 2004). This can also be concluded from the previous section.

2.4 Conclusion: E-fulfilment integrated or separated from OPS of Nedcargo

In this chapter, the e-fulfilment customer and his or her demands, together with order pick system strategies that determine the layout, process and performance of an order pick system have been researched. The theory on these subjects was followed by an analysis of the company Nedcargo in which first general information of the company was provided and secondly, the analysis of the process, performance and strategies in the order pick systems of Nedcargo. The findings from the theory and practise have been compared in section 2.3 and from these, the challenges, advantages and disadvantages of integrating e-fulfilment in the current order pick system of Nedcargo are discussed.

Since the implementation of e-fulfilment in the OPS of Nedcargo cannot guarantee the safety of the personnel, the quality of the products and orders, the demanded service level of the customers and does not increase the probability of Nedcargo to reach its objectives stated in the mission and vision, the conclusion can be drawn that e-fulfilment should not be integrated in the current OPS of Nedcargo. A separate e-fulfilment order pick system should be designed for Nedcargo to offer e-fulfilment.

The aspects that cannot be guaranteed when integrating e-fulfilment in the OPS of Nedcargo, should be guaranteed in the separate e-fulfilment system. Some of these aspects are guaranteed already by separating the e-fulfilment system, e.g. the safety of personnel by not allowing more interaction between order pickers with reachtrucks. Other aspects can be guaranteed when implementing the correct strategies, equipment and processes. As mentioned in section 2.3, the *picking strategy*, the *storage strategy* and the *routing method* applied in the order pick system are of high influence on its performance. These three strategies will be further researched to evaluate which can be implemented best for Nedcargo and its clients.

The research question formed at the beginning of the research is partly answered by this conclusion. The order pick system of e-fulfilment should not be integrated with the existing order pick system at an LSP. Therefore, a new, more specific, research question is formed to continue this research:

'Which picking strategy, storage strategy and routing method should be applied,
to ensure an order pick system for e-fulfilment that can cope with the e-fulfilment customers' demand
and the objectives of the LSP?'

3. Generation: Design alternatives

In this chapter, the design alternatives are generated. For this generation, knowledge is gained on the requirements of the system and possible attributes of the design variables. The design variables of the alternatives are mentioned in the research question, namely: the picking strategy, the storage strategy and the routing method.

The chapter commences with the theory on how to define these requirements and to generate design alternatives, described in section 3. Following is section 3.2 in which the system requirements are defined and the order profile of the case clients is discussed. Section 3.3 and 3.4 describe the attributes of the order pick system which can be based on the requirements, and the variated attributes in the alternatives, respectively. Section 3.5 provides an overview of the design alternatives.

3.1 Theory: Defining system requirements & generating design alternatives

As mentioned, before designing a system, the system requirements have to be defined. In this section the methods that can and will be used for defining the system requirements are discussed. Also the methods for generating design alternatives are outlined in this section. From the system requirements certain operating procedures and methods can also be designed. These do not vary over the alternatives. In this chapter, these are described in section 3.3 and in this section the possible methods for this step in the design process are also discussed.

Define system requirements and constraints: Suzanne Robertson describes a requirement as some capability that somebody or something needs or wants (Robertson, 2001). A broaden definition of a requirement is given by Bahill and Dean. According to them, a requirement is a statement that identifies a capability or function that is needed by a system in order to satisfy its customer's needs (Bahill & Dean, 2009). The techniques selected for this research are explained in this paragraph.

For discovering and defining requirements, Baker and Canessa propose to split the functions in a system. In this study, all functions of an order pick system and specify requirements per function from multiple perspectives (Baker & Canessa, 2009). These techniques are referred to as *'business events'* and *'attribute listing'*. Both techniques are similar except executed on a different level. '*Business event'* refers to all subsystems in an order pick system. While '*attribute listing'* list all steps and attributes within one subsystem. (Dennis, Wixom, & Roth, 2012). A technique often combined with these two techniques is '*Reusing Requirements'*. It implies the repetition of certain requirements whereby the knowledge gained at one part of the system, might be usable within other parts of the system (Whitten & Bentley , 2007). Since an order pick system in a warehouse consists of multiple 'events' with each their own requirements, these three methods have been used simultaneously in this research.

Still the requirements for these events, steps and attributes need to be discovered, this can be done with multiple techniques. According to Yoon and Sharp, requirements need to be discovered from various perspectives, like economic, environmental and system perspectives (Yoon & Sharp, 1996). The technique *'Interviewing'* is the most common technique and can be very effective in gaining knowledge about these perspectives. It is used best when the interviewee is an expert on a specific subject

(Robertson, 2001) (Whitten & Bentley , 2007). The technique 'interviewing' is applied in an informal way during this research. A few interviews with potential clients have taken place to gain insight in the perspective of the clients and their wishes.

Other techniques that are useful in system and operational design are *'observation/apprenticing'*. The formal definition of *'Observation/Apprenticing'* is performing the tasks that the stakeholders do and learn by doing about their work and the requirements related to that work (Robertson, 2001). In the beginning of the research, three days of 'observation' and 'apprenticing' have been taken place within the warehouse of Nedcargo. 'Observation' has also taken place at other e-fulfilment centres.

Determine operating procedures and methods: Mainly, there are no techniques or models applied in this step, commonly it is based on the expertise of the designer. Specifying the requirements of the system, will lead to exclusion of certain operating procedures (Baker & Canessa, 2009). Since in this research an order pick system is designed for an existing logistic service provider, with order data from clients, the order profile of these clients and the current operating procedures and methods will be taken into account when determining new procedures and methods.

Generate design alternatives: An enormous amount of methods and techniques for generating alternatives exist. Herring, Jones and Bailey even distinguish 172 different methods, grouped in 19 categories. Even though a lot is written about the importance of this step, in design and engineering, little is written about the methods and their application itself (Herring, Jones, & Bailey, 2009). The common aspect many researchers are writing about, is the fact that when starting this step, an engineer should first apply *'divergent thinking'*, followed up by *'convergent thinking'*. The former way of thinking is to stimulate the creation of as many ideas as possible, and the latter is to complete this step with a manageable amount of ideas, which are also realistic (Brown, 2009). Still, there are many techniques to conduct this step. The techniques selected for this is: *'morphological analysis'*.

'Morphological analysis' splits a system into multiple subsystems, representing a variable. For each of the subsystems, the possible applications need to be named, representing the attributes of the variable (Rochford, 1991). When combining one attribute of each subsystem, one creates a new system, representing a design alternative (Cross, 2000). Multiple combinations of these attributes, in other words, multiple design alternatives, will be evaluated. (Yoon & Sharp, 1996). The technique is very useful when dealing with complex system that have multiple subsystems in it. Since the order pick system for e-fulfilment designed in this research can be seen as a complex system, the technique 'morphological analysis' is seen as the most fitting technique for the generation of design alternatives.

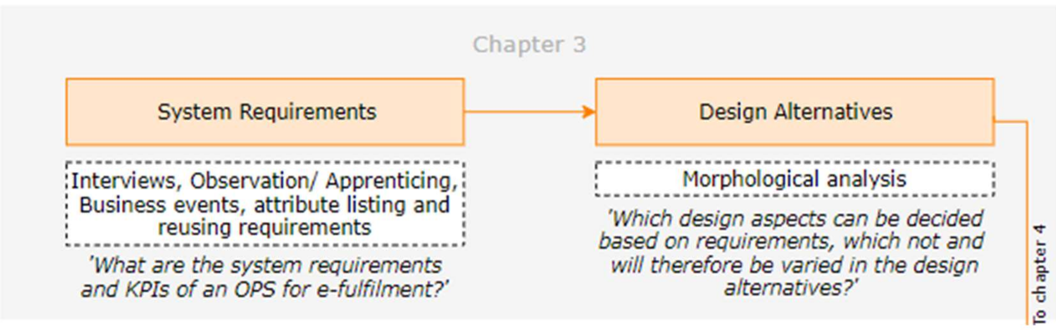


Figure 16: Scheme of approach: chapter 3

3.2 System requirements & order profile

The system requirements define what kind of functions and qualities a system must have. The definition of the requirements is performed in section 3.2.1. The order pick system designed in this research is for the client Moet Hennessy of Nedcargo. Some design decisions will be based on the order profile of this client, this order profile is discussed in section 3.2.2.

3.2.1 System requirements

The system requirements can be divided into two categories, the functional and non-functional requirements. A functional requirement represents a function the system must have and a non-functional requirement represents a quality the system must have. Furthermore, the system will have to cope with certain constraints, these can be of influence on functional and non-functional requirements. Also named in this section are the key performance indicators (KPIs) on which the system will be evaluated. The subquestion answered in this section is: *'What are the system requirements and KPIs of an OPS for e-fulfilment?'*.

Functional requirements

The main function of the order pick system is to fulfil orders, generated by e-commerce, consisting of five or less cases and of items. The fulfilment of orders requires multiple subfunctions. First of all, the order entry in which the order need to be *processed*, probably *categorized* and *batched* to a pick order when the picking strategy batch-picking is applied. The categorization of orders is also dependent on the type of batch-picking that is applied. The pick order should be based on the routing method applied. Next, the pick order need to be *released* and *coupled* to an order picker. Order pickers should be equipped with some handheld device on which they can accept a pick order assignment. An order picker will have to *collect* the equipment he or she needs for the picking of the orders, for this a workstation or something similar is required. When the order picker has all the equipment and is ready for picking he or she will follow the pick route stated on the pick order through the storage area and pick all products stated on the pick order. During the picking of the products, the products will be *scanned* and placed on a cart or into a tote or box. After picking all the products the orders will be *decoupled* from the order picker and continue through the system independently. The orders need to be *controlled*, firmly *packed* and *sorted* on distribution network.

The tasks of the e-fulfillment order pick system can be distinguished into three categories, namely *order entry* in which the order is made ready for picking, the *order picking* itself and the *order shipping* in which the orders are made ready for shipping.

Table 6: Functional requirements of an OPS for e-fulfilment at Nedcargo

Functional requirements		
Order entry	Processing	When an order has entered the system, an automatic control needs to take place on whether all products ordered are in stock - If not, an employee should interfere to determine further steps
	Categorizing	Depending on the *batch-strategy* applied, order are categorized on certain criteria
	Batching	Orders should be batched in batches of a certain batch quantity, and combined into a pick order
	Released	When a pick order is ready and build based on the routing method, it should be released into the system and ready for coupling to an order picker

Order picking	Coupling	An order picker who has no task, can couple him- or herself through a portable device to the pick order, meaning he or she will fulfil the pick order
	Collecting	An order picker will collect the equipment needed for the picking of the pick order, this can consist of a cart, totes and or boxes. - In case of boxes, the system should provide which box size is needed for which orders. These boxes should also be provided with a label to know to which order the box belongs
	Scanning	When the order picker picks a product he or she scans the product and places it onto the cart or into the tote or box. - Scanning is preferred to update the inventory level of the system and keep track of the products that have been picked for that pick order
Order shipping	Decoupling	A pick order will be decoupled from the order picker when the order picker has placed all products and totes or boxes at the designated location and confirms the pick order has been finished.
	Checking	The orders need to be controlled and compared to the initial order placed by the customer
	Packed	An order should be firmly packed with the information needed for delivery to ensure a save and good delivery at the customer
	Sorting	The order should be sorted over three distribution networks

Non-functional requirements

The non-functional requirements represent the qualities the system should have. Since Nedcargo is implementing e-fulfilment taking the future into account, the system should be able to handle a certain growth in volume. Also, currently Moet Hennessy only provides B2B customers with their products. With launching a website, this might change to more B2C customers which can be of influence on the order configuration. Order configuration entails the share of cases compared to the share of items within an order. The system should be able to cope with this growth in demand and change in order configuration.

The e-fulfilment customer wants a fast lead-time, preferable next-day delivery, this demand is getting even more important over time. Therefore, the system should be designed to deliver orders that have been placed before 22:00 o'clock, the next day. Since Nedcargo is not distributing these small orders themselves, the external distributor PostNL has been asked at what time the orders should be ready to make sure this can be accomplished. To this question, PostNL responded that the orders should be ready at 06:00 o'clock in the morning of the day that the delivery should take place. The operational hours of Nedcargo are from 06:00 until 00:00, implying that all orders should be ready at 00:00h the day before.

As mentioned in section 2.2.1, Nedcargo values the reduction in waste as an important pillar of their business. The products that Nedcargo is processing, are food and beverage products and of Moet Hennessy only beverage products. Many of these products are bottled items with an expiry date, the handling of the products should be done carefully. Nedcargo wants a system that has a low probability of breakage and spillage of products and a first-expired-first-out policy has to be implemented.

Furthermore, the customer of e-fulfilment values the order accuracy as of high important, therefore the correct products and the correct amount of products has to be picked and the design of the system should ensure this.

Table 7: Non-functional requirements of an OPS for e-fulfilment at Nedcargo

Non-functional requirements	
Whole system	- **Future:** Able of handling a growth in volume and change in order configuration - **Lead-time:** Order entry before 22:00, next-day delivery - **Lead-time:** Orders ready for external distributor at 06:00 for delivery that day - **Environment:** Low risk of breakage and spillage of products
Order picking	- **Accuracy:** Picking the correct products (100%) - **Accuracy:** Picking the correct amount of products (100%) - **Product type:** Apply first-expired-first-out policy

Constraints

Beside functional and non-functional requirements, the system can have certain constraints under which it is expected to function. When the orders enter the system, it can be any time during the day and night. Since Nedcargo does not always operate 24 hours a day, the orders will have to wait until the operational hours of Nedcargo start again before being processed. This occurs also with the breaks during the operational hours.

Furthermore, the workstations that will be implemented do have a certain capacity. When the workstation is occupied, the order picker or order will have to wait until there is room at the workstation. This occurs also during the picking of the product at a shelf. Since the order picker will have a cart on which the picked products will be placed, the order picker and the cart will block a certain space for other order pickers, representing the shelf capacity.

Another constraint is the walking speed of the order picker, the speed of the conveyor belts and the processing time at workstation. All the values selected for these variables will be fixed over all alternatives.

Table 8: Constraints of an OPS for e-fulfilment at Nedcargo

Constraints	
Operational hours	The operational hours of Nedcargo, mainly 06:00h to 00:00h
Working hours	The working hours of the employees, including breaks and shift changes
Workstation capacity	Workstation will have a fixed capacity
Processing time	Each workstation and pick at a shelf will have a certain processing time
Shelf capacity	The order picker will block a part of the shelf during picking for other order pickers
Speed	The order pickers and conveyor belts will have a certain speed in the system

Key performance indicators

The strategies that have to be evaluated and decided have influence on the efficiency of the order pick system. The term efficient can be translated in the key performance indicators, as the lead-time of the system. A lead-time need to be managed in which customer can still place the orders until 22:00h and will receive them the following day. Also the system needs to be able to cope with a change in demand and order configuration.

To measure the actual time an order is in the system, the time from order entry to order exit needs to be known, namely: TIS, total time in system. However, when a batch strategy is applied, this can influence the total time in the system tremendously, making the TIS not representable for the actual performance of the order pick system. Therefore, the total time in system without the time waiting for a batch will be KPI: TIS - WTB. If the order has been placed during the day, the waiting for a batch has no consequences for the delivery time, as long as at 22:00 o'clock all orders still waiting for fulfilment will be fulfilled. If at 22:00h a batch is not complete, it can be decided to perform a pick round with a smaller batch quantity.

Since the orders are coupled to an order picker for the picking of the products and later decoupled and continue through the system individually, the time of the order picker spend in the system represents the collecting equipment of the products, the picking of the products and possibly the sorting of the products per order. Since the picking strategy, storage strategy and routing method variated in the designs have mainly influence on this time, it is seen as the KPI: total time in picking system: TIPS

Lastly, the TIPS can include activities that are not performed in each of the alternatives, or not performed in the same way throughout all alternatives, the actual time that the order picker is in the storage system and picking the products is the actual translation of the storage strategy and routing method selected. This KPI is the TISS: total time in storage system.

The TISS is determined by adding the time on links to and from the shelves and the time at the shelves. The TIPS is the TISS with the time spend at the workstations and the links to these workstations. The TIS – WTB is determined by the TIPS plus the time spend in all activities performed individually by the order, i.e. the time at the control station, the time at the pack station and the links to and from these stations. Listed below are all four KPIs with their meaning written in short. Before analysing the results of the evaluation, these KPIs will be named again and a visualisation of the part of the system representing the specific KPI is given.

- TIS: Total time in system:
  Minimum, average and maximum time in system from order entry to order exit.
- TIPS: Total time in picking system:
  Minimum, average and maximum time in picking system from the batching process to the unbatching process.
- TISS: Total time in storage system order pickers:
  Minimum, average and maximum time in storage system; the time on links to and from flowracks and the time at the flowracks.
- TIS - WTB: Total time in system excluding the batching process (waiting for a batch)
  Minimum, average and maximum time in the system from order batching to order exit.

3.2.2 Order profile: Moet Hennessy

The order pick system will be designed for the client Moet Hennessy, (in short: Moet). Moet is planning on starting website sales of their products and wants Nedcargo to process these orders, as already is done for business customers of Moet. To build an order pick system for Moet the order profile needs to be known. The order profile consist of the annual amount of orders, the orders categorized on turnover, the distribution of the amount of SKUs per order, the distribution in order configuration and the distribution of the amount of products per SKU. Based on this information the required amount of shelves is calculated. Moet is the wine and spirits division of a conglomerate of very luxurious products. They are mainly familiar because of their champagne 'Moet & Chandon'. This can also be seen in the amount of orders and the goods delivered per week. During the whole year, the amount of orders is quite stable, with a small overall increase. Only at the end of the year, during Christmas and New Year a peak is visible, see Figure 17.

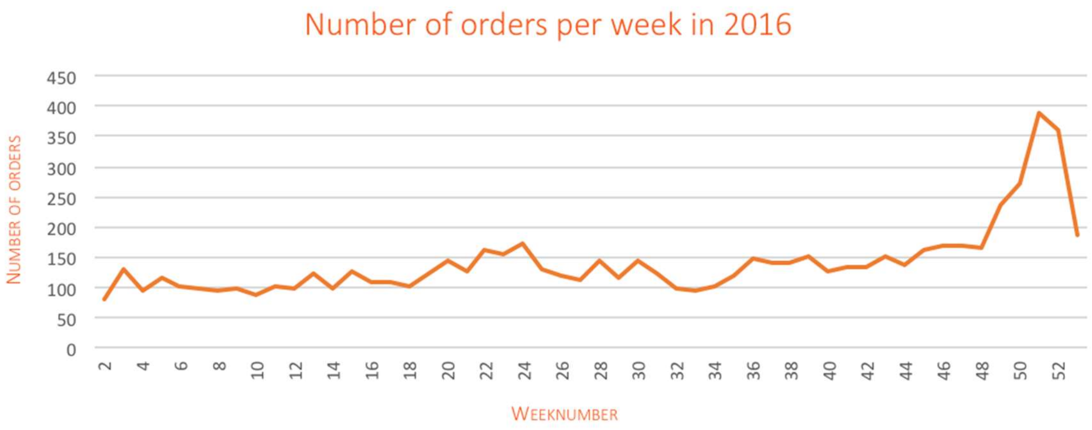


Figure 17: Distribution of the amount of orders per week in 2016

In total 10.527 orders have been delivered for Moet, of these orders 7.340 orders consisted of five or less cases and / or items and are suitable for the order pick system designed here. These 7.340 orders have been ordered over 253 days, resulting in an arrival rate of 1.21 orders per hour based on a 24-hour day. For the evaluation of the designs, this arrival rate will be used as base. Since the arrival rate is increasing at the end of the year, this will be taken into account. Furthermore, the amount of stock-keeping-units (SKUs) of Moet is 778 product types.

First, the orders are categorized in turnover category; fast mover, medium mover and slow mover orders, or any combination of these three attributes. Secondly, the amount of SKUs per order, i.e. the amount of product types per order, is determined and distributed per turnover category and thirdly the share in order configuration and the distribution per turnover category is determined. The order configuration attributes are, cases, case-item and items, or any combination of these three. A case order consists of only order lines in which cases have to be picked, similar for items. A case-item order line represents a product of which a case and an item have to be picked. First the product types are categorized as fast mover, medium mover or slow mover. The outcome of this shown in Table 9.

Example: Does an order consist of a fast-moving product of which only items need to be picked and of a medium-moving product of which a case and an item need to be picked, then the order falls in the turnover category AB, has 2 SKUs and the order configuration is case and case-item (C + CI).

Table 9: Order lines categorized on turnover category

Category	Code	% of product types	# order lines	% order lines	# cases	% cases	# items	% items
Fast	A	0-20%	31.079	87%	40.111	91%	38.605	79%
Medium	B	20-50%	3.794	11%	3.433	8%	7.876	16%
Slow	C	50-100%	829	2%	479	1%	2.367	5%

The categorization of an product type depends on the times it has been ordered and not on the volume of the orders combined, because for the evaluation of the system the amount of times visiting a shelf is more important than the volume picked at that shelf. Based on the amount of cases and items sold on average per week per product type, the space required in the shelves has been calculated for both the cases and items for a stock level of five working days, meaning replenishment is necessary once per week. The shelf dimensions used for this calculation have a width of 1,5 meter, a depth of 1,0 meter and a height of 1,6 meter. The width is based on the space an order picker, including his pick cart, blocks when he or she is picking products. The height is based on a reachable height for order pickers smaller than the average Dutch person. The depth is selected because it can hold the five-day stock but has the lowest floorspace required. For the turnover category C, a shelf depth of half a meter would also be sufficient. The amount of shelves in brackets is eventually the number taken into account with the evaluation, see Table 10.

Table 10: Amount of shelves needed per category

# of shelves	A	B	C	Total
Cases	16 *(16)*	16 *(20)*	32 *(36)*	64 *(72)*
Items	6 *(8)*	10 *(10)*	18 *(18)*	34 *(36)*
Total	22 *(24)*	26 *(30)*	50 *(54)*	98 *(108)*

In Table 11, the distribution of the turnover category and the order configuration over the orders placed in 2016 is given. Notable is that almost 70% of all orders consist of only fast-moving products. Also, the orders consisting of fast-moving and medium-moving products has a high share in orders. Clear is that orders in which no fast-moving product need to be picked have the lowest share. The order configuration distribution shows that most orders consist of product types of which cases or items need to be picked. Furthermore the orders in which only cases need to be picked have a high share and thirdly the orders in which only items need to be picked. Orders in which cases and items of one product type need to be picked have the lowest share.

Table 11: Distribution of turnover category and order configuration among orders

Turnover Category	A	B	C	AB	AC	BC	ABC	Total
%	68,1	2,9	0,9	22,0	1,7	0,7	3,7	100
#	5.000	210	65	1.612	127	55	271	7.340
Order Configuration	C	CI	I	C + CI	C + I	CI + I	C + CI + I	Total
%	26,2	2,4	13,4	2,8	47,5	1,5	6,3	100
#	1.926	173	981	207	3.484	110	459	7.340

The distribution of the amount of SKUs per order, i.e. product types per order is provided in Figure 18. The amount of orders decreases when the amount of SKUs per order is increasing. Still, almost 60% has three or more product types in an order and almost 30% even more than 5 product types per order. The amount of SKUs: 15, represents the weighted average of all orders with more than 10 product types. The average amount of SKUs per order is 4,43 SKUs.

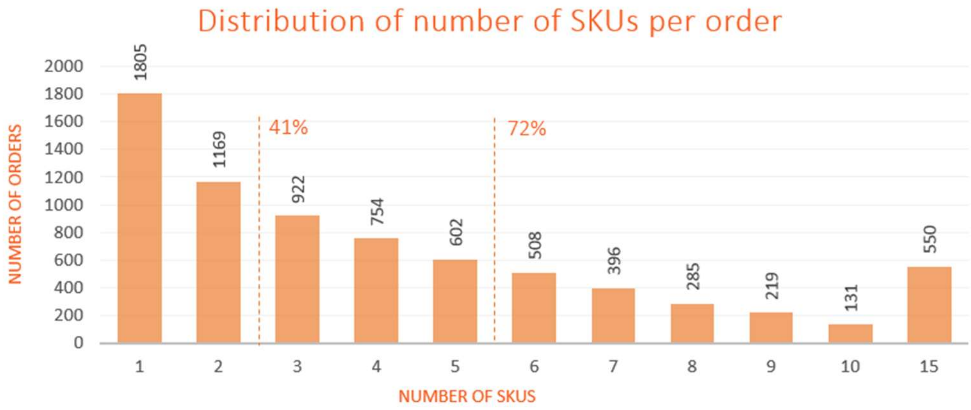


Figure 18: Distribution of the amount of SKUs per order

In Figure 19 the distribution of the amount of SKUs per order and the distribution of the share in order configuration is given per turnover category. As visualized, the B and C category mainly consist of 1 SKU, while for the A category this is more equally distributed. At the AB, AC and BC category the amount of SKUs starts at two since a minimum of two product types is required to be placed in these turnover categories. For the ABC category, the same counts except with three product types.

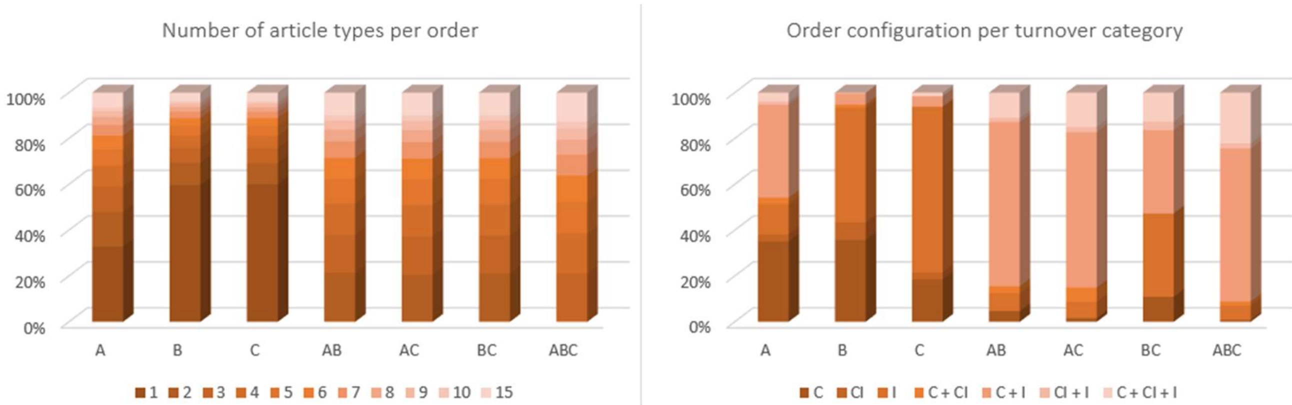


Figure 19: Distribution of the amount of SKUs per order and the distribution of order configuration per turnover category

The order configuration per turnover category shows that in the B and C category the most common order configuration is 'item' configuration. For turnover categories AB, BC and ABC this is the 'C + I' order configuration which entails that products in the order consist of either cases or items. In the turnover category A, order configuration cases and case and item is mainly present. In almost all turnover categories, the order configuration 'CI + I' has the lowest share, together with the 'CI' and the 'C + CI' order configurations.

Figure 20 shows the distribution of the amount of products per SKU. Of most SKUs three products need to be picked, these can be cases and/ or items. Furthermore almost 90% of the SKUs has a quantity of five or less products. The average amount of products per SKU is 3,8 products.

The order profile of Moet Hennessy is used for the design of the order pick system, some attributes of the design variables are selected based on this order profile. Also the order profile contributes to the evaluation of the alternatives.

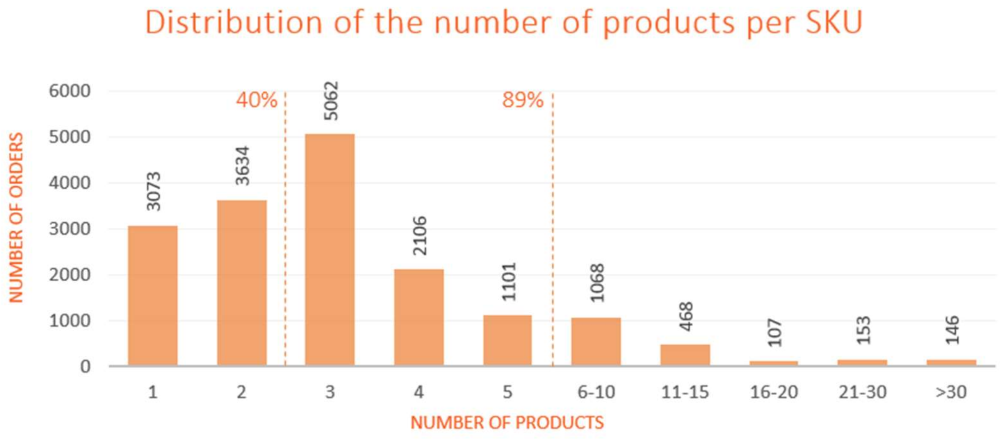


Figure 20: Distribution of the amount of products per SKU

3.3 OPS design attributes based on requirements and order profile

The research question formed in section 2.4, focusses on the picking strategy, the storage strategy and the routing method. Also stated in the research question is that the system should cope with the e-fulfilment customers' demands and the objectives of Nedcargo. Since one of the customers' demand is a short lead-time, translated into orders placed until 22:00hr will be delivered the following day, it has been decided to evaluate the complete order pick system from order entry until order exit. With order exit is meant that the order is ready to be picked up by the external distributor.

Some functions and processes of the order pick system can already be decided and defined based on the system requirements and the order profile of Moet Hennessy. The requirements have been defined in section 3.2.1. and the order profile in 3.2.2. In this section, the functions and processes not variated in the alternatives will be discussed. The subquestion that will be answered in this section and in section 3.4 is: *'Which design aspects can be decided based on the requirements, which not and will therefore compose the design alternatives?'* The design aspects will be described following the non-functional requirements named in section 3.2.1: product type, environment, accuracy, future and lead-time.

Product type: Since a first-expired-first-out policy have to be applied in the order pick system, it has been decided to use flowracks for the storage of the products. The replenishment of the products will take place on one side of the flowrack and the picking of the products on the other. This ensures the application of the first-expired-first-out policy within the e-fulfilment order pick system.

Environment: Furthermore, it is important for Nedcargo to create as little waste as possible, meaning that the probability of breakage or spillage of products should be as low as possible. This can be achieved, with the reduction in movements of the products. Therefore, it is decided that the products that are picked are immediately placed in the box in which the order is transported, if this is possible in combination with the strategies variated in the alternatives.

Accuracy: The accuracy of the orders can be assured if certain functions are implemented in the system. The order accuracy is influenced by three aspects; the product type picked, the amount of products picked and the box in which the product has been placed. To ensure the correct product is picked, each product will be scanned when taken from the flowrack. This also ensures the correct amount of products being picked. Whether or not the products are placed in the correct box can be controlled at the control station of the order, where the order will be weighted and the results compared to the weight of the products on the order. Implementing these processes will ensure a 100% accuracy, providing that the products are in stock.

Whether the non-functional requirements on lead-time and future are achieved is calculated during the evaluation of the design alternatives.

3.4 OPS design attributes variated in alternatives

In the section, the attributes of the variables that are evaluated in the design alternatives are discussed. These variables are the picking strategy, the storage strategy and the routing methods and are discussed in that order.

3.4.1 Picking strategy

As picking strategy, the two attributes *'single-order picking'* and *'batch-picking'* can be applied. As mentioned in section 2.1.2, *single-order picking* is mainly applied when the amount of SKUs in an order, i.e. the amount of stops in a pick round, and the amount of products per SKU is large. *Batch-picking* is applied when the amount of SKUs in an order and the amount of products per SKU is small. As can be seen in section 3.2.2. in the order profile of Moet, the amount of SKUs and therefore the amount of stops per orders is relatively low, 72% of the orders has five or less SKUs. The total amount of SKUs of Moet Hennessy is in comparison to the orders size quite large, namely 778 SKUs of which items and cases need to be stored, which requires quite some floor space. It would be inefficient if the order picker would pick per order and has to enter the storage area for only five stops, therefore the *batch-picking* strategy will be applied.

However, *batch-picking* can be applied in two ways, batching on order entry or batching on a certain characteristic of the orders. For this research it would be interesting to either apply batching on turnover category or on order configuration. The first, turnover category, is selected, because almost 70% of the orders consist of only fast-moving products and 22% of the orders of fast-moving and medium-moving products. In the distribution of order configuration, such a large share in one of the configurations is not seen. The highest is 45%, but this is the category in which an item and a case need to be picked, making almost no operational difference with many of the other categories. Batching on turnover category might not make any difference if class-based storage on turnover category is not also applied. Therefor each alternative will also be evaluated on batching on order entry.

When *batch-picking* is applied, a sorting strategy has to be decided as well. Since the amount of products per SKU is higher than 2 in 60% of the orders, the *sort-while-pick* strategy is applied. Only when almost all orders do have one or two products per SKU, the *sort-after-pick* strategy is applied, as explained in 2.1.2. The *sort-while-pick* strategy is also preferred, since products will be placed immediately in the box in which the transport takes place, the reduce the amount of movements of the products.

Another variable needs to be determined when implementing a *batching strategy*, namely the batch quantity, i.e. how many orders will form a batch. The weighted average of the amount of SKUs per order is 4,43 SKUs. The weighted average of the amount of products per SKU is 3,8 products. With a batch quantity of five orders, this results in 22 stops during a pick round in which 84 products are picked. The calculation of the best fitting batch quantity is time-consuming and does not have a large contribution to the objectives of this research. Therefore, a batch quantity of 5 is interpreted as a reasonable quantity and selected for this research.

3.4.2 Storage strategies

The second variable of the order pick system is the storage strategy. In section 2.1.2, the storage strategies *randomized storage, dedicated storage, family-grouped storage* and *class-based storage* have been explained. The *family-grouped storage* strategy will be excluded from the alternatives, since the data on products being ordered simultaneously might not be representative for B2C customers compared to B2B customer. *Class-based storage* will be applied in three ways, namely *class-based storage on product type*, *class-based storage on turnover* and *class-based storage on turnover and product type.*

Class-based storage on product type will be evaluated because the orders fulfilled in this e-fulfilment order pick system can consist of cases and of items. Nedcargo wants a reduction in the waste of products, meaning that the stacking of the products in a box need to be done firmly. Collecting first all cases and then the items, makes sure that almost no heavy products are placed on the lighter products. *Class-based storage on turnover* will be evaluated since 87% of the order lines consist of products in the fast-moving "A" category. Having these products situated closer to the entrance and exit of the storage area can increase the efficiency of the system. The two storage strategies are combined to have the advantages of both strategies. Within these storage strategies, a *dedicated storage* is applied. This is mainly because each product might have different dimensions and since flowracks are used, an efficient use of space can be achieved.

To measure the improvements of applying a more complex storage strategy, compared to the storage strategy currently applied at Nedcargo in the pallet and case storage, the *randomized storage* strategy is evaluated as well. The system of Nedcargo is able to implement *randomized storage* at the moment, while other type of storage strategies implies a development of the warehouse management system. Therefore the differences in performance between these strategies is interesting to compare. The four storage strategies and their meaning are stated below:

- Storage strategy: the sections and order in which the products will be stored
  - (1) Randomized storage
    - Products are placed on the first empty spot
  - (2) Class-based storage on turnover volume
    - A = fast movers (20% of product types, 87% of order lines)
    - B = medium movers (30% of product types, 11% of order lines)
    - C = slow movers (50% of product types, 2% of order lines)
  - (3) Class-based storage on product type
    - Cases and items are separately stored
  - (4) Class-based storage on turnover volume and product type
    - A^{Case} = cases of the fast mover product types
    - A^{Item} = items of the fast mover product types
    - B^{Case} = cases of the medium mover product types
    - B^{Item} = items of the medium mover product types
    - C^{Case} = cases of the slow mover product types
    - C^{Item} = items of the slow mover product types

Figure 21 shows the layout of the e-fulfilment area with the flowrack sections in which the products are stored. At each cross aisle or pick aisle a selection in route needs to made based on the routing method applied, explained in the next section.

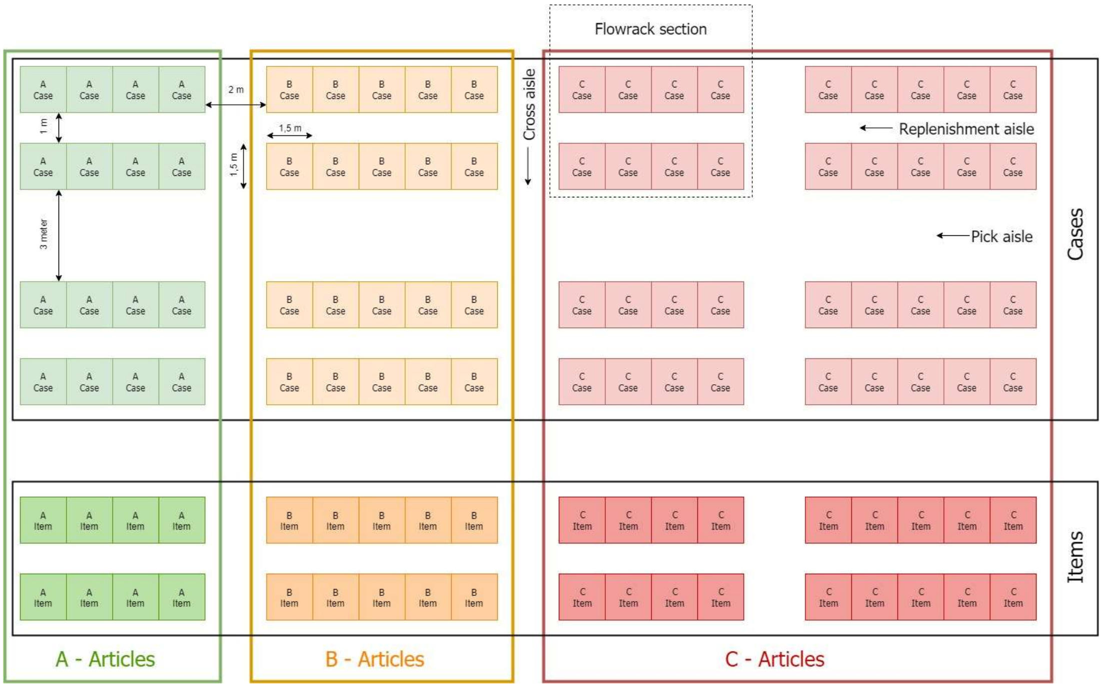


Figure 21: Flowrack sections based on storage strategies

Picking of cases and items

The e-fulfilment area is designed for the handling of items parts of orders and of order parts consisting of less than five cases, implying two types of unit loads have to be dealt with; cases and items. The storage of cases and items of the same product type can be done next to each other or separated, as the selected storage strategies apply. The picking of these products can be done simultaneously, i.e. in the same pick round, or separated in two pick rounds.

The disadvantage of picking in two rounds is that a consolidation needs to take place when orders consist of cases and items, this requires an extra step in the process and therefore an extra risk, and it requires an extra workstation. The main advantage is that at the consolidation of the order parts, the save and secure packaging of the order is expected to be performed better than packaging during picking, because the differences in weight in products can be taken into account and a more stable position of each products can be achieved. Therefore, beside the storage strategies named, another variable will be added, namely the picking in one pick round or in two pick rounds:

- Order parts picked simultaneously or separately
  - (1) Items and cases are picked in the same pick round
  - (2) Two separated rounds are performed, in which in the first round the cases are picked and in the second round the items. These two order parts need to be consolidated after picking.

3.4.3 Routing methods

The third strategy, and fourth variable, is the pick route that order pickers walk along the pick aisles. Six types of routes have been explained in section 2.1.2. Only three of these six be evaluated in the design alternatives. The *optimal route* will not be taken into account because mostly an illogical route is defined by this method, also the performance of the route is often not better than of the *combined routing,* this method will be evaluated. The routing methods *'largest gap'* and *'midpoint'* are not taken into account in the evaluation, because these methods imply that even though an aisle is skipped because no products have to be picked there, the order picker still has to walk around the whole area to get to the exit of the storage area. Since the amount of SKUs of Moet is relatively large and with that the storage area as well, these methods will not achieve efficiently. Also, the routing method *largest gap* can only be effectively applied with *randomized storage*. The *transversal, return* and *combined* routing method are evaluated in this research. For the *'transversal* routing methods the motivation is similar to the motivation of the *'randomized storage',* since it is applied currently, therefore easy to implement and it can provide a good comparison in performance with the other two methods. The *return* and *combined* routing are expected to provide a better performance than the transversal routing. Also some of the storage strategies have only the advantages that they can have in combination with a different routing method than the *transversal* routing method. The methods and their application in the system are described and visualised below and in Figure 22.

- Routing method: the route an order picker walks during a pick round
  - Transversal: cannot enter the cross aisles, but can enter and exit the storage area at the beginning (left side) of each pick aisle.
  - Return: can enter the cross aisles, but always returns to the beginning (left side) of the storage area, i.e. always turns right after leaving a cross aisle. Can also enter and exit the storage area at the beginning of each pick aisle.
  - Combined: can enter the cross aisles and take any route after that, except returning back to flowrack sections the order picker already passed. Can also enter and exit the storage area at the beginning of each pick aisle.

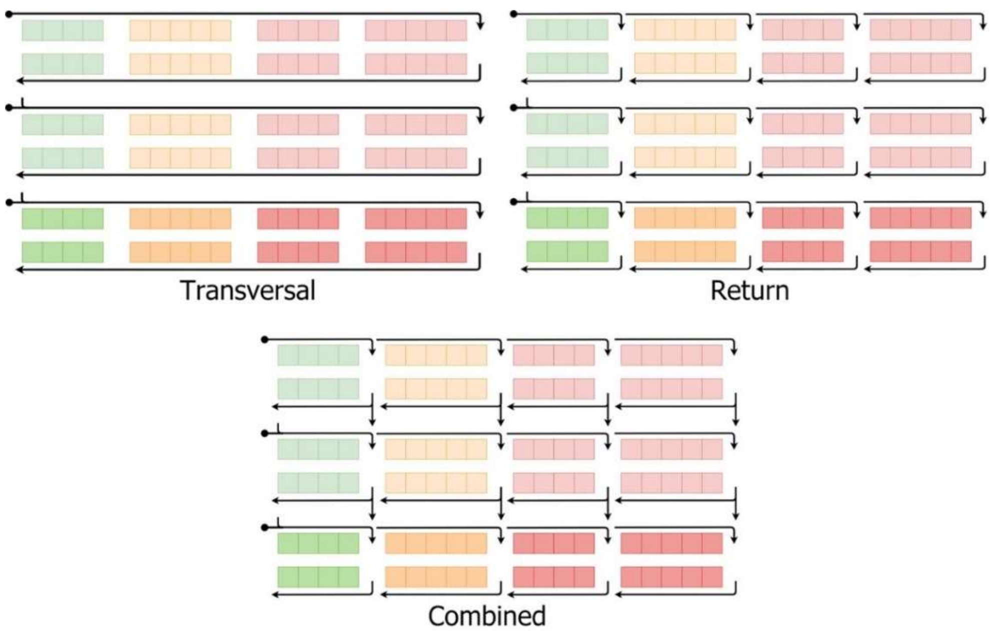


Figure 22: Routing methods evaluated visualised

3.5 Design alternatives

When combining all possible combinations of the attributes of the storage strategies, including one and two pick round alternatives, and the routing methods, 24 design alternatives are composed. These 24 alternatives will be evaluated with the batching strategy *based on order entry*. Only the alternatives in which the storage strategy is based or partly based on turnover category will also be evaluated with *batching on turnover category*. The 24 design alternatives with *batching on order entry* are given in the Table 12. In the left column, the name of the alternative is composed from abbreviations of the decision variables. The '1' stands for order parts are picked simultaneously, in one pick round and the '2' for order parts are not picked simultaneously, but in two separate pick rounds. The following letter indicates with routing method is applied. The 'T' stands for the *transversal* routing methods, the 'R' for the *return* routing method and the 'C' for the *combined* routing methods. The last part of the name defines the storage strategy of the alternative. *Randomized storage* is indicated with the word 'Random'*, class-based storage on turnover* is indicated with 'ABC, *class-based storage and product type* is indicated as 'CI', which stands for 'Case' and 'Item' and the storage strategy in which *class-based storage on turnover is combined with class-based storage is on product type* is indicated with 'ABC-CI'.

Table 12: Design alternatives

	Order parts picked simultaneously		Storage strategies			Routing methods		
	Yes (1)	**No (2)**	**Random**	**Turnover**	**Product type**	**Transversal**	**Return**	**Combined**
1-T-Random	X		X			X		
1-T-ABC (B)	X			X		X		
1-T-CI	X				X	X		
1-T-ABC-CI (B)	X			X	X	X		
1-R-Random	X		X				X	
1-R-ABC (B)	X			X			X	
1-R-CI	X				X		X	
1-R-ABC-CI (B)	X			X	X		X	
1-C-Random	X		X					X
1-C-ABC (B)	X			X				X
1-C-CI	X				X			X
1-C-ABC-CI (B)	X			X	X			X
2-T-Random		X	X			X		
2-T-ABC (B)		X		X		X		
2-T-CI		X			X	X		
2-T-ABC-CI (B)		X		X	X	X		
2-R-Random		X	X				X	
2-R-ABC (B)		X		X			X	
2-R-CI		X			X		X	
2-R-ABC-CI (B)		X		X	X		X	
2-C-Random		X	X					X
2-C-ABC (B)		X		X				X
2-C-CI		X			X			X
2-C-ABC-CI (B)		X		X	X			X

4. Evaluation: Design alternatives

In this chapter, the design alternatives composed in chapter 3 will be evaluated. In section 0, the theory on evaluation methods is provided, accompanied by the motivation for selecting the simulation method for this research. Section 4.2, describes the simulation model and how it is build. In section 4.3, the model is verified and validated to make sure it is working correctly. Next, the experiments that have been run are explained and the results of these experiments are given in section 0. The best overall performing solution design have been selected and described in section 4.5.

4.1 Theory: Evaluating design alternatives

In this section the methods used for the evaluation of the design alternatives are described, accompanied by a motivation for this selection. Similar to the theory in section 3.1, the methods are described per step of the methodology.

Evaluate and assess: Three types of evaluation methods can be distinguished; *'benchmarking', 'analytical models'* and *'simulation models'*. *'Benchmarking'* is a widely used method to evaluate performance. It is most valuable when no objective or engineered standard is available to define efficient and effective performance. Benchmarks are quite limited as they work solely with a single measurement at the time and cannot evaluate a performance influenced by multiple metrics simultaneously (Zhu, 2008), (Gu, Goetschalckx, & McGinnis, 2010).

'Analytical methods' split the system alternative into subsystems and evaluate each of these subsystems on certain criteria. Combining the performance of each subsystem gives a total score for the whole system. The whole system needs to be evaluated on the same criteria as well. *'Analytical methods'* can be split into two types, the qualitative and the quantitative models. With the former, the score given to a subsystem is subjectively determined and mostly given in relation to the scores of the other alternatives. The criteria are given a weight representing the level of importance, which is determined by experts in the field. Qualitative approaches contribute to the decision making between alternatives, when limited information is available. With quantitative models the criteria on which the subsystems and system will be evaluated, are exactly measurable. In system design, often a combination of qualitative and quantitative analytical models is use (Yoon & Sharp, 1996).

'Simulations' can be used as an evaluation and validation tool. Depending on the complexity of the system, the design objectives and the design time, evaluation and validation or only validation is done by *'simulation'*. Since *'simulation'* is quite time consuming, it is mainly used as validation tool since only one alternative has to be simulated (Gu, Goetschalckx, & McGinnis, 2010). The benefit of using simulation when evaluating design alternatives is that it can show the flexibility of the system by changing demand patterns or order profiles (Baker & Canessa, 2009). This is very useful when designing a system for which the exact demand patterns and order profiles are still unknown, it can show the most robust system.

In this research *'simulation'* is used as an evaluation method. Since a complex system with multiple interrelated variables has to be evaluated. *'Benchmarking'* is not an option, as it can only perform the influence of one metric simultaneously. Also *'analytical methods'* are not preferred in this research since the system will be evaluated using exact key performance indicators that cannot be measured using related scores. Simulation is also preferred in this research because 32 alternatives will be evaluated on different demand patterns and order configurations. Evaluating this with an *'analytical method'* is a very challenging task and because the possible congestion within the system needs to be taken into account, which is also not possible with the other evaluation methods.

The batching strategy, storage strategy, and routing methods of an order pick system are evaluated. Section 3.4 describes which attributes of these variables will be simulated. For the simulation, the tool 'Simio' is used. Simio is a tool with many possibility, easy usage and no programming skills are necessary. The main motivation for this tool is that it is a relatively easy tool to learn and to understand, also for people without programming skills. This is one of Nedcargo's preferences since the model is client-based built but in a way that it can be used for multiple clients. Therefore the tool and model need to be understandable for people with different backgrounds. In section 4.2, the simulation model is explained

Identify preferred design: The outcome of the simulation will show whether a preferred design is easily identified or whether the performance measures are so close to each other that multiple design can be preferable. In the latter case, additional qualitative or quantitative methods can be applied to identify the preferred design based on other criteria. An example of a quantitative method is a financial business case to calculate the return on investment. Other quantitative methods can be used to calculate the resources needed per alternative, like the amount of employees, the floor space required, etc. On the qualitative side, a SWOT analysis can be performed that can be reflected on the objectives to see which meets them the best (Baker & Canessa, 2009). In a SWOT analysis, the strengths, weaknesses, opportunities and threats of an alternative are discussed.

In this research, the outcome of the simulation does not provide a straightaway answer to which alternative is the best solution. Therefore the outcomes of the experiments will be analysed with an analytical qualitative method. Meaning that the likeliness of occurrence of the experiments and the advantages and disadvantages of the alternatives are taken into account. The framework on the executing steps in the design process is provided in Figure 23.

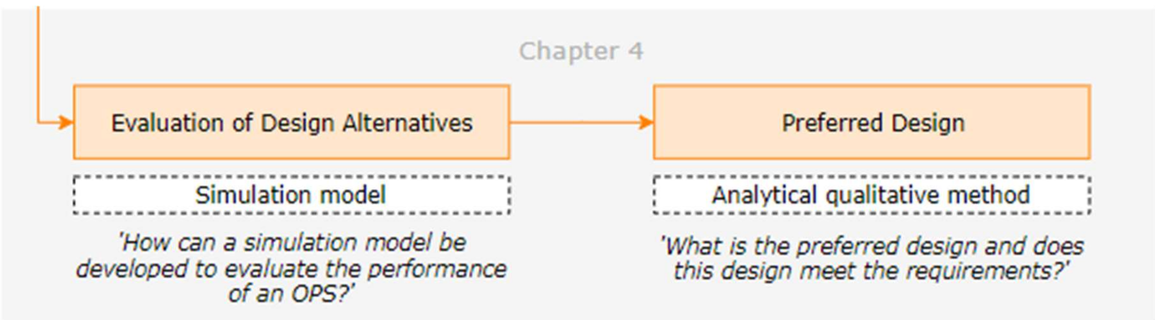


Figure 23: Scheme of approach: chapter 4

4.2 Simulation model

For the evaluation of the design alternatives, an simulation model is constructed. In this section the simulation model is explained following the order pick process from order entry to order exit. Figure 24 shows a visualization of the model.

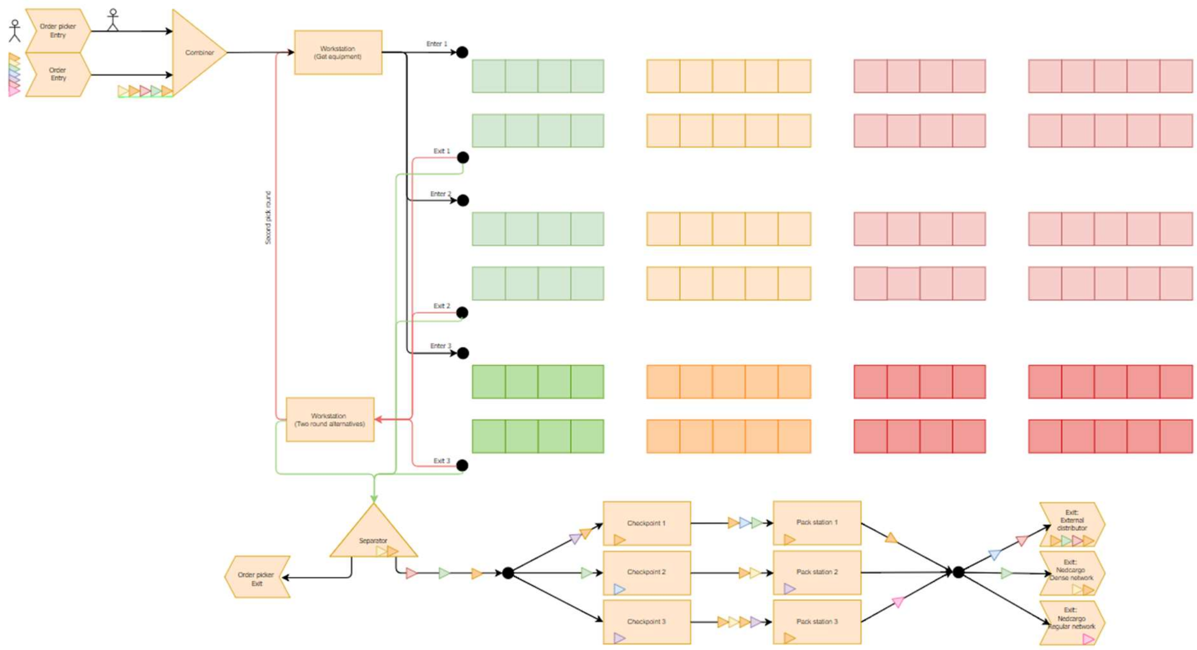


Figure 24: Visualisation of the simulation model

When building the simulation model, values and characteristics of functions and objects in the model are determined. These are explained when the functions or objects that have these characteristics are outlined. The order pick process consist of the functions determined by functional requirements in section 3.2. These functions are:

- Order entry
- Batching, coupling to an order picker and equipment collection
- Entering the storage area
- (Re)-entering a flowrack for picking
- Passing a (part of a) flowrack section
- Exiting the storage area, placing orders on a conveyor belt and unbatching the orders
- Controlling, packaging and sorting on output type (order exit)

The objective of the simulation is two folded. On one side it is to measure the response of the alternatives to a growth in demand and a change in order configuration. On the other side, to calculate the lead-time of orders, compare the picking time and the time in the storage area of the alternatives. In this section the answer to the subquestion: *'How can a simulation model be developed to evaluate the performance of an OPS?'* is given.

Order entry

Orders are placed at Nedcargo with a certain arrival rate. The arrival rate is based on the amount of orders in 2016, divided over the amount of working days in which these orders have been placed, divided by the amount of hours in a day, i.e. 24 hours. This results in the following formula, in which the annual amount of orders is 7.340 orders.

This results in: $$\frac{Annual\ \#\ orders}{253*24} = 1{,}21\ orders\ per\ hour$$

As mentioned in the data analysis of the orders of Moet in section 3.2.2, an order has certain characteristics. The products ordered determine the order characteristics. One of these characteristics is whether an order consists of fast-moving products, medium-moving products, slow-moving products or a combination of these three, resulting in seven order types. The model creates these seven order types in a proportion related to the other order types. The seven order types and the proportion of each type is provided in Table 13.

Table 13: Distribution of the orders per turnover category

Order type	Meaning	Proportion (%)
A	Order consisting of only fast-moving product types	68,1
B	Order consisting of only medium moving product types	2,9
C	Order consisting of only slow-moving product types	0,9
AB	Order consisting of fast and medium moving product types	22,0
AC	Order consisting of fast and slow-moving product types	1,7
BC	Order consisting of medium and slow-moving product types	0,7
ABC	Order consisting of fast, medium and slow-moving product types	3,7

Besides the turnover category, three more characteristics are determined for the order. The first is the amount of SKUs in the order, i.e. the amount of product types. The amount of product types can be from 1 to 10 and 15, which represents a weighted average for all orders with more than 10 product types. The probability of the amount of product types in an order variates per order type.

The third characteristic is the order configuration, indicating whether the product types within the order should be picked in cases, in items or in cases and items. Since an order can consist of more product types, any combination of these three attributes is also a possible characteristic for the order. Also with the order configuration, the probability of it occurring is depended on the order type.

Lastly, the picking time per stop is determined. The picking time is dependent on the order configuration. When a case need to be picked, it is assumed that this takes longer than picking an item and when both have to be picked, this takes up relatively the longest time. The picking time per order is the average of the picking times of the products in the order.

The four characteristics, stated below, are determined in the order in which they have been explained and named. Data on the probability of each of the characteristics can be found in section 3.2.2

- Determine the order type (A, B, C, AB, AC, BC or ABC)
- Determine the amount of article types (Probability per number per order type)
- Determine the order configuration (Probability per configuration per order type)
- Determine the picking time per stop (based on the configuration of the order)

After this process each order has a value given to each of the characteristics named above. These values are necessary for the determination of the routes and picks in the picking area. For the exact process, steps and formulas used to determine the values of the variables, see Appendix G: Simulation Process.

Batching, coupling to an order picker and equipment collection

After order entry, the orders are batched per five orders. Two batching strategies are applied, namely batching on order entry and batching on turnover category. Section 2.1.2 explains what these two strategies entail. When five orders have been batched, a pick order is created in which the sequence of the products on the pick order represent in which order the products have to be picked. This sequence determines the route the order picker walks as well. Next, the batch is released and can be coupled to an order picker. An order picker that has finished its previous task can couple him- or herself via a handheld device to the released order.

The order picker has to collect the equipment he or she needs for the picking at a workstation. The equipment consist of boxes in which the products are placed during picking. The system should provide which box has to be used for which order. Each box represents an order. The order picker has to fold these boxes and provide them with a label with which the order can be identified at any time. The boxes will be placed on a cart for easy transport. In the simulation model, the processing time at the workstation is random uniformly distributed with a minimum of 100 seconds (20 seconds per box) and a maximum of 180 seconds (30 seconds per box). A uniform distribution is assigned since no accurate information is available on the time distribution. The minimum and maximum have been selected by manual testing 20 replications of the specific activity. The batching, coupling and getting equipment activities are visualised in Figure 25.

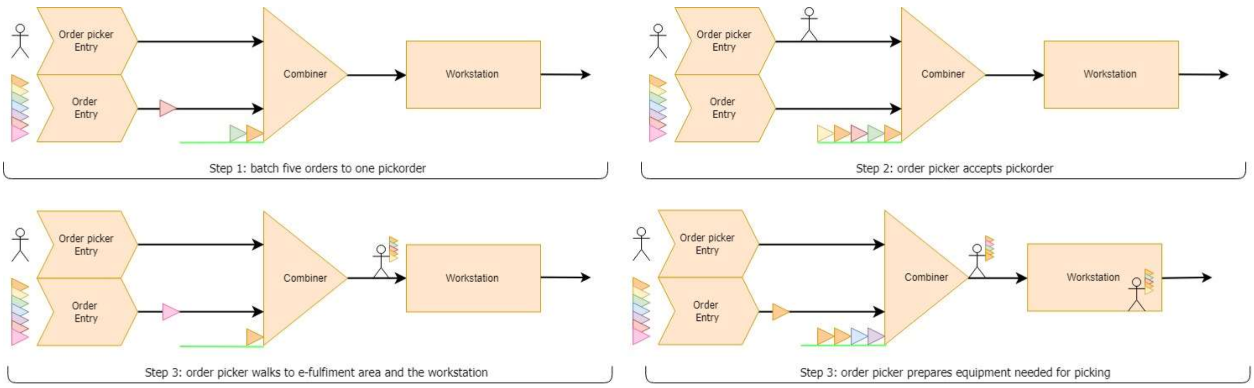


Figure 25: Order entry, batching, coupling to orderpicker and workstation for equipment visualization

Entering the storage area

Throughout the storage area the order picker walks and picks the products on the pick order. The walking speed of the order picker in the simulation model is set to an average of 3,0 kilometer per hour throughout the whole system. This speed has been based on two scientific articles on order pick system. In one, a speed of 2.16 km/h is applied, but in this research the aisles are smaller (de Kosten & Van der Poort, 1998). In the other a walking speed of 3.5 km/h is applied, but part of this storage system contains of palletslots, resulting in less pickslots per meter which makes it easy to search for the next pickslot with a higher walking speed (Moeller, 2011).

The order picker can start its pick round at three different entrances in the storage area, depending on the location of the products he or she has to pick. In the simulation model, the probability of each of the three entrances is determined by a calculation. The formulas for this calculation differ per alternative. Initially, each of the three entrances have an equal probability, but if entered via the second or the third entrance, it implies that not all flowrack section can be reached anymore. Therefore, the selection of the entrance comes with certain limitations. In case of the alternative in which the products are sorted on *turnover category and product type*, the probability of selecting each of the entrances is calculated with the following formulas:

1. First enter: $(SA^{Case} \leq (16 * MSPF)) * (S\ ^{Case} \leq (20 * MSPF)) * (SC^{Case} \leq (36 * MSPF))$
   The amount of stops at flowrack section Case A need to be less than or equal to the amount of flowracks of Case A, times the maximum amount of stops per flowrack. The same holds for other flowrack parts.
2. Second enter: $(SA^{Case} \leq (8 * MSPF)) * (S\ ^{Case} \leq (10 * MSPF)) * (SC^{Case} \leq (18 * MSPF))$
3. Third enter: $(SA^{Case} = 0) * (SB^{Case} = 0) * (SC^{Case} = 0)$

In these formulas, the maximum amount of stops per flowrack (MSPF) represents the amount of product types per flowrack. In the simulation model used for this evaluation the maximum amount of stops per flowrack is set to 10 product types. The reason being a batch of orders can never exceed 75 different product types within one flowrack section. A batch consists of five orders, each order can have a maximum of 15 product types and there is a probability, even though it is very small, that these 15 product types belong to the same order type and order configuration. The minimum amount of flowracks per section is 8 flowracks, namely in the section of fast-moving items products. 75 over 8, results in an average 9,4 picks per flowrack at maximum. The formulas used for the other alternatives are stated in Appendix G: Simulation Process.

(Re)-Entering a flowrack for picking

After entering the storage area, the actual picking of the products can take place. An order picker has to enter a flowrack for picking a product (1A). A flowrack can also be passed if no products have to be picked at that flowrack (1B). When a flowrack is entered and a pick has taken place, the following pick can take place at the same flowrack, representing a flowrack is re-entered (2A + 3A), the connecting flowrack (2A + 3B) or none of those flowracks, representing the orderpicker is exiting the flowracks (2B or 4B). For an overview of these options, see Figure 26.

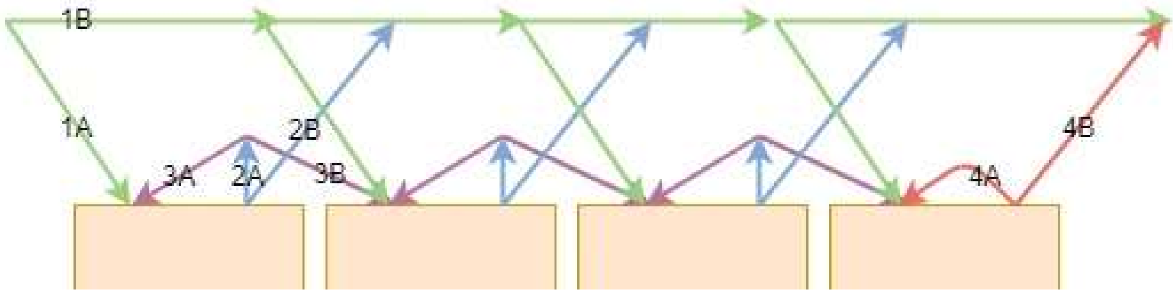


Figure 26: (Re)-entering decisions within a flowrack section

In the simulation model, whether to enter or re-enter a flowrack to pick a specific product is determined based on probability functions. In general, each option, has an equal probability of 50%. Also in this case, some conditions may influence this probability. The probability is based on the amount of picks left in the system of that specific flowrack type and of the amount of picks that still have to be executed by the order picker. The formulas used for all alternatives are stated in Appendix G: Simulation Process.

When a flowrack is entered and a pick takes place, the order picker checks the exact location of the product on the pick order, picks the product from this location, scans the product and places the product in the box. With every product the order picker picks, the same process is executed, even though two products of the same product type are picked, both are scanned. Scanning each product will result in a higher accuracy, and since the products immediately go the end-customer it has to be registered which product goes to which customer in case of any actions in which products have to be returned to the producer.

Passing a (part of a) flowrack section

Depending on the routing method applied, the order picker can decide to enter a cross aisle. Entering a cross aisle has as a result that some of the flowracks sections are passed and that these sections cannot be entered again. An order picker can of course decide to walk back to these sections, but this is not the intention of the pick route determined and might have influence on the pick performance of the order picker.

Similar to the entrance selection of the storage area and the decision on whether to enter a flowrack, the decision on whether to enter a cross aisle is based on a probability. The initial probability is 50%, but can be influenced by certain conditions. Whether to pass a (part of a) flowrack section is dependent on the ratio between the flowrack sections still able to enter after a specific (part of a) section has been passed and on the amount of stops still to be executed in that specific (part of a) flowrack section. Passing a (part of a) flowrack section can have a probability of 0%, 50% or 100%. All formulas for each of the intersections per alternative are provided in Appendix G: Simulation Process. An overview of the intersections is given in Figure 27.

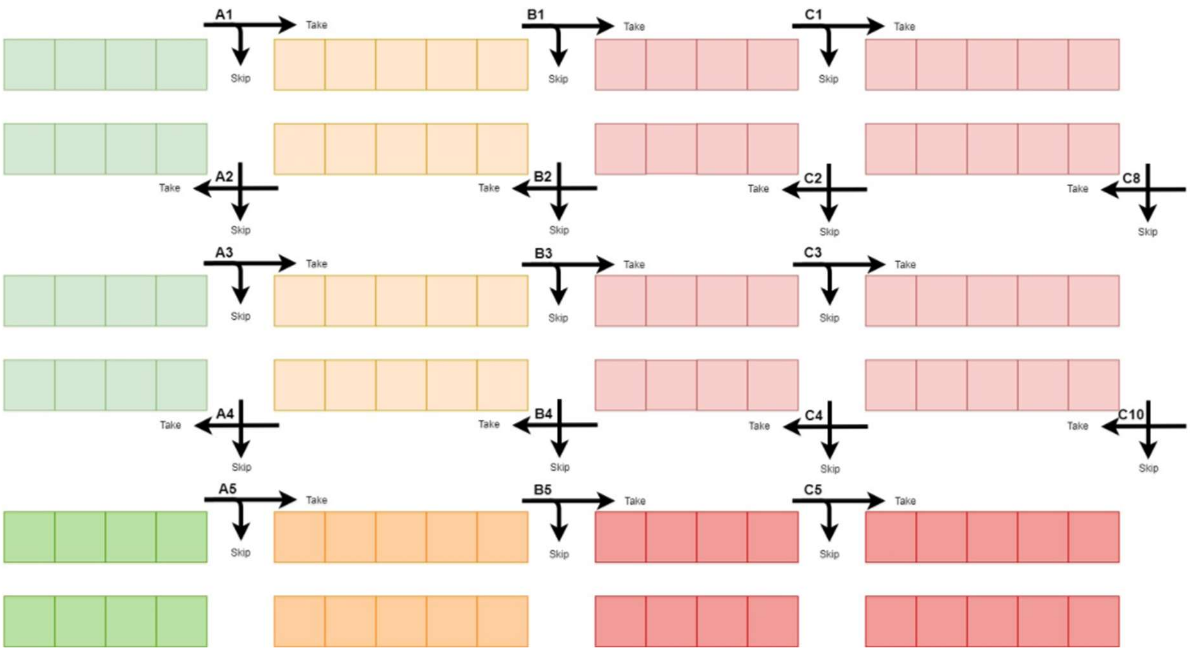


Figure 27: Intersections for the possibility to pass certain flowrack sections

Exiting storage area, placing orders on a conveyor belt and unbatching the orders

After all picks are executed by the order picker, the order picker can exit the storage area. At each aisle side most closest to the enter and exit point of the storage area, an order picker can exit the storage area, see Figure 28. He or she will only exit the storage area if all products, that are in stock, are picked. In the simulation model, this is again based on a formula representing a finished pick round. The formulas used for this, are also stated in Appendix G: Simulation Process.

In a part of the alternatives, the cases and items are picked in two separate rounds. The order pickers in these alternatives will follow the red lines in the simulation model as visualised in Figure 28. The red line guide the order picker after the first pick round to a station where he or she can temporarily store the picked products. After the second pick round, when all products are picked, this workstation is used for the consolidation of the two order parts.

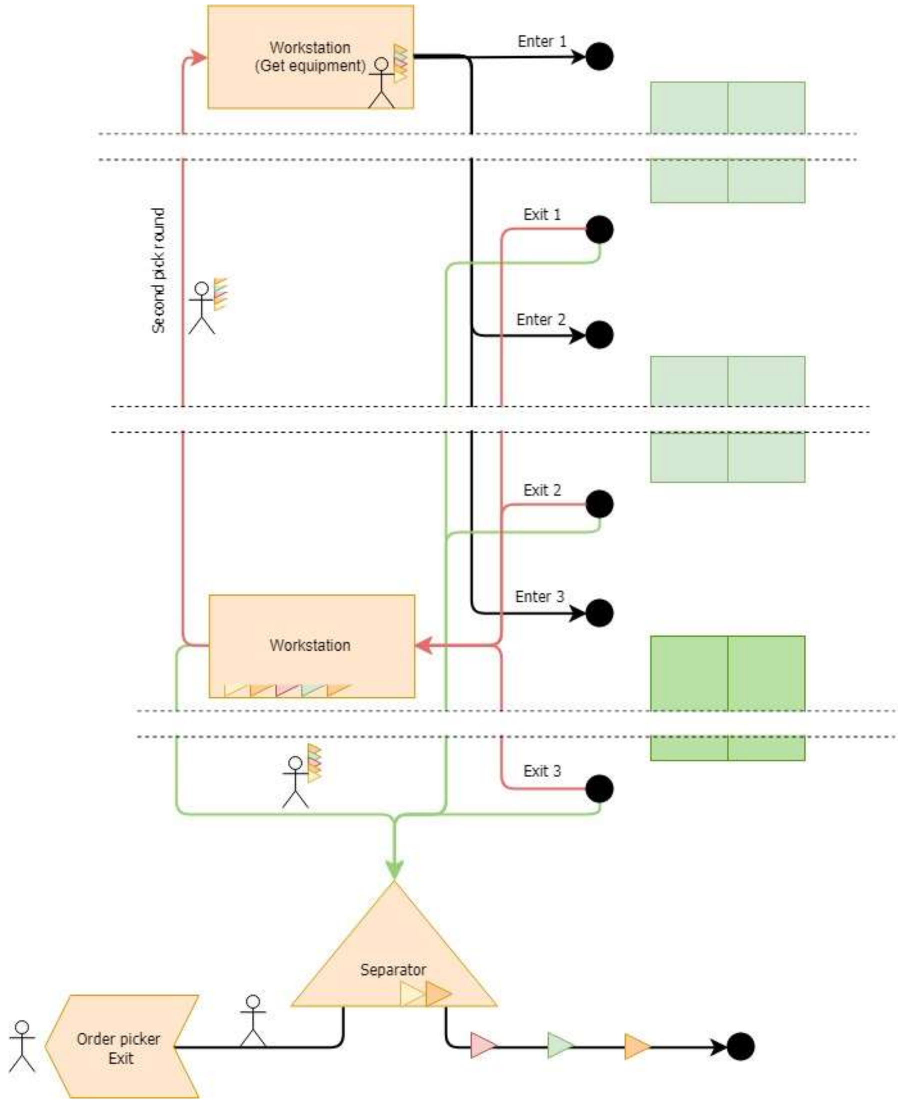


Figure 28: Exiting storage area, putting orders on conveyors and unbatching of orders

The processing time of the workstation depends on whether it is the first round or the second round. In the first round, when boxes are only stored at the workstation, the processing time is triangular distributed with a minimum of 4 seconds per box, so 20 seconds in total, a mode of 6 seconds per box, 30 seconds in total and a maximum of 8 seconds per box, 40 seconds in total. The processing time of the second round is higher because orders have to be consolidated. Again, the processing time is random triangular distributed, but with a minimum of 300 seconds, 60 seconds per order, a mean of 450 seconds, 90 seconds per order and a maximum of 1200 seconds, representing 4 minutes per orders.

After consolidation of the orders in the two-pick round alternatives, or exiting the storage area in the one-pick round alternatives, the order picker walks to the separation station. Here the orders are placed from the cart onto a conveyor belt. The order picker registers that the picked orders are on the conveyor belt via his or her handheld device. This action represents the decoupling of the orders from the order picker and the unbatching of the orders. The processing time per batch of the separator is random triangular distributed with a minimum of 30 seconds, a mode of 40 seconds and a maximum of 50 seconds. The orders independently transport to the next set of functions, see Figure 28.

Controlling, packaging and sorting on output type

After the orders have been split from the batch and placed on a conveyor, they continue to the control station. The speed of the conveyors is set to a speed of 3 kilometre per hour. The control station entails a scale where the weight of the orders is measures and compared to with the sum of the weight of the products ordered. In combination with the scanning of the products when picked, this ensures a 100% accuracy of the picked orders, as explained in section 3.3.

The simulation model has three similar checkpoints over which the orders can be distributed. A checkpoint has a processing time of 3 seconds per box. The processing time is constant since the tasks are computer controlled and no human involvement is necessary. Which checkpoint is selected is of based on the amount of orders waiting in a queue of the checkpoint. Checkpoint 1 will always be selected when the amount of orders waiting in the queue is less than five. This implies that five orders from one batch can go to the same checkpoint. When the arrival rate of orders is relatively low, the five orders from one batch might be finished at the checkpoint before the next orders arrive. In that way, only the first checkpoint has to be used.

After the checkpoint, the orders are transported to the packing station. Each checkpoint is connected to one packing station. If only one checkpoint is in use, also only one packing station has to be in use. A packing station is manned with one employee. He or she fills the empty parts of the box with filling material for save transport, adds the delivery note of the order and tapes the box. The processing time at the packing station is random triangular distributed with a minimum of 15 seconds, a mode of 25 seconds and a maximum of 50 seconds, resulting from a test of 20 replications with three different box sizes.

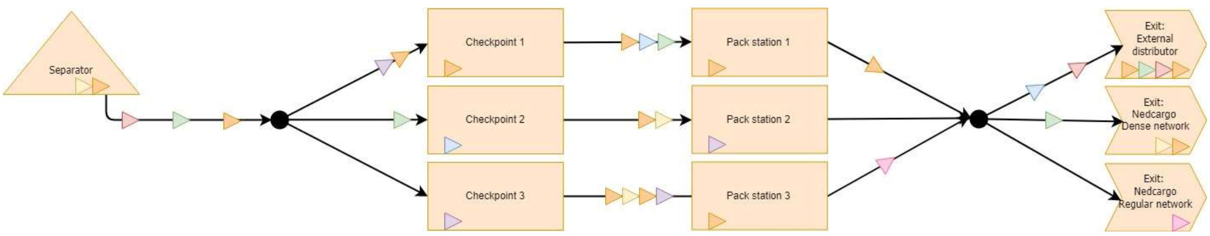


Figure 29: Order control, packing and distribution network sorting

As last activity the orders are sorted on output type. The output types differ in distribution network. 80% of the orders are transported by an external distributor, 19% goes with the dense network distribution of Nedcargo and 1% of the orders is consolidated with a pallet order and distributed through the regular network of Nedcargo.

Assumptions

In the model characteristics to objects, pick orders, storage equipment and other utilities have to be determined. For some of these characteristics assumptions have been made. The made assumption are stated in Table 14.

Table 14: Assumptions and simplifications of the simulation model

Assumptions and simplifications	
Input data	All input data is based on 2016 and averaged over that year
Stock level	A stock level of five days (one working week) has been used
Enough stock	For the model, there is always enough stock. Failures in picks do not occur
Batch quantity	The batch quantity is five orders per batch
Order pickers	There is an infinite amount of order pickers available
Order pickers	If items and cases are separately picked in two pick rounds, both rounds are performed by the same order picker
Picking time	Difference in pick time due to the location on the shelf are not taken into account
Picking time	Difference in pick time due to product types are taken into account but averaged over all picks in one pick round
Speed	The speed of the order picker and of the conveyors is 3 km/hr
Flowrack space	The volume an item occupies, used to calculate the flowrack space, is determined based on the case volume, since the item volume is unknown
Workstations processing time	
Get equipment	Random uniform distribution (100, 180) seconds
Place case-part of orders	Random triangular distribution (30, 40, 60) seconds
Consolidate orders	Random triangular distribution (300, 450, 1200) seconds
Checkpoint	Constant: 3 seconds
Packing station	Random triangular distribution (15, 25, 50) seconds

The assumptions have been set to narrow down the simulation variables. It might be recommendable to analyse the results with a different stock level or a different amount of orders per batch in a latter research.

4.3 Verification and validation of the model

After the model has been build, a verification and validation of the model has to be performed to evaluate whether the model is working correctly. During verification, described in section 4.3.1, the model is controlled on whether the model itself works right. During validation, described in section 4.3.2, the model is controlled on whether it represents the system correctly. In other words, the results of the simulation model are representative as results for the real system (Sargent, 1998).

4.3.1 Verification

As mentioned, verification of the model entails the control of whether the model does what it has to do and does it correctly. Since the model is calculating a lead-time, this lead-time can also be calculated analytically as well. When both results do not significantly differ from each other, the model gives the correct results. For the analytical calculation the same characteristics as the model should be taken into account. Furthermore, to control whether each step in the model is executed as it should be, a step by step walkthrough where multiple traces are placed, is performed as well (Sargent, 1998).

Analytical calculation of simplified model

For this technique, a simplified model has been built with the same functions, but less in number and with no random value selection. The analytical calculation of the average time in system is given in Table 15. The average time in system according to the model is 159.02 minutes = 9541.20 seconds.

The analytically calculated time is 9377,6 seconds = 156,29 minutes. The analytical calculation is in 98,3 % similar to the simulation time. The 1,7% difference can partly be caused by the paths in and out a flowrack that have not been taken into account. The reason for this is that a flowrack can be visited multiple times and therefore the exact time cannot be given. The time to enter and exit a flowrack is around 6 seconds, the time to re-enter a flowrack is 3 seconds, so the minimum time spend with 4,69 stops per order is 66 seconds and the maximum time 120 seconds, on average would be 93 seconds. Including this time would make the results of the analytical calculation and the simulation model comparable for 99,5%, indicating that the simulation model does what is needs to do correctly.

Table 15: Analytical calculation of the (simplified) order pick system

	Order 1	Order 2	Order 3	Order 4	Order 5	Average
Order entry	T = 0	T = 72.6	T = 145.2	T = 217.8	T = 290.4	-
Path to batching			1.05 m			3,9
Waiting time batching	17428	13072	8716	4360	3.9	8716
Path to workstation			1.08 m			3,9
Processing time workstation			100 seconds			100
Path to storage area entry			3.5 m			12,6
Paths in storage area			65 m			234
Processing time picks (10s)			469 picks total, over 100 orders = 4,69 picks per order			93,8
Path to unbatch station			4.6 m			16,6
Processing time unbatch station			30 seconds per batch			6
Path to check station			8.5 m			30,7
Processing time check station (3s)	3	6	9	12	15	15
Path to pack station			7.55 m			27,3
Processing time pack station (20s)	20	37	54	71	88	88
Path to exit			8.25 m			29,8
Total						**9377.6**

Step by step walk through

With the step by step walk through, each step in the system will be controlled on whether it is executed in the right way. For example, the information of the five batched orders should be summed and provided to the order picker, or the time in a certain workstation cannot be smaller or larger than a specified value. The following steps will be traced.

- Per five orders the amount of stops per flowrack section will be measured.
- The amount of stops per flowrack section of the order picker collection the five orders are counted.
- The processing time of the order picker at the workstations will be measured and compared to the processing time set in the system.
- The amount of stops per flowrack section will be counted during the simulation run by hand.
- The registered amount of stops done per flowrack section at the sink of the order picker

This process has been repeated five times and is done for the alternative with two pick rounds, the *'combined'* routing method and the storage strategy *'class-based on turnover and product type'*. The results are stated in the tables in Appendix H: Verification results. In each of the tests, the total amount of stops per flowrack section of the five orders within one batch, match the total amount of stops per flowrack section of the order picker. Also in four out of five of the test the stops counted at the flowrack sections during the simulation is similar to the amount of the order picker. In test four, the orders 3 and 5 do consist of 'case-item' picks. In this alternative, one 'case-item' pick represents a case pick and an item pick. In both orders, two 'case-item' picks are present, one for turnover category 'A' and one for category 'B', therefore in total a 'case of B' pick, a 'case of A' pick, a 'item of B' pick and a 'item of A' pick is added to the total amount of picks of the order picker. If the same would have occurred with a strategy in which the storage strategy '*class-based on product type'* is not applied, the amount of picks of each flowrack section performed would match the amount of picks of the order picker. Furthermore, all times are within the minimum and maximum time spend in a workstation.

Since both technique show that the model is doing what it is designed for and in a way that it represents a realistic system, the model is hereby verified.

4.3.2 Validation

The validation of a simulation model is more difficult to reach than the verification. In most cases, a simulation model is developed to measure what a real system would be, since it is too expensive and time-consuming to build the real system. Model validation actually implies to compare the results of the simulation model with data or results of the real system. However, a real system has not been built making the validation more difficult. Still there are techniques that can contribute to the validation of the model (Sargent, 1998), (Kleijnen, 1995). Among which are *'comparison to other models'* and *'sensitivity analysis by continuity and degeneracy testing'*.

Comparison to other models

Since in this research the results of the simulation model cannot be compared with the results of a real system, therefore the results are compared with results of evaluation of order pick systems found in literature. For this, the data of 2016 of the simulation model is taken into account. In table xx, the performance of the routing methods and storage strategies in comparison to each other are stated.

Table 16: Performance of the attributes of the design variables

	Storage strategy	Routing method	Batching strategy
Best performing attribute	Class-based storage on turnover category	Combined	Batching on order entry
2nd best performing attribute	Class-based storage on turnover category and product type	Return	Batching on turnover category
3rd best performing attribute	Class-based storage on product type	Transversal	
4th best performing attribute	Randomized storage		

According to Marchet et. al., the batching strategy on which the batching is based on proximity, in this research on turnover category, outperforms the batching based on order entry (Marchet, Melacini, & Perotti, 2011). This is confirmed by other researches as well (Aase & Peterson, 2004). According to

Petersen, the class-based storage strategies on volume should outperform the randomized storage strategy (Petersen, 1999) (Aase & Peterson, 2004). This situation is also present at the results of the simulation model. The result of class-based storage on product type as third best performing attribute cannot be compared with any literature, since no research is performed on picking multiple unit loads and sorting the storage area on these unit loads. Still, it is expected to be correct since with class-based storage on product type the order picker is directed to a specific section in the storage area, which might result in less time in the storage area.

Also according to Petersen, the routing method combined is performing the best and transversal the weakest, with quite a large difference when the amount of order pickers in the system is relatively low. When the amount of order pickers is decreasing, the difference becomes smaller and could result in transversal outperforming the combined method (Petersen, 1999). In the research article of Chan & Chan, the same three routing heuristics as in this research have been evaluated. Also, the same sequence from best performing to least performing alternative is similar. Only difference is that in this research the difference the performance of the return method is more closely to the of the combined method, while in the research of Chan & Chan, the performance of the return method is more closely to the performance of the transversal method (Chan & Chan, 2011).

From the comparison of the results of the simulation and the findings in literature it can be concluded that the performance of the simulation model is representative for the performance of a real system.

Sensitivity analysis: Continuity and degeneracy testing

A sensitivity analysis can be performed in two ways and both should work correctly to validate the model. The two ways are continuity testing and degeneracy testing, which can be seen as opposite techniques. With continuity testing the values of the input variables are adjusted with small differences. This should lead to almost the same results as the initial value. The opposite of this is changing the input values with large difference, sometimes even extreme numbers. In this case, the results of the system should change tremendously (Kleijnen, 1995). The two variables that are varied are the arrival rate and the picking time. The base scenario has an arrival rate of 1.21 orders per hour and a picking time of 14 seconds for cases, 20 seconds for cases and item picks and 10 seconds for an item pick. First the expected behaviour of the model is described, before running the simulation model with these values. For a more validated result the expected behaviour should not only be described or discussed by the model designer, but also by other knowledgeable people (Kleijnen, 1995).

For the arrival time variation, it is expected that with degeneracy testing the number in system will increase, the time in system will decrease and especially the time waiting for batching will increase. The picking time, time in system without waiting for batch, will not differ much. It might increase just a little since the more orders need to be picked, the higher the probability of congestion. For the picking time variation, it is expected that with degeneracy testing, number in system will stay similar between the alternatives, as well as the waiting time for a batch, the time in system should increase and the time in picking system, without waiting on a batch, would increase as well. The results of the tests are given in Table 17. The results are as expected and therefore this part of the model is verified.

Table 17: Continuity and degeneracy simulation results

	Variables				Sink of external distributor - orders		Sink of dense network - orders		All orders	
Test	AR	PT^{Case}	PT^{C+I}	PT^{item}	NIS	TIS	NIS	TIS	WTB	TIPS_O
O.1	1.21	14	20	10	113.8	177,73	24.0	175.94	108.73	68.68
C.2	1.25	14	20	10	124.6	165,52	29.2	172.49	95.42	71.43
C.3	1.17	14	20	10	115.8	185.14	25.0	171.67	106.67	74.06
D.4	4.84	14	20	10	470.5	107.48	102.0	111.44	32.11	76.08
D.5	9.86	14	20	10	923.0	97.52	220.2	92.82	16.55	80.07
O.1	1.21	14	20	10	113.8	177,73	24.0	175.94	108.73	68.68
C.6	1.21	15	21	11	114.2	174.20	26.8	164.65	105.03	67.36
C.7	1.21	13	19	9	110.0	185.52	23.0	170.84	112.39	70.64
D.8	1.21	45	63	33	111.0	192.84	23.8	201.04	104.04	90.25
D.9	1.21	90	126	66	122.4	202.73	27.4	202.13	99.84	102.78
D.10	1.21	180	252	128	114.4	239.45	27.4	247.73	104.46	136.58

Since both validation techniques show that the model is acting the way a real system would act as well and with that represents this real system, the model is hereby verified.

4.4 Experiments and simulation results

This section explains the different experiments on which each alternative is evaluated and the results of these experiments. The experiments evaluate how each of the alternatives cope with a growth in demand and a change in order configuration. Section 4.4.1 gives a description of the experiments and provides the values of the variables in each experiment. In section 4.4.2, the results of these experiments measured through the KPIs formed in 3.2.1 are outlined.

4.4.1 Experiments

The simulation model is built based on data of the order placed by the customer of Moet Hennessy in 2016. Moet is selected because of the wish to open a webshop and let the fulfilment of the orders be processed by Nedcargo. Whether the webshop will increase the total sales of Moet Hennessy products is unknown. It can also be that customer who bought the products first at a retailer will now buy them via the webshop, resulting in more sales via the webshop, but not certainly more total sales. However, the amount of small orders that have to be processed by Nedcargo will increase.

Therefore, and because internet sales is continuously growing, the e-fulfilment OPS should be able to handle a growth in orders. Another change in the future might be the order configuration. The orders analysed in the data in section 3.2.2, are orders Nedcargo delivered for Moet to its customer, these customers are other business entities. The webshop will also attract end-consumers, who are expected to order in different quantities than business entities. Meaning that the order configuration will change over time. Therefore, the experiments are varied on these two variables:

- Order volume: translate in a higher arrival rate of orders
- Order configuration: translate in a higher probability of item orders

The turnover category distribution will be kept similar to the distribution of the orders of 2016 because it is not possible to give an accurate prediction about the change in distribution over the turnover categories. The amount of product types per order and the amount of products per product type will also be similar to the orders of 2016, because no reasonable assumption can be made about this variable. The experiments that are conducted are given in Table 18.

Table 18: Simulation experiments with attributes

	Batching strategy	Volume	Arrival rate (hourly)	Prob. Case	Prob. Item
Experiment 1A: Base	Order entry	100%	1.21 orders	Probabilities of 2016	
Experiment 1B: Base	Turnover cat.	100%	1.21 orders	Probabilities of 2016	
Experiment 2A	Order entry	200%	2.42 orders	Probabilities of 2016	
Experiment 2B	Turnover cat.	200%	2.42 orders	Probabilities of 2016	
Experiment 3A	Order entry	400%	4.84 orders	Probabilities of 2016	
Experiment 3B	Turnover cat.	400%	4.84 orders	Probabilities of 2016	
Experiment 4A	Order entry	400%	4.84 orders	50%	50%
Experiment 4B	Turnover cat.	400%	4.84 orders	50%	50%
Experiment 5A	Order entry	400%	4.84 orders	25%	75%
Experiment 5B	Turnover cat.	400%	4.84 orders	25%	75%
Experiment 6A	Order entry	400%	4.84 orders	10%	90%
Experiment 6B	Turnover cat.	400%	4.84 orders	10%	90%
Experiment 7A	Order entry	800%	9.68 orders	50%	50%
Experiment 7B	Turnover cat.	800%	9.68 orders	50%	50%
Experiment 8A	Order entry	800%	9.68 orders	25%	75%
Experiment 8B	Turnover cat.	800%	9.68 orders	25%	75%
Experiment 9A	Order entry	1600%	19.36 orders	25%	75%
Experiment 9B	Turnover cat.	1600%	19.36 orders	25%	75%

Probabilities of 2016: 60% cases, 40% items.

The selection of these experiments is based on the reaction expected from buyers on the the website release. Currently, a trend is seen in a growth of small orders. Even without the website launch, it is expected that the amount of small orders is increasing, this is represented by experiment two. At experiment three, the website is launched and promoted. Since Moet has a group of customer that directly order at herself, these will probably be the first group among which the website is promoted. Resulting in more business entities as customers, leaving the order configuration for now unchanged but let the order volume increase.

In experiment 4, a change in order configuration is occurring, because even for business entities the small order sizes get more attractive. From experiment 5 on, the end-customer will get involved and the probability of ordered items compared to cases increases. Experiment 6 is expected to be a more unrealistic alternative, but will be performed to test the robustness of the e-fulfilment system. On the long-term planning, experiment 7 till 9 can become realistic.

All experiments have a simulation run length of 5 working days in which the current operational hours of Nedcargo have been taken into account. A run starts at Monday 00:00 o'clock, until Saturday 00:00 o'clock, operational hours are between 06:00 and 00:00. The warm-up period of each simulation run is 6 hours, representing the first hours before the warehouse is operational. Orders arrive at an arrival rate, with a random exponential distribution, in which daily demand patterns are not taking into account. The orders arriving during the non-operational hours, will wait until the operation starts again. Since the run length is one work week and the order profiles are based on annual data, each run is replicated 52 times, to represent a full year.

4.4.2 Simulation results

The simulation results are evaluated by comparing the Key Performance Indicators, composed in section 3.2.1. The indicators are all time based and given in minutes, and include:

- TIS: Total time in system:
  Minimum, average and maximum time in system from order entry to order exit.
- TIPS: Total time in picking system:
  Minimum, average and maximum time in picking system from the batching process to the unbatching process.
- TISS: Total time in storage system:
  Minimum, average and maximum time in storage system; the time on links to and from flowracks and the time at the flowracks.
- TIS - WTB: Total time in system excluding the batching process (waiting for a batch)
  Minimum, average and maximum time in the system from order batching to order exit.

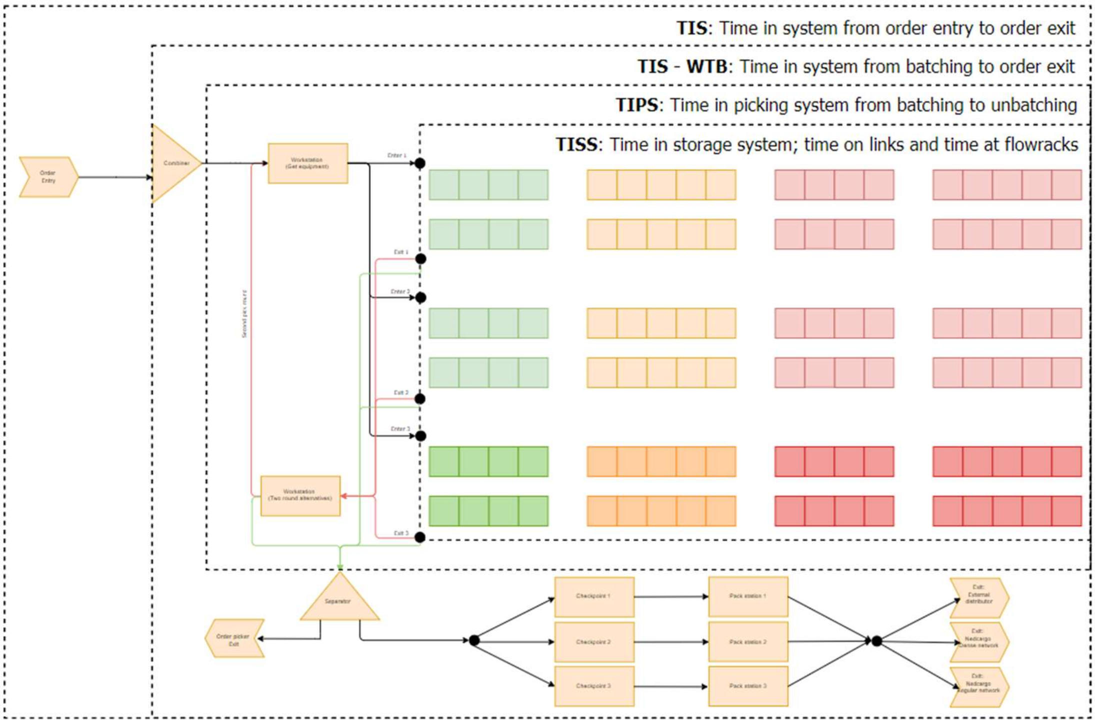


Figure 30: Visualization of the key performance indicators

Figure 30 visualises which parts of the order pick system are indicated by total system, picking system and storage system. The performance indicators are selected for the following reasons. The '*total time in system of orders*' represent the actual time the order is in the system, including all waiting times. This time will probably change with a different demand pattern. This KPI shows little about the actual picking time and with that the performance of the design variables. Therefore, the '*total time in picking system'* can provide more detailed information about the time spend in the picking system, this includes every step between batching and unbatching. The next performance indicator, '*total time in storage system*, gives the time in the actual storage system, i.e. the time without all workstations and paths between workstations. This time is the most representative for evaluating the performance of the different attribute combinations in the alternatives. The *'total waiting time in queue for batching of order'* shows us the waiting time before an order is processed. This indicator is expected to decrease when the order volume is increasing.

Experiment 1, 2 and 3

Experiment 1, 2 and 3 vary only on the experiment variable *order volume*. Experiment 1 represent the situation in 2016, experiment 2 has a doubled order volume compared to experiment 1, namely 200% and in experiment 3, this is doubled again to 400% of the order volume of 2016. The order volume is translated into the arrival rate, where experiment 1 has an arrival rate of 1,21 orders per hour, experiment 2 of 2,42 and experiment 3 has an arrival rate of 4,84 orders per hour. In the following figures and tables, the three experiments are compared to each other per alternative.

In Figure 31 the minimum, average and maximum times in the picking system (TIPS) and in the storage system (TISS) are provided per alternative. The TIPS represents the time between batching and unbatching and the TISS represents the time at the flowracks and on the links between these flowracks, i.e. the actual picking time. The TISS is excluding any activities that contribute to the order picking such as getting the equipment or consolidation of the order parts. In Figure 30, a visualisation of the performance indicators is given to provide better understanding of the KPIs. Furthermore, to make the graphs more readable an overlay has been placed to distinguish the alternatives more easily. The 'orange' represents all *one-pick round* alternatives and the 'blue' all *two-pick rounds* alternatives. The alternatives are sorted on routing method. The lightest colour of orange and blue represents the *transversal* routing method, a bit darker the *return* routing method and the darkest colour the *combined* routing method. Within these sections the order of the storage strategies is always: *randomized, class-based on turnover, class-based on product type* and *class-based on turnover and product type.* The alternatives with *class-based storage on turnover* as (part of) the storage strategy are also evaluated with the *batching strategy on turnover category*. In the graph, the results of these alternatives are situated next to the results of the respective alternative with *batching on order entry*.

TIPS and TISS

<u>One-pick round or two-pick rounds:</u> From the graphs, it is clearly visible that the *one-pick round* alternatives perform better than the *two-pick round* alternatives. This is especially for the time in picking system (TIPS). For the time in storage system (TISS), the alternatives 2-R-ABC-CI(B) and 2-C-ABC-CI(B) have quite similar results as some of the *one-pick round* alternatives. This indicates that the two pick rounds of the *two-pick round* alternatives combined take up a similar amount of time as the pick round of the *one-pick round* alternative.

<u>Routing method:</u> In both the *one-pick round* and *two-pick round* alternatives the graph is decreasing slowly from left to right, this indicates that the *return* and *combined* routing perform better than the *transversal* routing. It depends on the storage strategy applied whether the *return* routing or the *combined* routing is performing better. In the *two-pick round* alternatives the routing method *combined* is performing better than the *return* routing method for alternatives with the same storage strategy. For the *one-pick round* alternatives, differences between the performance of *return* or *combined* are hardly seen.

Batching strategy: At all alternatives in which both batching strategies is applied, the batching on turnover category performs a little bit better than on the batching on order entry strategy. Figure 32 shows that this improvement in performance is mainly cost by the time spend on the links and is more present in alternatives with a higher volume. The differences in time spend on links between the alternatives are larger when the volume increases.

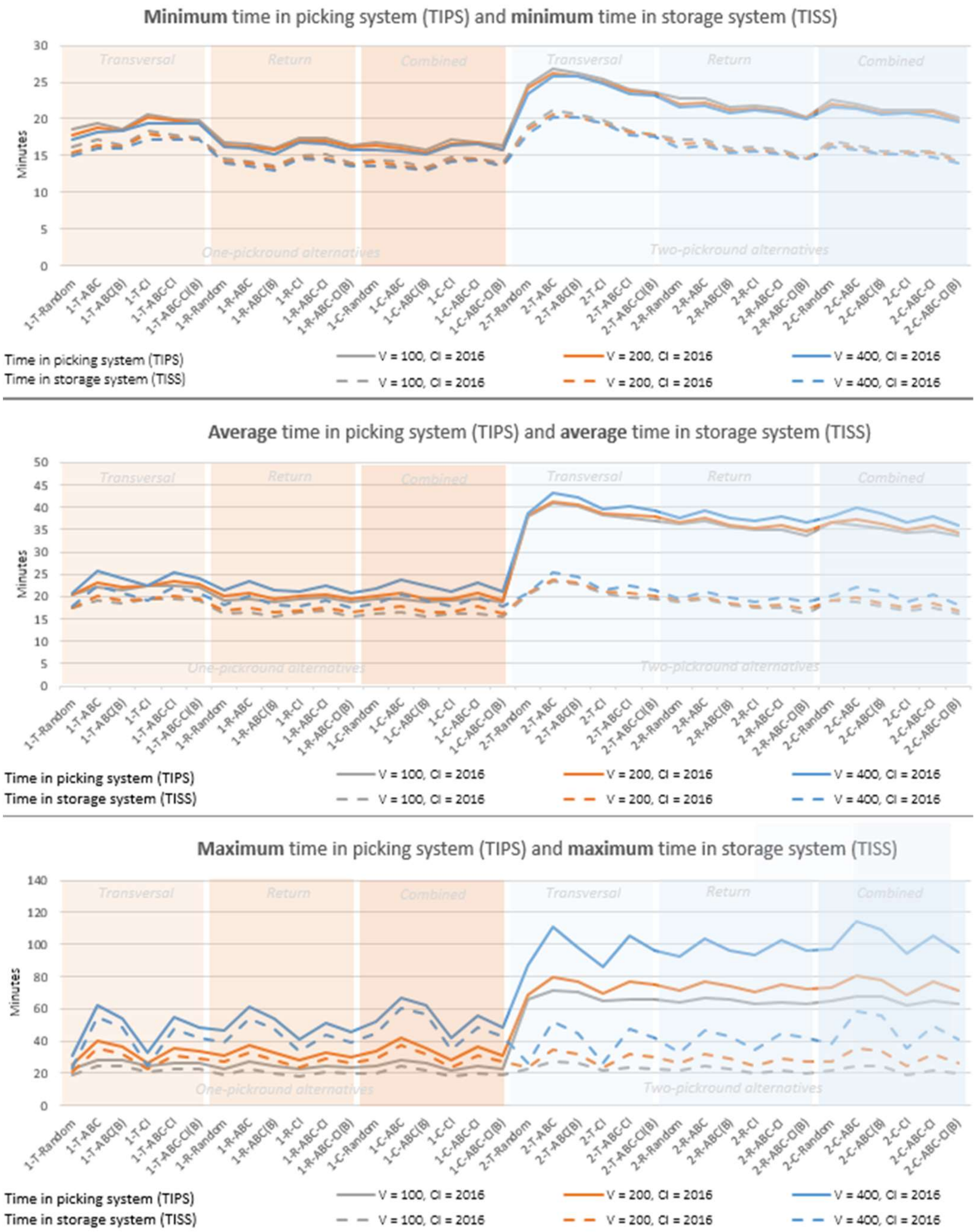


Figure 31: Results experiment 1 to 3: minimum, average and maximum TIPS_OP and TISS_OP in minutes

Storage strategy: The performance of the different storage strategies is hard to evaluate based on the average TIPS and TISS. The *class-based storage on turnover category* seems to perform less when the volume is increasing. The alternatives with *class-based storage on product type* in it seem to perform a little bit better, but not significant. Since the TISS is constructed by adding the time on links between the flowracks and the time spend at the flowracks, these two variables are be evaluated more in detail.

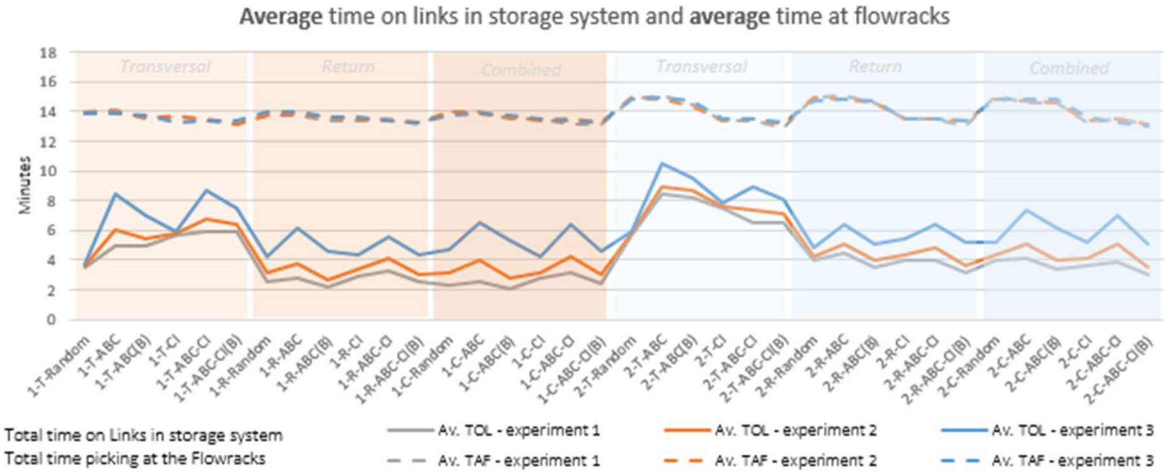


Figure 32: Average time on links to and from flowracks and average time at flowracks of experiment 1 to 3

Figure 32 shows the average time on links between the flowracks (continued line) and the average time spend at the flowracks (dotted line). The average time at the flowracks does not change with a growth in volume, this is logical since the amount of orders is increasing but not the amount of SKUs per order or the amount of orders in a batch; still the same amount of picks have to be made. Interesting is that the time on the links between the flowracks is increasing when the volume is increasing. Also between the alternatives much more variety is seen. The time on the links between flowracks is the highest with *transversal* routing method. The increasing TISS and TIPS, seen in Figure 31 at the *class-based storage on turnover category* alternatives with an increase in volume, is mainly influenced by the time spend on the links. Indicating that congestion is occurring on the links in these alternatives.

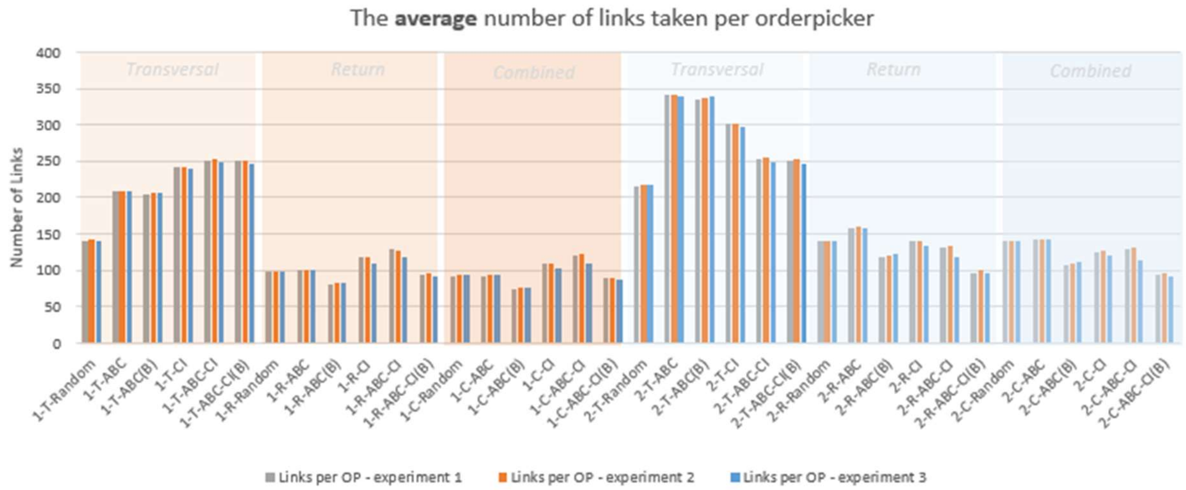


Figure 33: Average amount of links taken within the storage area of experiment 1-3

In Figure 33 the average amount of links an order picker walks is shown for each alternative and each experiment. Comparing Figure 32 and Figure 33, shows that more paths are entered in the alternatives with a *transversal* routing method. For the *return* and *combined* method the amount of links entered are quite similar. Another interesting fact is that in between the experiments the amount of links does not differ much, and if it differs, experiment 3 shows that less links have been entered. However, the total average time on the links is higher in experiment 3 than in experiment 1 and 2, see Figure 32. This can be explained, because the average time per link is also higher in experiment 3, see Figure 34. Meaning that congestion is occurring in experiment 3, since order pickers have to wait on these links before entering a flowrack. Figure 34 shows the average time spend on a link. It can be seen that for the *return* and *combined* routing methods the average time spend per link is increasing when the volume is increasing, which indicates congestion. Especially with the alternatives that have *class-based storage on turnover category* the congestion is present. This can be explained since 87% of the order lines have to be picked in the flowrack section in which the fast-moving articles are present. This is the smallest and the busiest flowrack section.

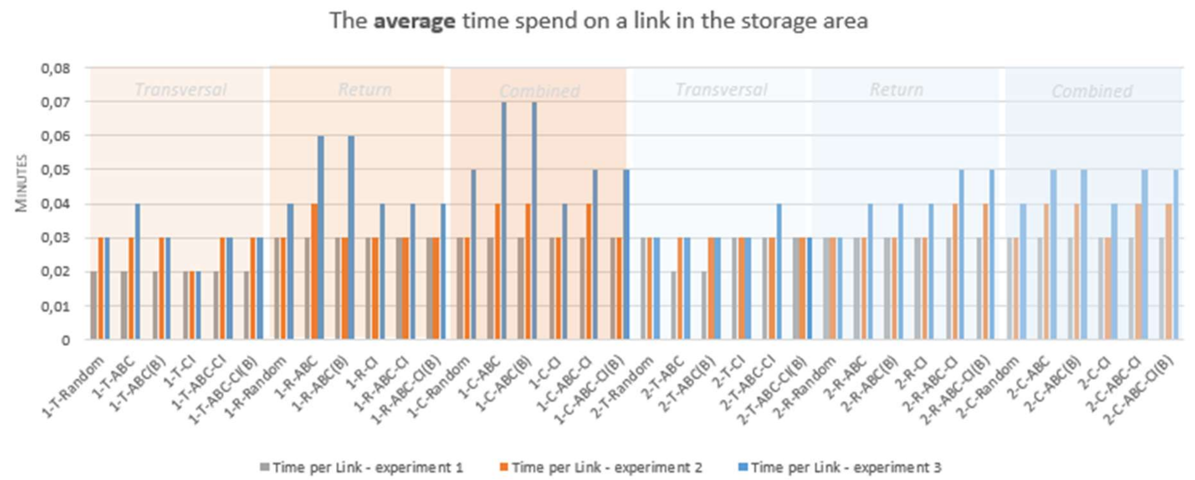


Figure 34: Average time spend on a link in the storage area of experiment 1-3

TIS and TIS-WTB

The total time in system from order entry to order exit (TIS) is decreasing when the volume is increasing, The figures showing these results can be found in Appendix I: Simulation results. This decrease in time is explained by the decrease in the waiting time for a batch since more orders per hour arrive and therefore the batches are faster completed. The TIS-WTB follows the same pattern as the TIPS, see Figure 31, except that the values are higher because the TIS-WTB includes the control station, packing station and the links to and from these stations and the TIPS does not include these activities.

Conclusion

Based on the results, the batching strategy with *batching on turnover category* would be preferred over *batching on order entry*. In all KPIs this strategy is performing better than its respective alternative with *batching on order entry*. Furthermore, the *transversal* routing can be eliminated since the *return* and *combined* routing methods perform much better than the *transversal.* Also the *one-pick round* alternatives are preferred over the *two-pick rounds* alternatives if taking the TIPS into account. If the TISS is seen as the most important KPI, than some of the *two-pick round* alternatives are performing good as well. Lastly, alternatives with *class-based storage on product type* within it are outperforming the other storage strategies, even though the differences are not large.

Experiment 4, 5 and 6

In the following three experiments, the order volume is set to be 400% of the volume in 2016, this is the same volume as in experiment 3. The order configuration of cases and items variate from 50% cases over 50% items, 25% cases over 75% items and 10% cases over 90% items, respectively in experiment 4, 5 and 6. Even though the previous experiments have shown that certain alternatives score relatively low compared to other, all alternatives are still taken into account in these experiments, since a different variable is varied.

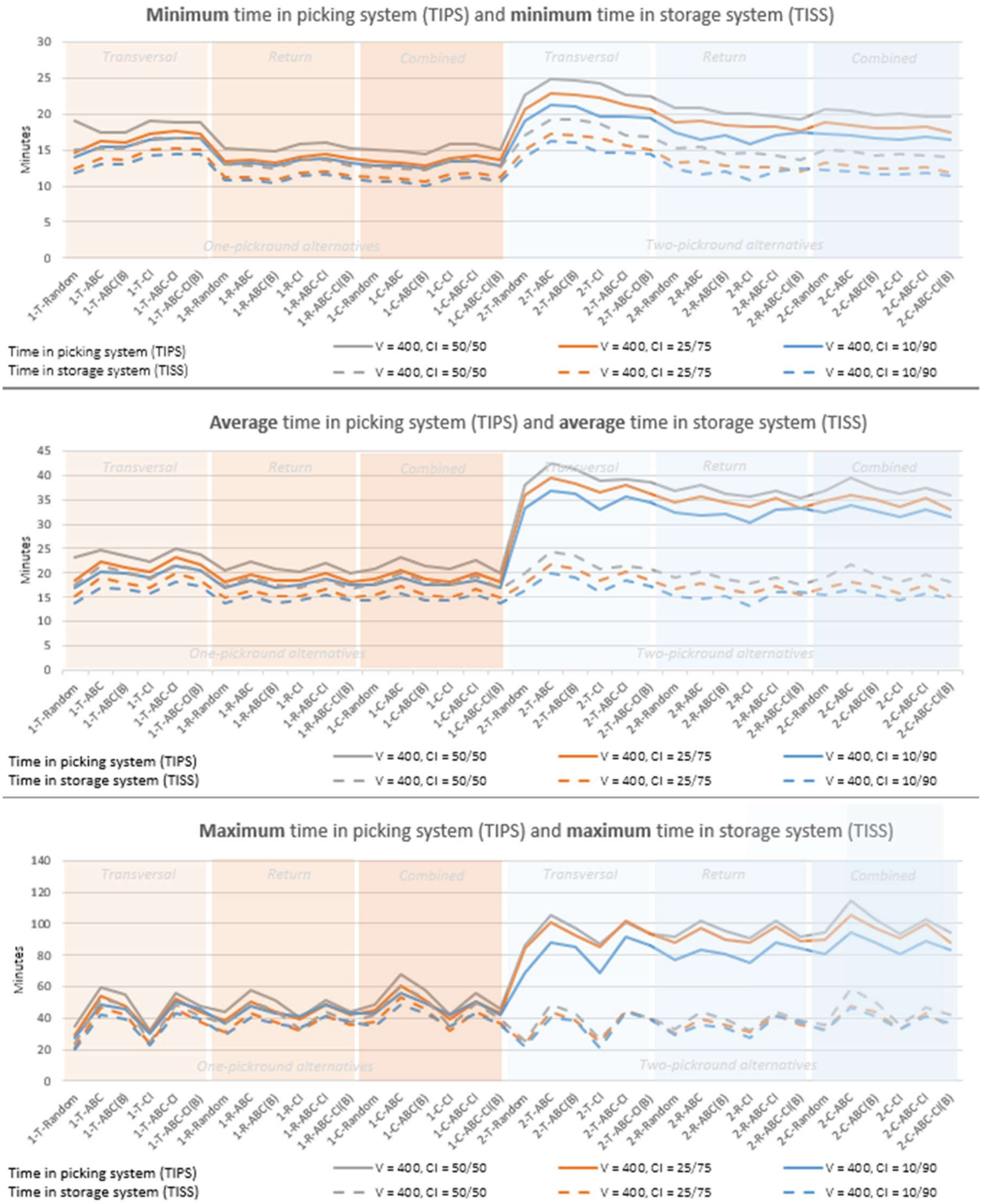


Figure 35: Results experiment 4 to 6: minimum, average and maximum TIPS_OP and TISS_OP in minutes

TIPS and TISS

One-pick round or two-pick rounds: the one-pick round alternatives still outperform the two-pick round alternatives if looking at the time in the picking system, TIPS. However, for experiment 6 in which the largest share of items is present, the alternative 2-R-CI outperforms it respective alternative with one-pick round: 1-R-CI based on the TISS. An explanation for this can be that with 2-R-CI more orders with only items have been batched, resulting in only one-pick round directed to the flowracks sections with items. This could have occurred since the order type distribution over the arrived orders is done randomly. Another explanation cannot be given since both alternatives should act the same in the storage system.

Routing method: Also in this set of experiments the *return* and *combined* routing method are performing better than the *transversal* routing method. For the *one-pick round* alternatives, the performance of the *return* and *combined* method are similar, but for some of the *two-pick round* alternatives the *return* method is performing better than the *combined* method, especially in the sixth experiment.

Batching strategy: For the batching strategy, the same conclusion can be drawn as with experiment 1 to 3, namely that the *batching on turnover category* outperforms the respective alternative with *batching on order entry*. The batching strategy *on turnover category* has a similar performance as the *batching on order entry* with *randomized* storage or *class-based storage on product type*. Indicating that the *class-based storage on turnover category* is performing weaker than the other storage strategies.

Storage strategy: Looking further into the storage strategies and comparing Figure 35 and Figure 36, shows that the weaker performance of the *class-based storage on turnover category* is again caused by the time spend on the links. The overall increase in performance with a higher share of items in the order configuration is caused by the time spend at a flowrack. This time is decreasing because the picking of an item takes less time than the picking of a case or a case-item order line. Since this picking time is decreasing, also the time on links in the *class-based storage on turnover category* alternatives is decreasing, meaning that the congestion is reducing. The lower picking time of the items, indicate that the order picker is sooner finished at a flowrack, resulting in less waiting time for the next order picker at that flowrack and with that less time on the links.

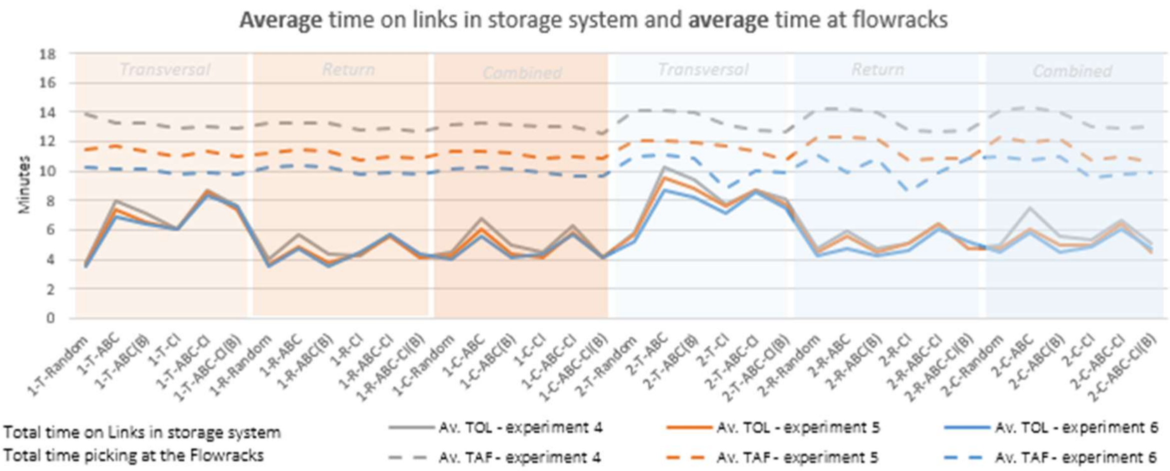


Figure 36: Average time on links to and from flowracks and average time at flowracks of experiment 4 to 6

The average amount of links taken per order picker for experiment 4 to 6 follows the same pattern as for experiment 1 to 3. The amount of links is higher at the transversal routing method compared to the other two routing methods. Also the amount of links of alternatives with *class-based storage on product type* is higher than other storage strategies. The amount of links for the alternatives with *batching on turnover category* is lower. And lastly, the amount of links per order picker is a little higher for the *two-pick round* alternatives than for the *one-pick round* alternatives.

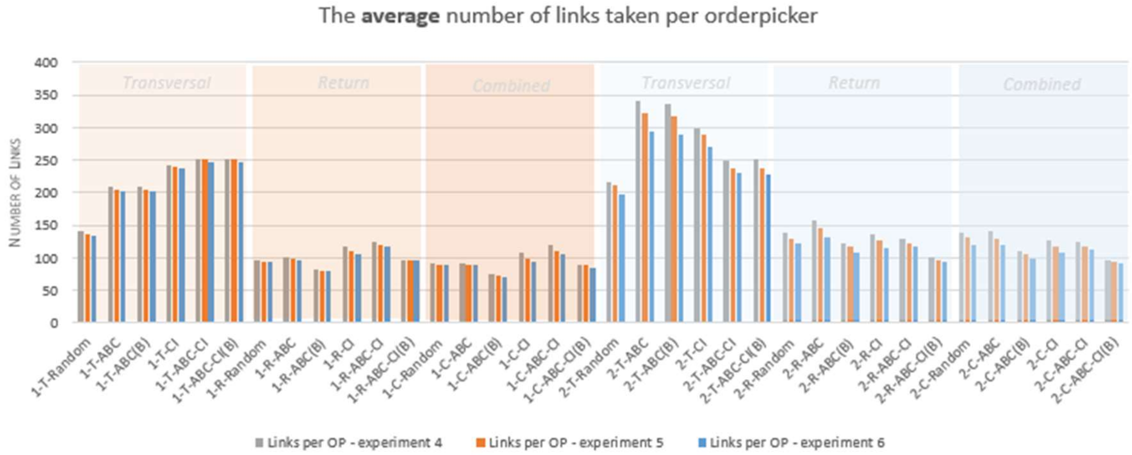


Figure 37: Average amount of links per orderpicker of experiment 4 to 6

The average time spend per links is higher for the *return* and *combined* method than for the *transversal* routing method. Furthermore, when *class-based storage on turnover category* is applied in the *return* or *combined* routing method, the average time spend on links is higher than with the other storage strategies. This difference is not clearly seen in the *transversal* routing, indicating that the *transversal* routing decreases the probability of congestion. The figures of the average amount of links and the average time spend per link are provided in Figure 37 and Figure 38.

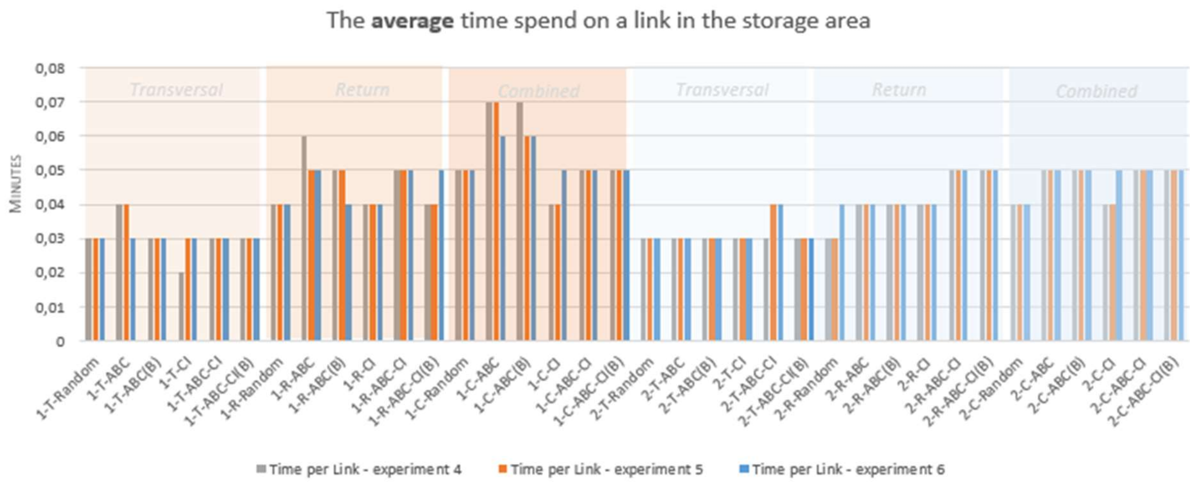


Figure 38: Average time spend per link of experiment 4 to 6

TIS and TIS-WTB

The figures of TIS and TIS-WTB are stated in Appendix I: Simulation results as well. Overall the performance in TIS and TIS-WTB do not differ much over the alternatives and the experiments. For the minimum and average TIS, the time in system decreases when the share in items in the order configuration increases, meaning that in experiment 6 the TIS is lower than in experiment 4 for the same alternative. This difference is also caused by the time spend at the flowracks, which is lower with an increase in the share of items in the order configuration. Furthermore, not much other conclusions can be drawn from these graph as already been noted at the TIPS and TISS results.

Conclusion

Also in these experiments the *one-pick round* alternative have shown to perform overall better than the *two-pick round* alternatives. Furthermore, the conclusion can be drawn that no matter the alternative, when the share in items is increasing, the time at the flowracks and with that all KPIs are decreasing in time and therefore performing better. The storage strategy with *class-based storage on turnover category* is still performing the weakest due to congestion, but the amount of links taken in these alternatives is the lowest and therefore it can be said that the shortest (in meters) route is walked with these alternatives.

Experiment 7, 8 and 9

In experiment 7 and 8 the volume is raised to 800%. The order configuration in experiment 7 is 50% cases and 50% items, and in experiment 8, 25% cases and 75% items. Experiment 9 is a follow up of experiment 8, here the volume is doubled again and raised to 1600%, the order configuration is still 25% cases and 75% items.

TIPS and TISS

Figure 39 is showing the TIPS and TISS of experiment 7 to 9. First thing to notice is the larger differences in performance between the alternatives and the experiments. The experiments show that an increase in the share of items in the order configuration, the difference between experiment 7 and 8, results in a decrease in the TIPS and TISS. This has also been seen in experiment 4 to 6. Experiment 9 in comparison with experiment 8 shows that the increase in volume is causing an increase in time in picking and storage system. According to Figure 40 and Figure 41, this increase is mainly caused by time spend on the links which is higher for each of the alternatives in experiment 9 than in experiment 8. This increase is more extreme with the *class-based on turnover category* alternatives than with other alternatives.

One-pick round or two-pick rounds: Again the *one-pick round* alternatives outperform the *two-pick round alternatives.* However, the differences are smaller when the volume increases. An explanation for this is that the average amount of links per order picker is higher for the *two-pick round* alternatives than for the *one-pick round* alternatives, but is not doubled in number. Meaning that the amount of links per round is lower with *two-pick round* alternatives. Combined with the fact that the average time spend per link is lower in the *two-pick round* alternatives, indicates that in these alternatives less congestion occurs.

Routing method: As was clear at the previous experiments that the *transversal* routing is performing less than the other two routing methods, is not as clear in these experiments. The *transversal* routing method is performing similar to the other routing methods or even better for some of the alternatives, especially in experiment 9. Concluding that the congestions with a 1600% volume is getting that large that it is more efficient to implement a transversal routing method.

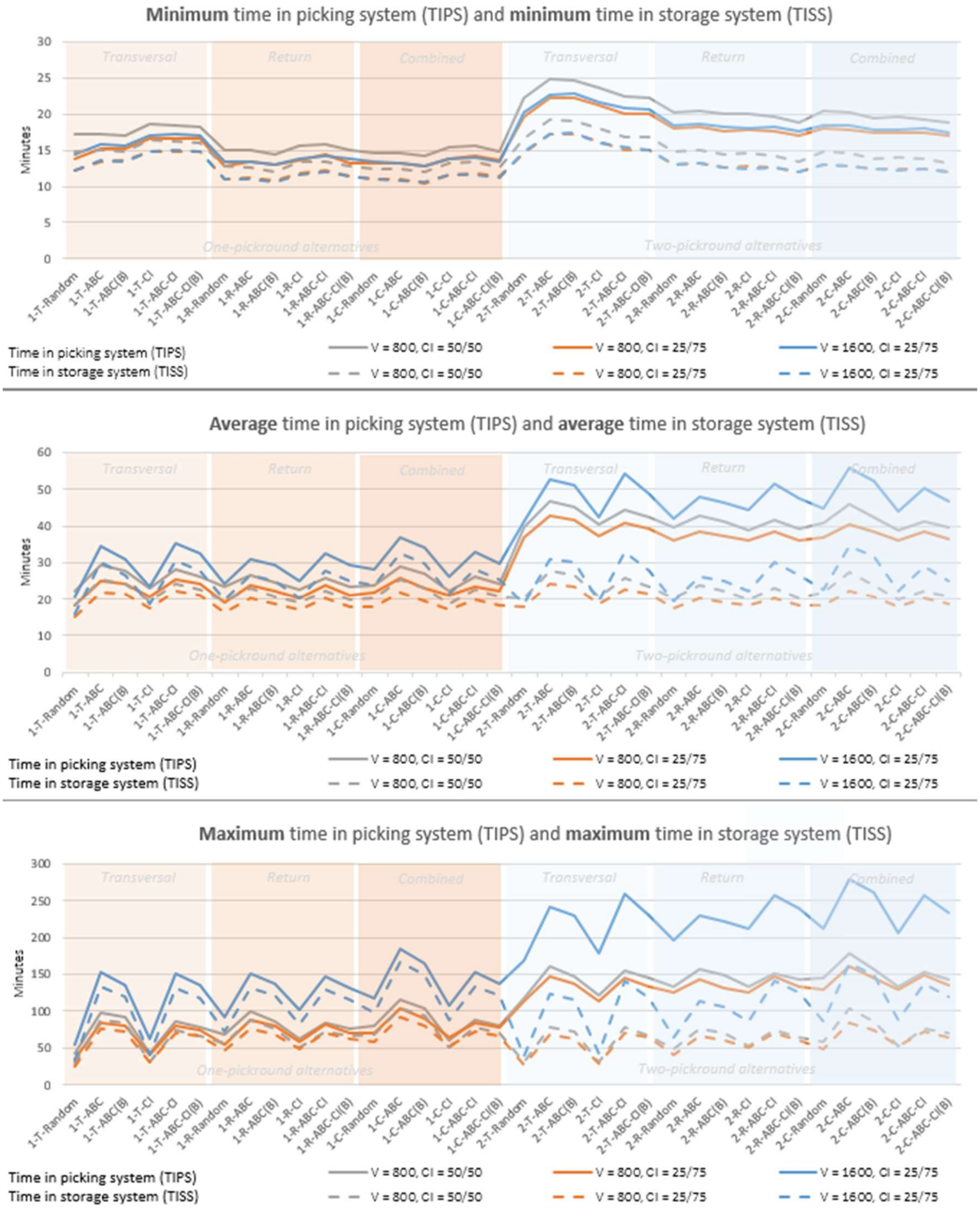


Figure 39: Results experiment 7 to 9: minimum, average and maximum TIPS_OP and TISS_OP in minutes

<u>Batching strategy:</u> Also in these experiments the *batching strategy based on turnover category* performs better than its respective alternative with *batching on order entry*. In the previous experiments, the alternatives with *batching on turnover category*, and so with *class-based storage on turnover category,* could still perform similar to alternatives not having a *class-based storage on turnover category*. In these experiments it is clear that too much congestion occurs in these alternatives, which cannot be compensated anymore with a shorter amount of links taken by the order pickers,

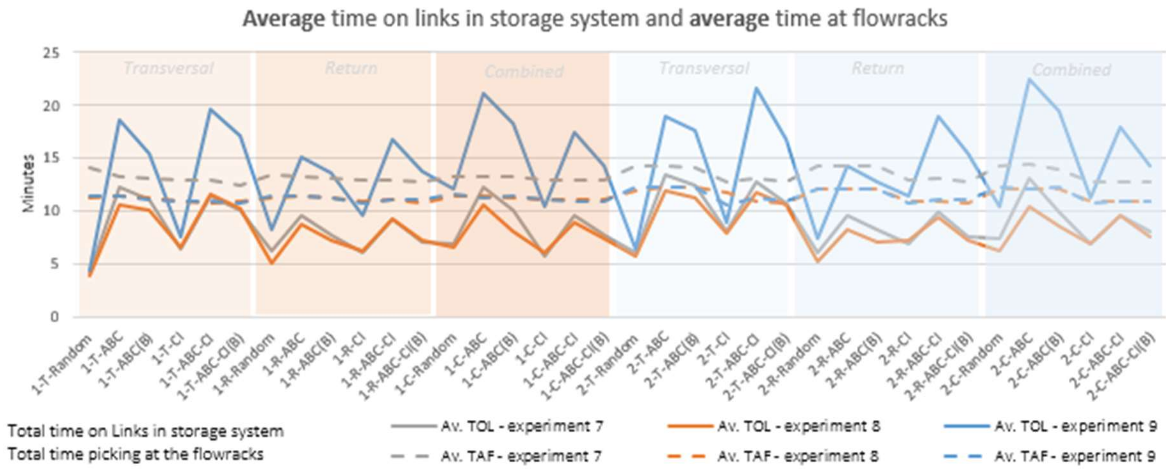


Figure 40: Average time on links to and from flowracks and average time at flowracks of experiment 4 to 6

Storage strategy: For the storage strategies, it is clear that *class-based storage on turnover category* within this design and with such an increase in volume will not be efficient compared to other alternatives. The *randomized* storage and the *class-based storage on product type* are performing better than the other storage strategies, especially in experiment 9.

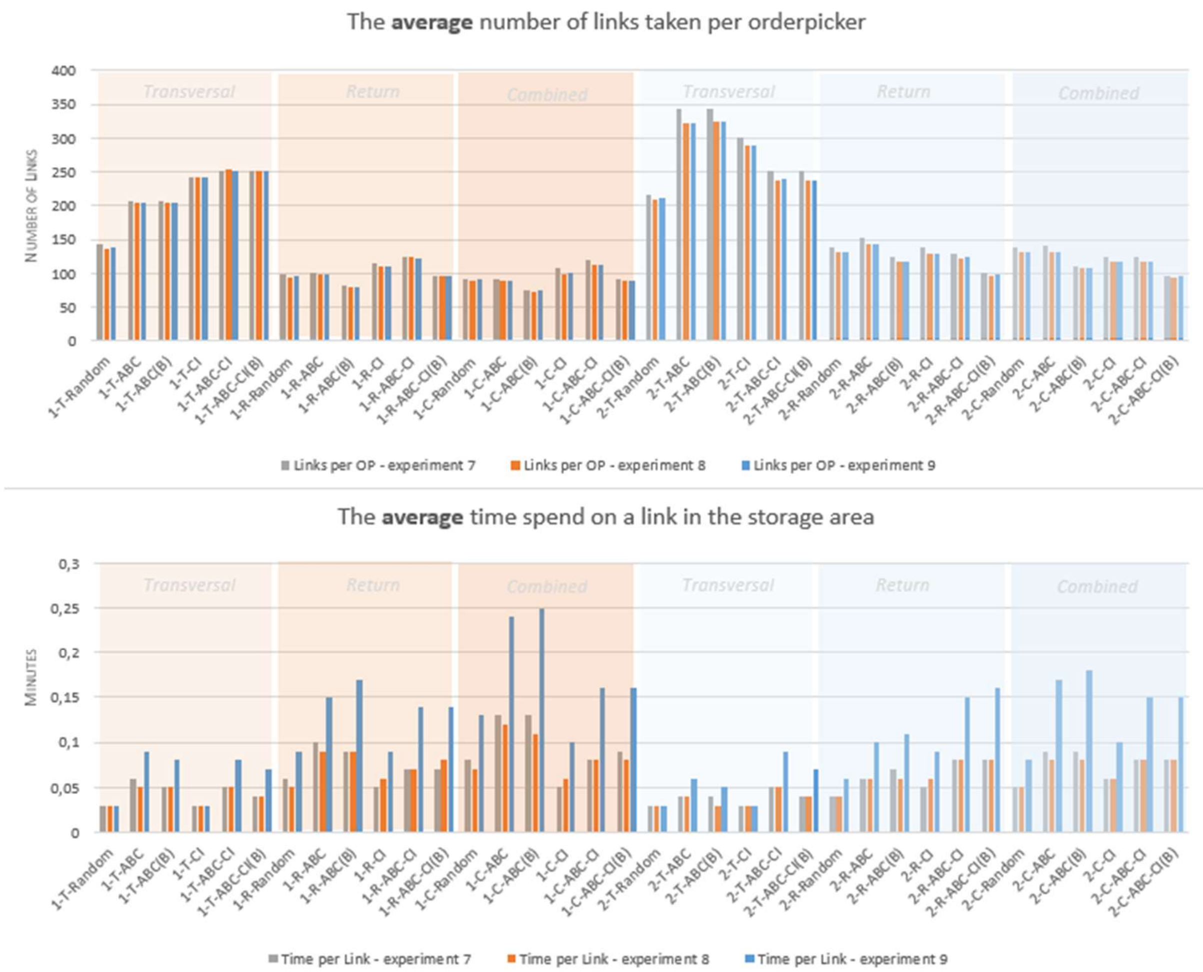


Figure 41: Average amount of links per orderpicker and time spend per link of experiment 4 to 6

TIS and TIS-WTB

Again, the TIS follows almost the same pattern as the TIPS. And looking at the average TIS, the total time in system is the highest in experiment 9, with 1600% volume. For the TIS-WTB the same can be concluded. All can be concluded by the congestion occurring in these experiments.

Conclusion

The conclusion can be drawn that somewhere between the 400% and 800% volume of the volume in 2016, the performance of the alternative with *class-based storage on turnover category* in it in combination with *batching on turnover category* is decreasing exponential. The congestion that occurs in the flowrack section with the higher volume, flowrack section A, is too large to compete with a transversal routing method and other storage strategies. Furthermore, based on experiment 4 to 6 and 7 to 9, it can still be said that the higher the share in items in the order configuration the better the performance.

Discussion

The results of the experiments are representing the real system as much as possible within the limits it has been built in. Still these limitations should be taken into account with the analysis of the results. This model has as limitation that each route choice made in the model is based on a probability. When no constraints are influencing this probability, it is always 50%. In all routing methods the flowrack sections of A, mainly cases of A is passed first, nevertheless the storage strategy. With the combined and return method, the order picker has the choice of taking a shorter route after passing a part of flowrack A. Again, this choice is based on a 50% probability if the constraints are all met. When this shorter route has been selected, it is not possible anymore for the order picker to walk back to the section he or she did not pass. The probability of not passing flowrack section C is higher than not passing B and of not passing B is higher than not passing A. Therefore, the *randomized storage* and *class-based storage on product type* might seem to perform better in the simulation model than in the real system, because they act a bit the same as the alternatives with *class-based storage on turnover category*. Therefore, the alternatives with *class-based storage on turnover category* in it might perform less in the simulation model, than in the real system.

Another limitation is that one lay out principle for the flowrack and flowrack sections have been evaluated. If the flowrack section in which fast-moving products are stored is larger designed or in another sequence or layout, it might be that the performance of the *class-based storage on turnover category* is better than with this layout.

Best performing alternatives per experiment

The best performing alternative(s) per experiment based on the simulation results are given in Table 19. When the results of multiple alternatives are almost equal, the average of the results is given. The best performing alternative is selected based on the average time in the storage system (TISS). This is the average time at the flowracks combined with the average time on the links between these flowracks. This KPI is selected as most important since the picking strategy, storage strategy and routing strategy have direct effect on this KPI. With the other KPIs, more variables and functions in the system have influence on the performance.

The KPI: TIS-WTB, will be used to see whether the alternatives can cope with a lead time of order entry at 22:00hr, order ready for shipment at 00:00hr. As can be seen in the last column of Table 19, all alternative manage this lead-time except for the alternative in experiment 9, in which the maximum TIS-WTB can be 207,39 minutes, resulting in almost 3,5 hours. The reason for this is the extreme time on certain links in the system. Although this alternative will not manage the lead-time stated in the system requirements. It is expected that this maximum time have not occurred at 22:00 o'clock. The reason for this is that the orders have been placed with an arrival rate of 19,36 orders per hour and will not be processed during non-operational hours, meaning that all orders placed during the night will wait until 06:00 o'clock in the morning to be processed and all order pickers will start at this time processing the batches, which makes it the busiest moment in the system.

Table 19: Overview of the best performing alternative(s) per experiment and their results

Best performing alternative(s) per experiment and their results						
Exp.	Best performing alternative(s)		TISS	TIPS	TIS	TIS-WTB
1	1-R-ABC(B), 1-R-ABC-CI(B), 1-C-ABC(B) and 1-R-ABC-CI(B)	Min.	13.74	16.10	18.45	18.22
		Av.	15.57	18.67	164.51	21.70
		Max.	20.34	24.225	534.54	29.02
2	1-R-ABC(B), 1-R-ABC-CI(B), 1-C-ABC(B) and 1-R-ABC-CI(B)	Min.	13.49	15.78	18.13	17.90
		Av.	16.34	19.41	62.96	22.50
		Max.	28.27	32.30	264.31	38.35
3	1-C-ABC-CI(B), 1-C-CI, 1-R-ABC-CI(B), 1-R-CI and 1-T-Random	Min.	14.17	16.44	18.75	18.56
		Av.	17.77	21.03	51.99	24.53
		Max.	34.76	41.79	335.60	52.56
4	1-C-ABC-CI(B), 1-C-CI, 1-R-ABC(B), 1-R-CI, 1-R-Random and 2-R-ABC-CI(B)	Min.	13.15	15.98	18.30	18.09
		Av.	17.26	22.93	54.05	26.28
		Max.	37.71	52.19	338.43	61.83
5	1-C-ABC-CI(B), 1-C-CI, 1-R-ABC(B), 1-R-CI, 1-R-Random, 1-T-Random and 2-R-ABC-CI(B)	Min.	11.55	14.24	16.55	16.36
		Av.	15.03	20.12	51.44	23.55
		Max.	32.73	45.43	332.44	55.57
6	1-C-ABC-CI(B), 1-R-ABC(B), 1-R-Random, 1-T-Random and 2-C-CI	Min.	10.85	13.67	15.99	15.79
		Av.	13.63	19.67	50.78	23.16
		Max.	29.61	44.76	336.84	55.32
7	1-C-Random, 1-R-CI, 1-T-CI and 1-T-Random	Min.	14.48	16.73	19.04	18.84
		Av.	18.82	22.54	56.69	27.11
		Max.	40.47	52.43	404.00	73.66
8	1-R-Random and 1-T-Random	Min.	11.57	13.31	15.13	14.51
		Av.	15.71	18.68	51.13	20.13
		Max.	35.64	45.19	390.73	46.95
9	1-T-Random	Min.	12.17	14.41	16.52	22.44
		Av.	15.87	20.64	28.80	47.99
		Max.	33.41	54.31	98.84	207.39

The best 12 alternatives named in Table 19 have been outlined in Table 20 with the experiments in which the alternatives perform best. The total amount of experiments in which the alternatives perform best is shown in the last column. As can be seen the alternatives in which *class-based storage on turnover category* is applied in combination with the *batching strategy on turnover category* are performing the best in the first two experiments. In experiment 3 congestion is occurring making the *randomized storage* and *class-based storage on product type* performing also perform well. The routing methods *return* and *combined* perform better in the first two alternatives and from alternative 3 on, the *transversal* routing method is gaining in on these other routing methods. Furthermore, the following conclusions can be drawn from the analysis of the results:

- The higher the volume, the more congestion at the alternatives with class-based storage on turnover category occurs and therefore the better randomized storage and class-based storage on product type perform.
- The class-based storage on product type performs well at 400% and 800% with an order configuration of 50%/50% and 25%/75%. If the share of items is increasing more than 75%, the performance of this storage strategy reduces.
- Batching strategy on turnover category performs always better than its respective alternative with batching strategy on order entry.
- The higher the volume the better a more simple routing strategy is performing, because with transversal and return routing order pickers walk more behind each other and less interference in the paths takes place.

Table 20: An overview of the best performing alternative and the experiment in which they perform best

	1	2	3	4	5	6	7	8	9	Total
1-C-Random							x			1
1-C-ABC(B)	x	x								2
1-C-ABC-CI(B)			x	x	x	x				4
1-C-CI			x	x	x					3
1-R-Random				x	x	x		x		4
1-R-ABC(B)	x	x		x	x	x				5
1-R-CI			x	x	x		x			4
1-R-ABC-CI(B)	x	x	x							3
1-T-Random			x		x	x	x	x	x	6
1-T-CI							x			1
2-C-CI						x				1
2-R-ABC-CI(B)				x	x					2

4.5 Conclusion: Design solution

From the results of the simulation an alternative is selected that is performing the best considering the requirements. The subquestion answered in this section is: '*What is the preferred design and does this design meet the requirements?*'

The alternatives 1-T-Random is in most of the experiments one of the best performing alternatives. Second best is the alternative 1-R-ABC(B). Shared third place are the alternatives 1-C-ABC-CI(B) and 1-R-CI. The results of the average time in storage system (TISS) of the alternatives are given in Table 21 per experiment and added up per experiment group.

Table 21: Average time in storage system of the four best alternatives per experiment

	1-T-Random	1-R-ABC(B)	1-R-CI	1-C-ABC-CI(B)
Experiment 1	17,51	15,58	16,35	15,55
Experiment 2	17,43	16,38	16,90	16,19
Experiment 3	17,65	18,16	17,95	17,93

	1-T-Random	1-R-ABC(B)	1-R-CI	1-C-ABC-CI(B)
Experiment 4	17,65	17,53	17,07	16,72
Experiment 5	15,14	15,05	15,10	14,99
Experiment 6	13,78	13,80	13,72	14,34
Experiment 7	18,25	20,72	18,60	19,41
Experiment 8	15,17	18,47	17,17	18,46
Experiment 9	15,87	24,90	20,40	25,28
Total (exp. 1-3)	52,59 (4th)	50,12 (2nd)	51,20 (3rd)	49,67 (1st)
Total (exp. 1-6)	99,16 (4th)	96,50 (2nd)	97,09 (3rd)	95,72 (1st)
Total (exp. 1-8)	132,58 (1st)	135,69 (4th)	132,86 (2nd)	133,59 (3rd)
Total (all)	148,45 (1st)	160,59 (4th)	153,26 (2nd)	158,87 (3rd)

The best performing design solution is eventually dependent on the increase in volume and on what will be ordered, the order configuration. Since it is unclear how much the volume will increase and in what way the order configuration is changing, a straightforward answer cannot be given. On the other hand, it is quite secure to say that the volume will definitely increase if the client is opening a website and the e-fulfilment system is implemented. The best solution for the increase of volume is the 1-T-Random in which a *one-pick round strategy*, *batching strategy based on order entry*, the *'transversal'* routing method and the *randomized* storage strategy are applied. But this difference is just made from the volume level of 800%. With a lower volume this alternative scores weaker or similar to other alternatives. An advantage of this alternative is the fact that is it for Nedcargo quite easy to implement since this alternative is also applied in the pallet and case pick storage areas.

To be able to select the best design solution, the likeliness of the experiments should be taken into account. Experiment 1 is the current situation and therefore a 100% likely, experiment 2 is also very likely to happen. Experiment 3 a little bit less, since it is quite likely that the volume is increasing to 400% but it is also more likely that the order configuration will change as well and therefore are experiment 4 and 5 more realistic than experiment 3. Experiment 6 is less likely to occur since many of the customers of Moet are still B2B customer who will order more per case than per item. Experiment 7 and 9 are also less likely, in which the arguments for experiment 7 are the same as for experiment 3 and experiment 9 has an extremely high volume which will probably not be realistic. Experiment 8 is more likely to occur than 7 and 9, but less likely than 2, 4 and 5. So the most important experiments to look at are: 1, 2, 4, 5 and partly 8.

Table 22: Added results of the most likely experiments per alternative

	1-T-Random	1-R-ABC(B)	1-R-CI	1-C-ABC-CI(B)
Total (1, 2, 4, 5)	67,73 (4th)	64,54 (3rd)	64.42 (2nd)	63,45 (1st)
Total (1, 2, 4, 5 and 8)	82,90 (3rd)	83,01 (4th)	82,59 (2nd)	81,91 (1st)

According to Table 12, the alternative 1-C-ABC-CI(B) is the best performing alternative and should therefore be selected as solution design. However, the storage strategy *class-based storage on product type*, also applied in the second best alternative 1-R-CI, implies that the replenishment of the products should be done twice, once in the case part of the storage and once in the item part of the storage. If the time spend at a replenishment would be taken into account, this might not be the most efficient alternatives anymore. The alternative that is third best is the 1-R-ABC(B), especially for experiment 1, 2, 4 and 5 and taking into account that the results of the simulation model are better for the *randomized* storage and less good for the *class-based storage on turnover category* than the real system would be. In this alternative, the cases and items of one product type are situated near each other and the replenishment can be done more efficiently. The downside of this alternative is that the *return* routing method can be overruled by the order picker and eventually be executed as a *combined* routing method, resulting in alternative 1-C-ABC(B). The results of this alternative for experiment 1, 2, 4 and 5 added up are 65,64, which is still better than of alternative 1-T-Random.

Furthermore, the alternatives with *class-based storage on turnover category* are performing weaker from a volume of 400% due to the congestion that is occurring at the flowracks. This congestion can also be reduced by adjusting the layout of the storage area or by re-evaluating the assumptions made in this simulation model. For example, the flowrack is now block for 1,5 meter when an order picker is picking something from that flowrack. When more pick slots in the flowrack section are for the same product type, this blocked space can be reduced. This can also result in less depth of the flowrack but more width, implying a larger pick face for the flowracks at which congestion occurs currently, resulting in a reduction of the congestion. Another option to reduce the congestion at the flowracks is to not release all collected orders at 06:00 o'clock in the morning but more equally spread over the day. Or let e.g. only a maximum amount of order pickers operate in the storage area simultaneously.

Based on the results of the experiments, the limitations of the model and the possible solutions for the reduction of the congestion, the alternative 1-C-ABC(B) will be selected as best solution design. Recommended for Nedcargo is that when the volume is increasing, an analysis on the change in order configuration should take place and it should be reconsidered to implement 1-C-ABC-CI(B). The advantage of this alternative over 1-C-ABC(B) is also that the stacking of the products in a box is more easily and securely done.

5. Conclusion & Recommendations

This chapter concludes the research and provides recommendations for both Nedcargo and further research on implementing e-fulfilment in an order pick system of an existing logistic service provider. Section 5.1 provides the conclusion. In section 5.2, a discussion on the research is given, and the recommendations for Nedcargo and for further research are state in section 5.3 and 5.4, respectively.

5.1 Conclusion

The initial research question drafted at the start of the research was:

'How does an order pick system need to be designed in order to fulfil orders generated by e-commerce at an existing logistic service provider?'.

To answer this research question the e-fulfilment customer, the order pick systems strategies, the existing LSP and the order pick system of the existing LSP have been analysed. From this analysis, the conclusion is drawn that there are too many differences between the current processes at the LSP which are focussed on the retail industry, handling mainly pallets, and the fulfilling of orders generated by e-commerce.

The differences between e-fulfilment and retail are mainly the unit load handled and the customer's preferences and demand. The unit load for retail consists of pallets or cases transported on pallets and the unit load for e-fulfilment consists of items and a few cases. Furthermore the level of accuracy and the lead-time service level of the retail industry have less influence on customer's satisfaction than of the e-fulfilment industry. Since the order pick system of Nedcargo has been fully designed for retail, the process and performance of this order pick system cannot ensure a 100% accuracy and the fast lead-time as demanded by the e-fulfilment customer.

Besides these reasons, Nedcargo has a mission and a vision in which multiple objectives on the reduction of waste are important and the safety of the personnel throughout the whole process has to be secured. Integrating e-fulfilment in the current order pick system of Nedcargo will not contribute to the reduction in time, food, money and the environment and cannot guarantee the safety of the personnel due to the interaction between humans and trucks. This led to the conclusion that besides the general difference in process and performance, the combination would also not correspond with Nedcargos' ideals and therefore not be feasible.

Since based on these analysis it can concluded that the two order pick system should be separated, it was important to find out which order pick system aspects, or strategies, have influence on the process and performance of the system. These have been research more in detail to get to the best solution design. The order pick system analysis in which the strategies are outlined, combined with the analysis of the order pick system of Nedcargo, shows that the picking strategy, the storage strategy and the routing method applied have the most influence on the efficiency of the system. After this conclusion, a new research question have been drawn, namely:

'Which picking strategy, storage strategy and routing method should be applied to ensure an order pick system for e-fulfilment that can cope with the e-fulfilment customer's demand and the objectives of the LSP?'

This research question has been answered by defining the system requirements, generating the design alternatives and evaluating the design alternatives. The definition of the system requirements showed that the most important requirements are the lead-time in which and order is fulfilled, the flexibility of the system with respect to growth in demand and changes in order configuration and the accuracy level of the system. Furthermore the product type handled and the environment are taken into account.

Based on these requirements, some aspects of the order pick system are already decided. These are the use of flowracks to ensure a first-expired-first-out policy. The reduction in the movement of the products and therefore picking and placing the products directly in the box in which they are transported. And lastly, the implementation of scanning by picking and a weight control when the order is finished. With these decisions the accuracy level is ensured and the product type and the environment are taken into account.

The lead-time of the order pick system and the flexibility of changes in the future are evaluated with the use of a simulation model. For the picking strategy was decided to implement a batching strategy since the order sizes are small and single-order picking would not be efficient. The two batching strategies that are evaluated are *batching on order entry* and *batching on turnover category*. For the storage strategy, *randomized* storage, *class-based storage on turnover category, class-based storage on product type* and *class-based storage on turnover category and product type* are evaluated and for the routing method *transversal, return* and *combined* routing are evaluated. Furthermore all alternatives are evaluated based on an one-pick round strategy and on a two-pick rounds strategy. Where with the two-pick rounds strategy, in the first pick round the cases are picked and in the second pick round the items.

The analysis of the results have given four general conclusions. Mainly the higher the volume, the least specific the storage strategy must be. In other words, the more *randomized* storage is performing better. Also an increase in the share of items, contributes to an increase of the performance because items take less time to pick than cases. This is also present at the alternatives with *class-based storage on product type*, until a share of 75% items. From 90% items, the performance of these alternatives is decreasing because of congestion at the item flowrack sections. Furthermore, ba*tching on turnover category* does always outperform the respective alternative with *batching on order entry*. And lastly, the higher the volume the better a more simple routing method performs, i.e. *transversal* routing. This is for the same reason as the storage strategy, namely the congestion. With a high volume too many order pickers are send to the same flowrack sections causing congestion, while with the *randomized* storage strategy and the *transversal* routing method this is more equally spread over the storage area.

Alternative specific, the results have shown that the alternatives in which *one pick round* is performed and a *class-based storage on turnover category* is combined with the *batching on turnover category* strategy and a *return or combined* routing method, i.e. (1-R-ABC(B) and 1-C-ABC(B)), are performing the best considering the time in the storage system, i.e. the actual picking time. When the volume is increasing to 400% and more, congestion on the links and at the flowracks is causing a reduction in time and a reduction in the performance of these alternatives. The alternatives in which the storage strategy is also based on product type, so *class-based storage on turnover category and product type,* are still performing well with a volume of 400%. However, when the volume is increasing to 800% the congestion is getting too large, making these alternatives not the best performing alternatives anymore. The alternatives with *randomized* storage and a *transversal* routing are then performing better than the other alternatives.

Due to the limitations of the system, the fact that many other possible solutions can be brought up to reduce the congestion at the flowrack sections and that this alternatives still perform good compared to the best performing alternative, the alternative 1-C-ABC(B) has been selected as best solution design. This is the alternative with *one*-pick round, a *combined* routing method, *class-based storage on turnover category* and a *batching strategy based on turnover category.* It must be said that the alternative 1-C-ABC-CI(B) is performing better but with the current volume it will not be more efficient since a double replenishment has to be executed with this alternative. When the volume has increased to around 400%, a new analysis of the order configuration should take place and based on those results it can be decided to implement 1-C-ABC-CI(B). However for now it is recommended to implement 1-C-ABC(B) to get the best performance and to research further how a reduction in congestion can take place when the volume increases.

5.2 Discussion

During the research certain assumptions, limitations or company specific conclusions have been drawn that influence the results of the research. The objective of the research was to design an order pick system for e-fulfilment at an existing logistic service provider. Since this research is conducted for Nedcargo, company information and the order pick system analysis have been based on Nedcargo and might be different for other LSPs. Also, the simulation model design and some of the decisions made for the order pick system have been based on the data analysis of the company Moet Hennessy. This might also be different for other companies. Therefore the conclusion of the research cannot be copied one on one for other LSPs or other producers. However, it provides a good insight in the aspects that have to be taken into account when an LSP wants to add e-fulfilment to its services. Also, when the processes of an LSP are similar to the processes of Nedcargo and the client for which they want to implement this service have a similar order profile, the conclusion of this results can be used as well.

Furthermore, two important aspects of the order pick system and e-fulfilment have not been taken into account, namely the reverse logistics and the replenishment. The reverse logistics have been completely left out of this research and for the replenishment, only the effect on the e-fulfilment order pick system is named at the analysis of the simulation results. Since the replenishment of the e-fulfilment OPS has to be done from the existing case pick area, these processes do have influence on the current processes. With this research it has been kept in mind that the current OPS has a reduction of 7.340 orders per year, for which on average 52 replenishment orders have come into place. Therefore the assumption has been made that this will probably decrease, but definitely not increase, the pressure on the current OPS. The reverse logistics should still be researched and designed to make a complete e-fulfilment system design.

Some characteristics of the system or of parts of the system have been based on executing the specific task and on scientific articles. Still these characteristics, e.g. processing times, are assumptions that have not been quantified, reducing the validation of the model. Also as mentioned in section 4.4.2, the way the model has been build gives better results for some of the alternatives than in a real system would occur and with that makes other alternatives in comparison seem to perform less. This limitation of the model has been taken into account when analysing the results.

Another subject for discussion is the time window in which the orders can be placed. When opening a webshop, customers can place orders at any time a day and any day in a year. Also during weekends and holidays. In this research weekends have not been taken into account. The arrival rate is based on the annual amount of orders divided over the working days. When dividing this annual amount of orders over all days, the arrival rate would have a lower value. If orders are placed in the weekend, this will give a high peak in demand on Monday morning. The alternatives have been evaluated on different order volumes, therefore it can be said that this peak has been taken into account. At least for the first 6 experiments.

Another data driven subject for discussion is the large peak at Christmas, shown in section 3.2.2. It could have been that the orders and products that have been ordered these two weeks are very different from the orders placed during the whole year. And since all data has been averaged, this might have influenced the outcome quite much. For this research, it can be concluded that that is not the case, only that the base arrival rate during the year is lower than 1,21 orders per hour. But the order type and order configuration stay similar over the year. Still, this should be taken into account when other clients are analysed.

5.3 Recommendations for Nedcargo

The research shows which design can be best implemented for the company Moet Hennessy at this moment in time and for the future. Since Nedcargo has more clients with other order profiles, the results cannot be copied one on one for other clients. On the other hand, implementing this solution design will have consequences for the warehouse management system. It seems unrealistic to implement a client-specific solution design for every client. Therefore, when e-fulfilment will be implemented for other customers, it is recommended to analyse whether this solution design will work for that client as well. And if not, what adjustment should be made to make it work instead of applying completely different order pick strategies.

The research has been execute on a strategic level, little saying on the operational and tactical level of the system design. Some recommendations are given for the operational level but these are not properly evaluated in combination with other possibilities. Therefore, it is recommended for Nedcargo to perform further research on the operational and tactical level of the e-fulfilment OPS before implementation of the system. Since nowadays many intelligent and efficient picking equipment is applicable and the use of these equipment types is also mentioned in the mission and vision, an advice is to look into these types of technology, e.g. pick-to-light or pick-to-voice technology.

Furthermore, it is recommended for Nedcargo to start with e-fulfilment in cooperation with an existing client who agrees to design the system with Nedcargo and will and can be used as a pilot before implementing the service for other clients. This way, a better customer preference and demand driven system can be build, increasing the satisfaction of the customer.

5.4 Recommendations for further research

In the research multiple decisions have been made that narrowed down or specified the research. Each decision has influence on the outcome of the research and could or should be analysed more in detail in future research. The most important decisions are outlined in this section.

First of all, the decision not to integration the e-fulfilment OPS in the current OPS. This decision is fairly made based on the analysis on the e-fulfilment customer, the OPS strategies, the company Nedcargo and the OPS of Nedcargo. A different objective of the research could have been that the two systems must be integrated and that the best way to do this should be research. To broaden the scientific research on combining e-fulfilment with an retail OPS, this might be an interesting angle.

Furthermore, some of the storage strategies and routing strategies have been eliminated from the research. It is interesting to perform a research with the other storage strategies and routing method to compare the results to the results of these alternatives.

Lastly, some of the decisions have been based on the order profile of the customer. For Nedcargo, but also in general, it might be very efficient to have a kind of roadmap on which OPS strategies perform best under which circumstanced, i.e. with which order profile. E.g. in this research the order lines with fast-moving products have a share of 87% of all order lines, which is extremely high. This has an tremendous influence on the probability of congestion to occur. Therefore, for order profiles with a high share of fast-moving order lines, the more simplistic routing methods and storage strategies perform better in general.

BIBLIOGRAPHY

Aase, G., & Peterson, C. (2004). A comparison of picking, storage, and routing policies in manual order picking. *International Journal of Production Economics, 92*, 11-19.

Adams, K. (2015). Design Methodologies. In *Non-functional Requirements in System Analysis and Design.* Switzerland: Springer.

Agatz, N., Fleischmann, M., & van Nunen, J. (2008). E-fulfillment and multi-channel distribution – A review. *European Journal of Operational Research, 187*, 339-356.

Agatz, N., van Nunen, J., & Fleischmann, M. (2007). E-fulfilment and multi-channel distribution: A review. *European Journal of Operational Research*, 339-356.

Bahill, A., & Dean, F. (2009). Discovering System Reguirements. In A. Sage, & W. Rouse, *Handbook of Systems Engineering and Management.* Wiley.

Baker, P., & Canessa, M. (2009). Warehouse design: A structured approach. *European Journal of Operational Research, 193*, 425-436.

Blomqvist, T. (2010). *A warehouse design framework for order processing and material handling improvement.* Aalto University, Department of Business Technology. School of Economics.

Brown, T. (2009). *Change by Design.* HarperBusiness.

Chan, F., & Chan, H. (2011). Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage. *Expert Systems with Applications, 38*(3), 2686-2700.

Cross, N. (2000). *Engineering Design Methods* (3rd Edition ed.). England: Wiley.

Daly, S., Yilmaz, S., Christian, J., Seifert, C., & Gonzalez, R. (2012). Design Heuristics in Engineering Concept Generation. *Journal of Engineering Education, 101*(4), 601-629.

de Kosten, R., & Van der Poort, E. (1998). Routing orderpickers in a warehouse: a comparison between optimal and heuristic solutions. *IIE Transactions, 30*, 469-480.

de Koster, R. (2002b). Distribution structures for food home shopping. *International Journal of Physical Distribution & Logistics Management, 32*(5), 362-380.

de Koster, R., Le-Duc, T., & Roodbergen, K. (2006). *Design and control of warehouse order picking: a literature review.* RSM Erasmus University, Erasmus Research Institute of Management , Rotterdam.

de Vries, J., de Koster, R., & Stam, D. (n.d.). Aligning order picking methods, incentive systems, and regulatory focus to increase performance.

Dennis, A., Wixom, B., & Roth, R. (2012). *System Analysis & Design* (Vol. 5). New York, NY, U.S.A.: John Wiley & Sons.

Glock, C., & Grosse, E. (2012). Storage policies and order picking strategies in U-shaped order-picking systems with a movable base. *International Journal of Production Research, 50*(16), 4344-435.

Gu, J., Goetschalckx, M., & McGinnis, L. (2007). Research on warehouse operation: A comprehensive review. *European Journal of Operational Research*(177), 1-21.

Gu, J., Goetschalckx, M., & McGinnis, L. (2010). Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research, 203*, 539-549.

Gunasekaran, A., Marri, H., McGaughey, R., & Nebhwani, M. (2002). E-commerce and its Impact on Operations Management. *International Journal of Production Economics, 75*, 185-197.

Herring, S., Jones, B., & Bailey, B. (2009). Idea Generation Techniques among Creative Professionals . *Proceedings of the 42nd Hawaii International Conference on System Sciences.*

Jain, N., Gajjar, H., Shah, B., & Sadh, A. (2017). E-fulfillment dimensions and its influence on customers in e-tailing: a critical review. *Asia Pasific Journal of Marketing and Logistics, 29*(2), 347-369.

Jain, N., Shah, B., Gajjar, H., & Sadh, A. (2015). A Conceptual Framework for Measuring E-fulfilment Dimensions: A Consumer Perspective. *Journal of Internet Commerce*, 363-383.

Joong-Kun Cho, J. (2008). Logistic capability, logistic outsourcing and firm performance in a e-commerce martket. *International Journal of Physical Distribution and Logistics Management*, 336-359.

Kleijnen, J. (1995). Verification and validation of simulation models. *European Journal of Operational Research, 82*, 145-162.

Kunesova, H., & Micik, M. (2015). Development of B2C E-Commerce in Czech Republic after 1990. *Actual Problems of Economics, 5*(167), 470-480.

Lang, G. (2010). Multi-Channel Retail Supply Chain Management: Fulfillment systems in Multi-Channel Retailing - Customers Expectations and Economic Performance. *Strategy and Supply Chain Management* (pp. 1-25). Bordeaux: 8th International Research Conference in Logistics and Supply Chain Management (RIRL).

Leung, K., Choy, K., Siu, P., Ho, G., Lam, H., & Lee, C. (2018). A B2C e-commerce intelligent system for re-engineering the e-order fulfilment process. *Expert Systems With Applications*, 386-401.

Liu, Z., & Schonwetter, D. (2004). Teaching Creativity in Engineering. *International Journal of Engineering, 20*(5), pp. 801-808.

Marchet, G., Melacini, M., & Perotti, S. (2011). A model for design and performance estimation of pick-and-sort order picking systems. *Journal of Manufacturing Technology Management, 22*(2), 261-282.

Moeller, K. (2011, september 6). Increasing warehouse orderpicking performance by sequence optimization. *Procedia - Social and behavioral Sciences, 20*, 177-185.

Mohapatra, S. (2013). *E-Commerce Strategy.* New York: Springer.

Petersen, C. (1999). The impact of routing and storage policies on warehouse efficiency. *International Journal of Operations & Production Management, 19*(10), 1053-1064.

Petersen, C., Aase, G., & Heiser, D. (2004). Improving order-picking performance through the implementation of class-based storage. *International Journal of Physical Distribution and Logistics Management, 34*(7), 534 - 544.

Reimann, F., & Ketcher Jr., D. (2017, April 10). Power in Supply Chain Management. *Journal of Supply Chain Management, 63*(2), 3-9.

Ricker, F., & Kalakota, R. (1999). Order Fulfillment: The Hidden Key to e-Commerce Success. *Supply Chain Management Review*, 60-70.

Robertson, S. (2001). Requirements Trawlings: techniques for discovering requirements. *International Journal of Human-Computer Studies, 55*(4), 405-421.

Rochford, L. (1991). Generating and Screening New Product Ideas. *Industrial Marketing Management, 20*, 287-296.

Russell, M., & Meller, R. (2003). Cost and Throughput Modeling of Manual and Automated Order Fulfillment Systems. *IIE Transactions, 35*(7), 589-603.

Sargent, R. (1998). Verification and validation of simulation models. *Proceedings of the 1998 Winter Simulation Conference*, (pp. 121-130). Syracuse.

van der Veen, J., & Robben, H. (1997). Supply Chain Manangement: een Overzicht. *Nijenrode Mgmt. Review*, 62-75.

Whitten, J., & Bentley , L. (2007). *System Analysis & Design Methods* (Vol. 7). New York, NY, U.S.A.: McGraw-Hill/Irwin.

Xu, P. (2005). *Order Fulfillment in Online Retailing: What Goes Where.* Massachusetts Institute of Technology, Industrial Engineering and Management Sciences.

Yoon, C., & Sharp, G. (1996). A structured procedure for analysis and design of order pick systems. *IIE Transactions, 28*, 379-389.

Yuan Xing, D., Grant, A., & McKinnon, J. (2010). Physical distribution service quality in online retailing. *International Journal of Distribution & Logistics Management, 40*(5), 415-432.

Zhu, J. (2008). *Quantative Models for Performance Evaluation and Benchmarking* (3rd Edition ed.). Springer.

TU Delft Delft University of Technology

Nedcargo

Appendices

APPENDIX A: TRANSLATION OF THE METHODOLOGY

The framework of Baker and Canessa, on which the methodology for this research is based, has been translated to a framework applicable for this research. The translation has been explained in section 1.5. The visualisation of the translation is given in Figure 42.

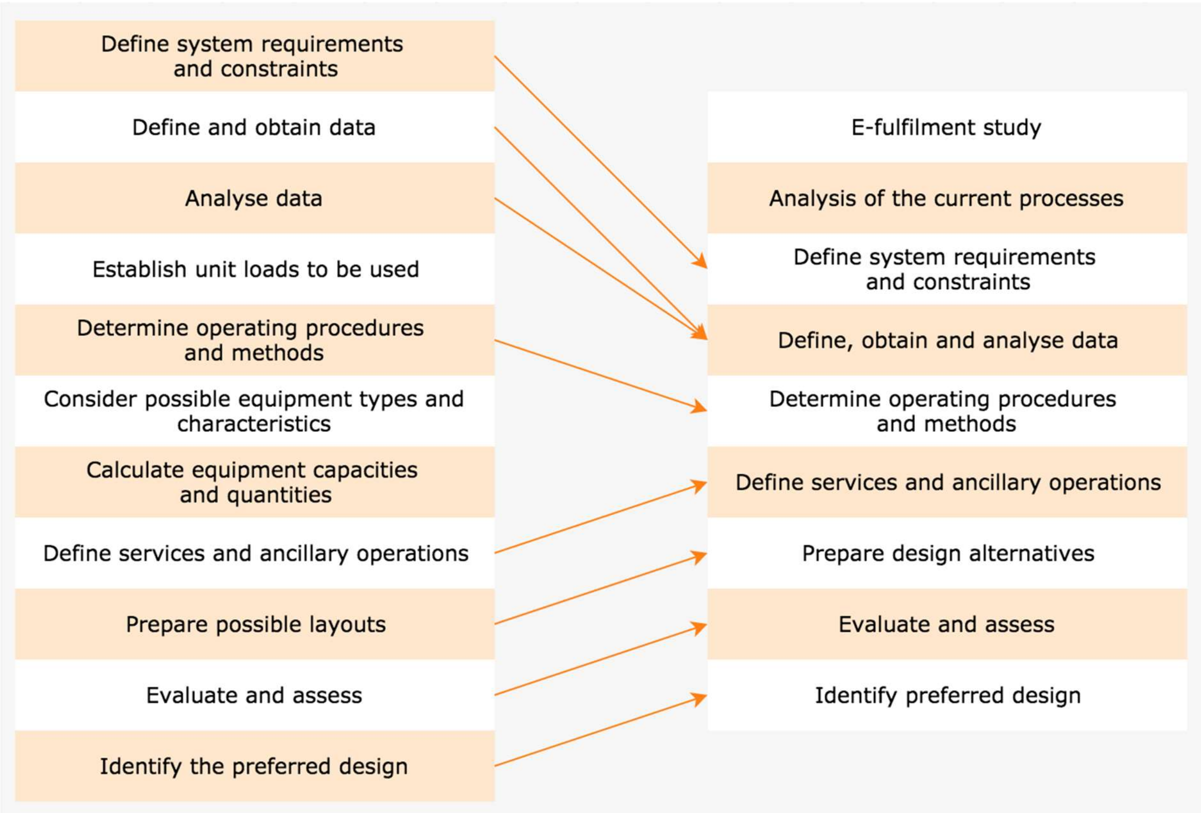


Figure 42: Translation of Baker and Canessa framework into methodology used for this research

Appendix B: Background information Nedcargo

Nedcargo International B.V. is a logistic service provider in the food, beverage and retail industry. The company has three divisions: Logistics, Forwarding and Multimodal. Nedcargo Logistics offers warehousing and distribution within the Benelux. It offers the collection from production location to the warehouses of Nedcargo, the warehousing itself, stock management and order processing as well as distribution to customers. Nedcargo Forwarding is specialized in the import and export of food, beverage and retail and the related business that comes with it, like customs, administration and temporarily storage. Nedcargo Multimodal offers diverse possibilities for container transport within the Benelux. With the exploitation of the inland terminals in Alphen aan de Rijn (Alpherium) and Willebroek in Belgium, where barging will act as an alternative to road transport, plays Nedcargo an important role in sustainable, environment friendly and reliable transport (Nedcargo B.V., 2017).

Background of Nedcargo

First, a little bit background information about the company 'Nedcargo'. Nedcargo, in its form it is nowadays, only exists from the first of June 2016. It all started in 1848 with a company named 'Van Uden', founded by the brothers Van Uden. They started with inland barging on the Rhine and after one and a half century grew to a large concern, which focused more and more on warehousing and distribution of retail, food and (alcoholic) beverage (Nedcargo B.V., 2017).

In 2000, Roderick de la Houssaye and Diederik Jan Antvelink founded Nedcargo International. In ten years the company has put itself on the market, specialized in expedition, international transport and container transport via road, air and water. Since 2002 Van Uden is working closely with Nedcargo International whereby Nedcargo took over a few of the activities performed by Van Uden (Nedcargo B.V., 2017).

It is 2011 when Nedcargo International takes over Van Uden. At that moment 'Van Uden – new style' has been born, a logistic service provider with over 450 employees. The motivation for the merge of the two companies was the synergy that would arise with it. This way, the client could be offered a wide, streamlined, international and multimodal package of services including warehousing, distribution, expedition and international transport. To make this all even livelier within the company, a new headquarters has been opened in 2012 in Waddinxveen (Nedcargo B.V., 2017).

Figure 43: Background of Nedcargo (Source: Nedcargo International B.V.)

The last step in this process of becoming Nedcargo is executed in 2016. On the first of June, Van Uden logistics, forwarding and multimodal receive the name of the mother company Nedcargo. Also, the company 'Eurobrokers' from Belgium that has merged with Nedcargo receives the name Nedcargo. Nowadays, you will still see the yellow and blue trucks of Van Uden, but slowly everything will change into the white and orange of Nedcargo (Nedcargo B.V., 2017).

Clients of Nedcargo

A few of the current clients of Nedcargo are stated below. These clients have different customers. Variating from large distribution centres of Albert Heijn and Jumbo, to smaller cafes or restaurants (Nedcargo B.V., 2017).

Figure 44: Part of the clients of Nedcargo

Appendix C: Receiving, Warehousing and Shipping

This appendix describes the main functions of the warehouse of Nedcargo that can contribute to general knowledge on the company, the warehouse and the order pick system. Three functions will be outlined, the receiving, the warehousing and the shipping.

Receiving

Nedcargo operates in food and beverage products, which are originating from the client of those products. Other inbound products can be cross dock pallets from other sites of Nedcargo and returned goods. Included in the receiving is the control of the received products. The process of inbound, unloading and controlling is outlined in Figure 45 and Figure 46. Before receiving the products from the client, Nedcargo has already received two types of information. The first is an 'ASN'-message, which is an advanced shipping notification and is send to Nedcargo, when the client has ordered raw materials for production at its supplier. The purpose of this notification is to inform about the products that are expected be send towards Nedcargo in a certain time period. The second type of information is a so-called DESADV, which confirms the products actually being send to Nedcargo. After receiving the products, Nedcargo sends a so-called RECADV to the client, confirming the received goods. All information sent between the client and Nedcargo are EDI, electronic data interchange, messages.

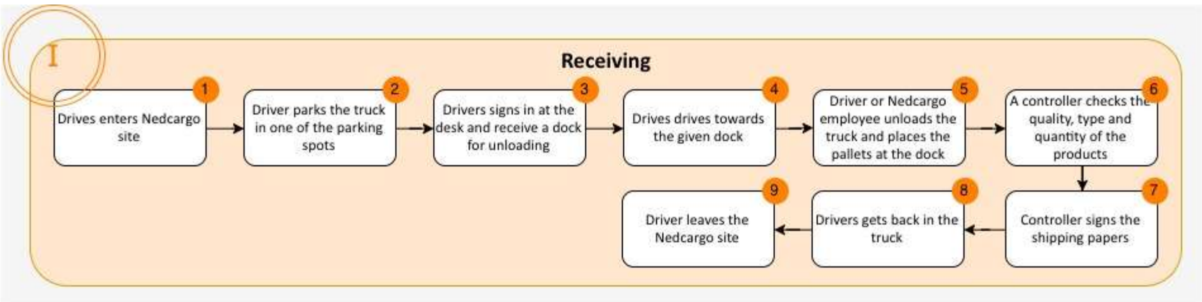


Figure 45: Process of function 'receiving'

Some causes for congestion, delay or other inconveniences in the receiving of the inbound pallets are listed below:

- If all docks are occupied, the truck driver has to wait.
- On site, there is little room for parking, implying that waiting trucks are inconvenient.
- An inbound operator needs to be available to unload the truck

The control can be executed in multiple ways. For some clients, automatic control is implemented. This implies that a quality check needs to be done by an operator but the pallets are automatically registered by scanning the so-called SSCC label. This is a 'serial shipping container code' and contains information about the products. These labels are uniform worldwide. A manual control is more time consuming, and hereby the controller needs to type in all information about the products, type and quantity. The manual process is explained in Figure 46. Some causes for congestion, delay or other inconveniences in the controlling of the inbound pallets are listed below:

- A controller needs to be available, otherwise the driver has to wait.
- Two controllers can go to the same dock for an assignment, resulting in one unnecessary movement.

- Manually typing all product information is time consuming
- The product type needs to be familiar with Nedcargo. In case a new product type is received and this product is not registered correctly on forehand, it can't be controlled and the clients will need to be contacted. The pallets will stay on the dock until this has been arranged.

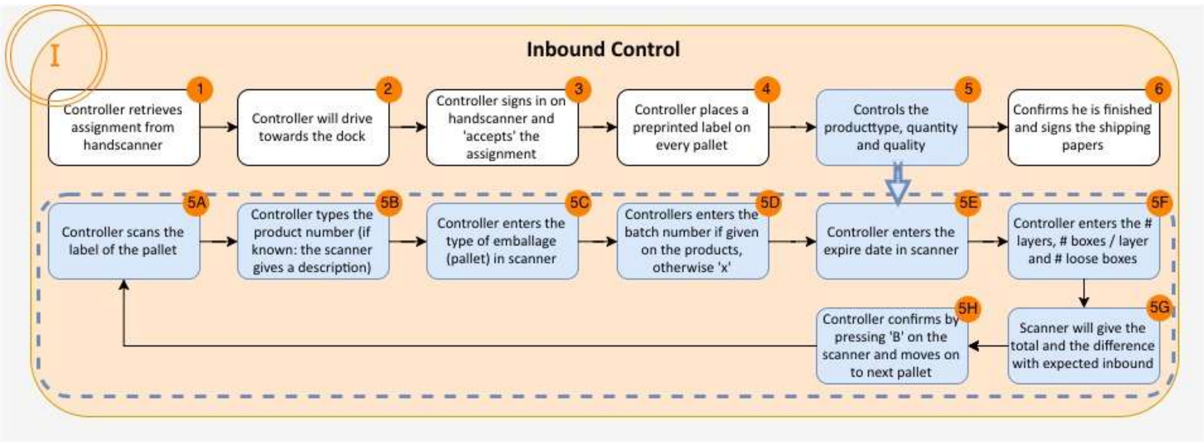


Figure 46: Process of sub function 'inbound control'

The 'receiving' process is finished with the update of the stock levels. The maximum inbound time in which Nedcargo needs to stock the products is between 4 to 6 hours, depending on the client.

Warehousing

Warehousing consist of the storage of inbound pallets and the replenishment of case pick locations. The warehousing activity is explained in Figure 47.

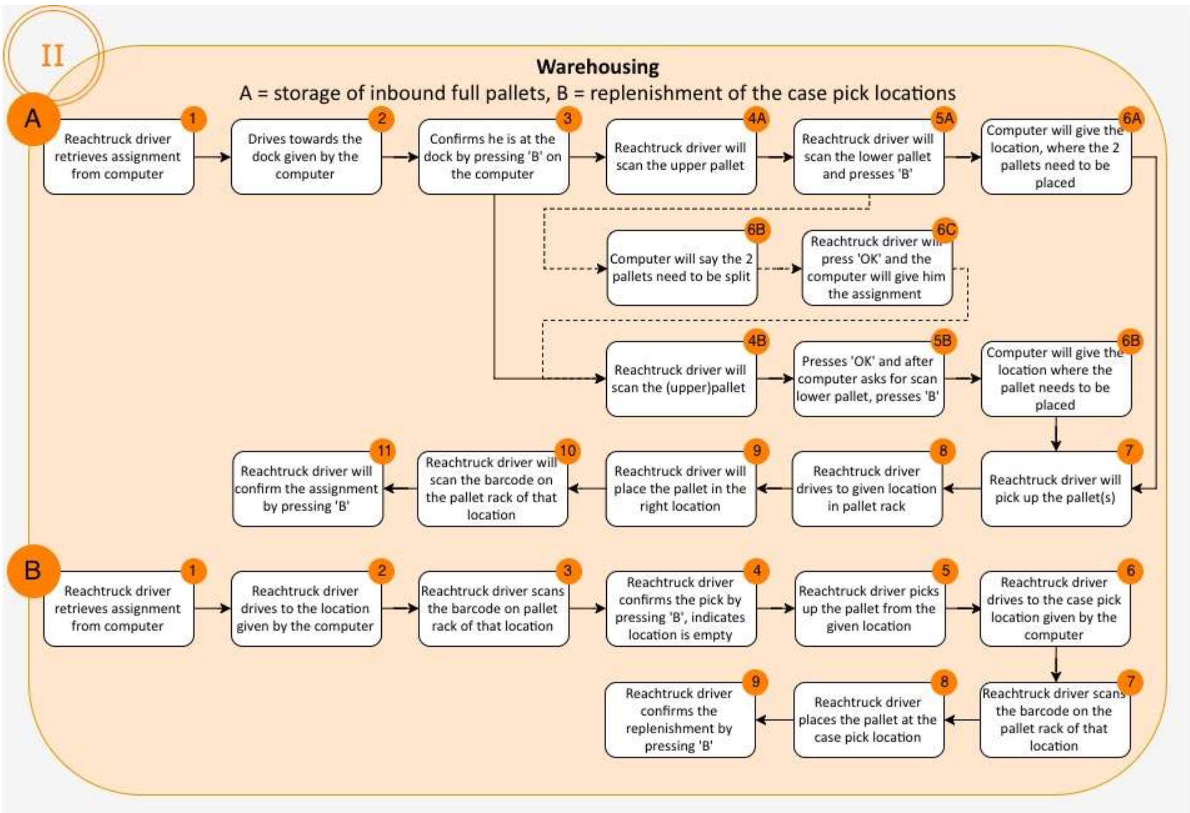


Figure 47: Process of function 'warehousing'

Causes for congestion, delay, pick flaws, risks or other inconveniences in the storage of inbound pallets and the replenishment of the pick locations are listed below:

- After scanning one pallet he can pick a different pallet, resulting in wrong pallet being moved.
- The location that is provided to the reach truck driver is configured as follows: '4 26 019 7'. This represents the 4th hall, the 26th path, the 19th vertical rack and the 7th level in the rack of which ground floor is level 1. Pallets can be placed on the wrong level.

Output: Shipping

The function 'shipping' consists of the control of the orders on product type, quantity and quality, the loading of the truck and distribution the orders to the customer. The process of controlling the outgoing order is given in Figure 48.

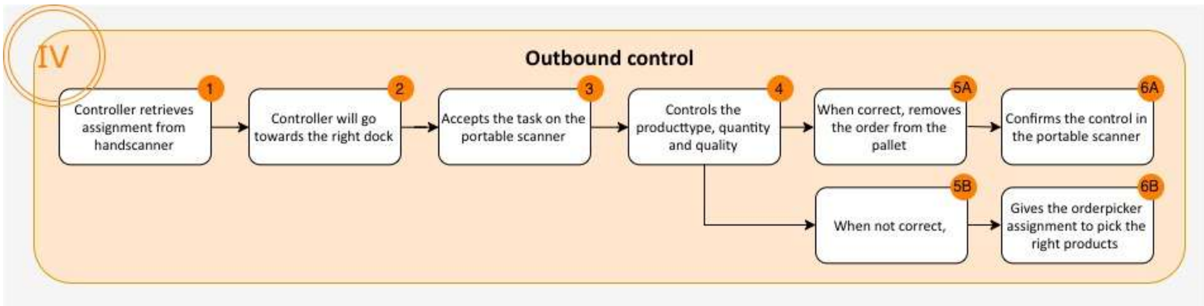


Figure 48: Process of sub function 'Outbound Control'

There are no risks in the process of controlling the products, but the task can be made very difficult. With different type of products and the different amount of the products the order picker has to think ahead about how to stack the products. For example, when a client wants its layers to be separated by a pallet. The lowest pallet will need hard and heavy products so that it can carry the other pallets. If these product types do not fill the complete layer, they will be placed mostly on the sides. The part in the middle of the pallet, can be filled with other products. When a new pallet is stacked on top of that with products and the whole pack is sealed, the controller can hardly see the products in the middle, let alone count them. Another example can be given when only picking wine boxes. Boxes in the middle of the pallet are hardly visible, let alone recognizable. This inconvenience is not present with the control of full pallet orders because a full pallet consists of one product type. Furthermore, the only risks are:

- A controller needs to be available, otherwise the process might be slowed down
- Two controllers can go to the same dock for an assignment, resulting in one unnecessary movement

The process of loading the truck and shipping is explained in Figure 49. Before sending the orders to the customers, Nedcargo sends a DESADV message to the customer and the client. This message confirms the order being processed and gives the date and time window in which the order will be delivered. After having delivered the orders at the customer, Nedcargo sends a RECADV to the client to confirm the delivery. At last, Nedcargo sends an invoice to the client for the service. It is the clients' responsibility to forward these costs to its customer.

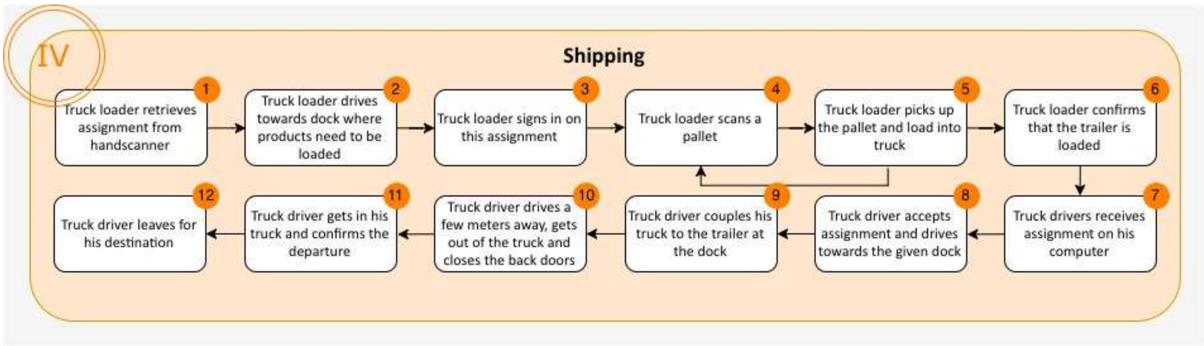


Figure 49: Process of function 'shipping'

Causes for congestion, delay, pick flaws, risks or other inconveniences in the picking of case pick orders are listed below:

- The truck loader can forget to scan a pallet before loading. This will only be noticed at the end of loader, resulting in unloading and rechecking all pallets again.
- Loading is a precise job and in many containers hardly no light is present.

Appendix D: Analysis E-fulfilment centres

Since knowledge on e-fulfilment and e-fulfilment order pick system had to be gained for this research, five companies have been analysed, of which of four a broad analysis is provided in this appendix.

Company description and motivation for selection

Three out four analysed companies have provided a tour in their warehouse to see the activities with own eyes. A fifth warehouse to which a visit has taken place, not included in this analysis, is the fulfilment centre of Greetz. The company Greetz creates personalized gifts, which are designed and ordered on their website by the messenger and delivered at the home of the receiver. Greetz adds value to every order they process. The warehouse process of Greetz is not suitable for the analysis of warehouse systems, mechanisms and equipment, however it can in the detailed design stage be used for the process of adding company branding and other value added services.

Bol.com

Bol.com is a webshop with around 10 million different products. Besides new products, it is also a platform for second-hand sales. The fulfilment company Docdata, located in Waalwijk, fulfils the warehouse operations of Bol.com. Docdata handles the warehouse operation of multiple companies, of which Bol.com is the largest. Bol.com has reached revenue of over 1 billion euros in 2016. The average order size of bol.com is between 1 and 2 products per order. Useful insight in fulfilment processes can be gained because this warehouse has automated some parts of the process, while other parts are still done manually. Also the difference in dimensions and types of products processed at Bol.com is comparable with products of Nedcargo.

Picnic

Picnic is an app-only grocery store and delivers to consumers at home. The supermarket is founded in 2015 and is expanding its operational area quite fast. Picnic has two fulfilment centres, one in Nijkerk and one in Utrecht. The fulfilment centre in Utrecht is the newest and largest warehouse. Picnic has two different fulfilment streams, one for non-cooled products and one for cooled and frozen products. Advantages for analysing this fulfilment centre is the similarity in products, the fact that they are still quite small but growing immensely and they are very open about their processes, techniques, systems and data. This also resulted in a visit to the fulfilment centre

PostNL

PostNL is mostly familiar from the distribution of packages, but in the fulfilment centre in Houten PostNL processes the e-commerce orders of multiple clients. The fulfilment centre still handles all the orders manually supported by mechanisms and digital registering of the process. In April 2017, they started with tested the AutoStore, an automated fulfilment system. Every month one client will be added to this system. The analysis, which has been performed, is about the old or current situation in which the orders are processed manually. Information about processing orders from different clients and adding clients-specific branding is what can be gained from this analysis.

Webshopservice Nederland (WSSN)

Webshopservice Nederland is an e-fulfilment company located in Nieuwveen. It started as a company who distributed all the travel magazines for multiple travel companies. Since this sector is decreasing, it has changed its target group to e-fulfilment for smaller companies and webshops. They have around 80 clients differing from clothes, to household products, to barbecues or magazines. WSSN applies a 100% order accuracy, since they believe that the only way to survive in this sector and having so many different clients, the order accuracy is the most important aspect. Some work is even done twice to ensure this.

Summary of the analysis

The analysis is split into the warehouse activities found during the research. Each activity can consist of multiple steps. Not all companies perform all the activities shown. In this case the cell will be given the notation 'Not applicable'. When the reason for not performing this activity is not straightforward or cannot be derivate from the analysis, an explanation is given in the same cell. The analysis starts at the inbound of the products and ends at the outbound, even though some of the activities are outside the scope. This is because the activities are linked to each other and the output of one activity is the input of the other activity. A better understanding is gained by the elaborate analysis. The complete analysis and all steps performed per warehouse are given in paragraph 2.4 of this appendix, Table 25, Table 26, Table 27 and Table 28. A summary of the analysis is given in the Table 24.

Table 23: Summary of the process descriptions of four e-fulfilment centres

	Bol.com	Picnic	PostNL	WSSN
Input	Pallets, roller cages and boxes	Roller cages and boxes	Pallets, roller cages and boxes	Pallets, roller cages and boxes
Output	Boxes with products	Totes with products	Boxes with products	Boxes with products
Pick system	Picker-to-parts	Picker-to-parts	Picker-to-parts	Picker-to-parts
Sort system	Sort-after-pick	Sort-while-pick	Sort-while-pick	Sort-while-pick
# Products per order	1-2	± 26	± 5	± 4
# Orders per pick	Between 50 and 100	12 or 18	Max 8	8 or 12
# Storage areas	2	1	2	2
# Piece storage area policy	*Family grouping*	Dedicated	Class-based/Family grouping	Class-based/Random
Process description of the fulfilment centres				
Unloading truck	Manually (1)	Manually	Manually (1)	Manually (1)
Control input	Manually	Manually	*Manually*	Manually
Bulk storage and retrieval	*Manually (1)*	N/A	Manually (1)	Manually (1)
Unpacking input	Manually	Manually	Manually	Manually
Unstack the bulk	Manually	Manually	Manually	Manually

Place product/case in tote	Manually	N/A	N/A	Manually
Place product/tote in storage	Manually	Manually	Manually	Manually
Pick product/tote from storage	Manually	Manually	Manually	Manually
Place product in box/tote	Manually	Manually	Manually	Manually
Place products in sorting machine	Manually	N/A	N/A	N/A
Sort the products per order	Automatically	N/A	N/A	N/A
Control of picked products	N/A	N/A	Manually	Manually
Pack the picked products	Automatically and manually (3)	N/A	Manually	Manually
Place label on the box	Automatically and manually (3)	N/A	Manually	Manually
Place products in sorting machine	Automatically and manually (3)	N/A	N/A	N/A
Sort the products on postal code	Automatically	N/A	N/A	Manually
Product /box in transport device	Manually	Manually	Manually	Manually
Seal the transport device	*Manually*	N/A	Manually	Manually
Place label on transport device	*Manually*		N/A	N/A
Place transport device in truck	Manually	Manually	Manually	Manually (1)

* When the content of a cell is written italic, it is not sure whether this activity is performed in that specific way or is performed at all. An assumption is made.
*(1): In case of pallets, lifting equipment supports the employee. In case of loose boxes, a movable conveyor belt is shifted into the truck, close to the boxes.
*(2): When a capacity increase is necessary, employees perform the activities manually as well. However, the workstations are designed in such manner that the employees do not have to carry anything.
*(3): With orders consisting only of one product, the packing, labelling and transport to sorting machine are done automatically. When an order consists of multiple products, these products first need to be consolidated. Afterwards, employees will perform the following steps, packing, labelling and placing in the sorting machine.

Amount of storage area(s)

All the fulfilment centres analysed, have full pallets or roller cages with cases, consisting of multiple products, as input. Three companies have two types of storages, the bulk storage consisting of pallets, roller containers or boxes, and the storages for items or cases. Only Picnic officially has one storage location, but they have a buffer for the products that do not fit in the item storage, which can be seen as bulk storage. Secondly, the input of Picnic is only roller containers with cases of different products and not many cases of the same product. Thirdly, Picnic does not provide the service of warehousing, which PostNL, Bol.com and WSSN do.

Level of automation

At Picnic, PostNL and WSSN all steps are performed manually with support of machines and IT mechanisms. At Bol.com, the picking is done manually, but the sorting is done automatically. Also Bol.com has a few automatic packing stations, but this depends on the order size and the product dimensions.

Order picking methods

All four e-fulfilment centres apply a *'picker-to-parts'* method. Only Bol.com has some parts automated, namely the sorting process and the packing process. The actual order picking is done manually.

Storage strategies

At PostNL, the area is split per client of PostNL because a customer's order will always be per clients. There is no specific policy applied within each zone, mainly because the picked products are repacked in different packing material for delivery so there is no need for a specific sequence, also because the client zones are relatively small so no large mistakes in routing can be made. The zoning on client can be seen as class-based zoning. Picnic has a dedicated storage policy because they work with food and beverage product, which are quite fragile, and because the totes in which the products are placed after picking are also the totes in which the products are delivered. Picnic sorted the area from heavy to light and within these zones from liquid to dry. This results in heavy products never crushing light products and liquid products never leaking over dry products. The zoning policy of bol.com is not completely known, they have five floors with each 40 shelves, but because of the sorting and consolidation after the picking, zoning is not really necessary. Probably, they have sorted their area on category like books or sports items, because they expand their assortment always with a complete new category. However, this is an assumption. WSSN places the products once in a while in a class-based strategy, the replenishments and returns are places on the first empty spot in the shelve.

Zoning strategies

At Picnic, no zoning strategy is applied. One order picker collects all the items belong to one order and walks every pick lane to collect the correct items, therefore splitting the order over different order pickers would be inefficient. At PostNL the pick areas are split per client and one order picker will pick the orders of that clients, so also no zoning is applied. Bol.com has a different type of process, because the route the order picker is given, is determined on the location of the products, therefore if one order contains two items which are not closely situated near another, the order will be split over multiple pickers and will after picking be sorted and consolidated. Therefore, it can be said that bol.com applies *'parallel picking'*. WSSN also does not apply a zoning strategy.

Picking strategies

All existing fulfilment centres analysed in this research use the batch order picking policy. At PostNL between 1 and 8 orders are collected within one route. Picnic has carts for 12 or 18 orders within one route WSS picked between 8 and 12 orders per pick route and Bol.com lets an order picker pick between 50 or 100 products in one route, which all can be from different orders.

Sorting strategies

Picnic and PostNL use the sort-while-pick-policy. At Picnic and PostNL, the products are picked, scanned and the hand scanner will provide in which tote the product needs to be placed. At WSSN, the products are sorted during picking, but the tote in which the products needs to be placed is given on the pick order. No control is taking place during picking, afterwards a 100% control procedure is performed. Only Bol.com has a pick-and-sort-policy because the average order size is between 1 or 2 products and items on one order can be split among different order pickers.

Routing methods

At Picnic the *'transversal'* method is applied. The routing method used at PostNL, Docdata and WSSN are unknown. It is expected, and therefore assumed, that the transversal or return method is applied. Especially at PostNL and WSSN, since the pick zones are relatively small and therefore a routing heuristic does not have a large effect. It can also be that no routing method is applied. This mostly results in a *'transversal'* or *'return'* method, or a combination of these two, the *'combined'* method.

Valuable discoveries

This analysis provides some valuable discoveries per decision step, which help with making design decisions and design alternatives. These valuable discoveries are stated in Table 24 and will be used to form requirements in chapter

The amount of storage area(s)
1) All companies analysed with bulk input and parcel orders as output, have two types of storage areas: the bulk storage and the case or piece storage.
The zoning policy for the storage area(s)
1) When multiple clients are situated in a warehouse and orders are per clients, it is useful to zone the picking are into zones per client
2) Food and beverage products have an expiry date, implying a first-in first-out policy needs to be applied with order picking and replenishment
3) Repacking the products, or picking the products directly into the transport device can have influence on the zoning policy
4) Place products of the same type near each other, because they are often ordered at the same time
5) The picking order of products with differences in dimensions and weights need to be taken into account.
6) Zoning the area into fast moving and slow moving products can reduce the travel times and with that the lead times
The order picking strategy
1) Parallel is useful when orders consist of items that are not nearly situation to one another
2) Sequential eliminates the step of consolidation
3) When the order picker is walking done all the aisles, parallel order picking is not necessary.
The order picking policy
1) When the amount of products per order and the dimensions of these products allow it, batch picking is a very effective method for order picking.
2) The amount of orders in a batch, depends on the amount of products per order
The sorting policy
1) A sorting policy is only necessary when batch picking is applied
2) The effectiveness of the policy is dependent on the amount of products per order picked

Table 24: Valuable discoveries from e-fulfilment centre analysis

Analysis of the warehouse process

The steps in the warehouse processes identified during this research, together with how they are performed are given per company in the following tables. In Table 25 the process description of the warehouse activities at the Bol.com fulfilment centre of Docdata in Waalwijk is given.

Process description of the warehouse activities at the Bol.com (Docdata) fulfilment centre in Waalwijk, semi-automated piece picking *In this analysis: large items that cannot be carried by hand are excluded*	
Unloading truck	1. Full pallets, roller cages and loose boxes are unloaded from the truck by employees supported by forklift trucks and movable conveyor belts.
Control input	2. The input is controlled manually
Bulk storage and retrieval	3. When loose boxes or boxes on roller cages need to go into the bulk storage, they will be palletized first 4. The pallets will be brought to and placed in the bulk storage with a reach truck It is unknown which scans take place for registering the location of the pallet.
Unpacking input	*How this activity is performed is unknown, but it is expected that the unpacking happens after retrieving the pallets from the bulk storage and is done manually*
Unstack the bulk	5. The boxes are unstacked from the pallets or roller cages and placed onto a conveyor belt to the unpacking station
Place product/case in tote	6. At the unpacking station, an employee unpacks the boxes and placed the products loose in plastic totes.
Place product/tote in storage	7. An employee will place the products from the totes into the shelves of the piece picking area 1. How the employee knows where to put these products and how this location is registered is unknown.
Pick product/tote from storage	8. An employee requests an assignment from the portable scanner. The assignment will consist of around 100 products from multiple orders and is based on the shortest route. 9. He or she will collect a large tote in which all the picked pieces will be placed. 10. The portable scanner will mention the location of the product and a description of the product 11. The employee will go to this certain location and scans the product
Place product in box/tote	12. The employee will place the product in the tote, together with the other products her or she has picked during this round.
Place products in sorting machine	13. He or she will bring the tote to the sorting machine 14. Two other employees will take the products one by one and place them on a moving conveyor with the barcode up.
Sort the products per order	15. The sorting machine will scan the product and the barcode stated on that part of the conveyor belt and will link the product tot that location. 16. The bottom of the conveyor can open up whereby the product will fall down. The sorting machine will do this at the moment the conveyor belt is above the tote dedicated for that order. This way, multiple products, which are ordered in one order, can be consolidated. 17. If the system recognizes that the product is the only product in an order, it can send the product to the automatic packing and stamping machine. This is also dependent on the capacity of that machine. 18. At the location of the order-consolidation tote, a screen will show whether all products are located in the box and are ready for packing.
Control of picked products	*Not applicable*
Pack the picked products	19. The products in the order-consolidation totes need to be packaged manually. The computer will provide information about which box needs to be chosen for this order.
Place label on the box	20. A label will be placed on the box. It seems that these labels (actually envelopes) are also sorted in the sorting machine, in the same way as the products are.
Place products in sorting machine	21. The box will be placed on a conveyor belt with the label upwards which will bring the box to another sorting machine.

Sort the products on postal code	22. A sorting machine will sort the boxes automatically on postal code and shifts the boxes down from the main conveyor onto side conveyors. The side conveyor ends at the stacking station.
Place case/ box in transport device	23. An employee places all the boxes on roller cages or on pallets.
Seal the transport device	24. The pallets are sealed with foil; the expectation is that this is done manually. Whether the roller cages are sealed is not known.
Place label on transport device	25. Whether a label is placed on the roller cages and pallet is unknown. It is expected that if performed, this is done manually
Place transport device in truck	26. The roller cages, pallets (and probably also loose boxes) are placed manually in the truck. In case of pallets a forklift truck is used and in the case of loose boxes a movable conveyor is placed insight the truck.

Table 25: Process description of the warehouse activities at the Bol.com (Docdata) fulfilment centre in Waalwijk

Table 26 provides the same process for the warehouse activities of Picnic fulfilment centre in Utrecht. This warehouse has been visited during the analysis phase of the research.

	Process description of the warehouse activities at the Picnic fulfilment centre in Utrecht, manual piece picking
Unloading truck	1. Roller cages are unloaded from the truck by employees and placed at the receiving dock.
Control input	2. The products are controlled manually when placed in the piece pick area
Bulk storage and retrieval	*Not applicable: there is only a buffer area for when the piece pick storage is full, but it is not meant that this buffer area is standardly used.*
Unpacking input	3. An employee removes the foil of the roller cages manually when the roller cages are unloaded from the truck and placed at the dock.
Unstack the bulk	Not applicable
Place product/case in tote	Not applicable
Place product/tote in storage	4. An employee will scan the upper product in the roller cage (when still located at the dock) with a portable scanner. The scanner will give the location of the pick area where this product is located. 5. An employee will place the roller cage in the replenishment aisle near the pick area location of the product. The floor has painted squares with numbers on it, which indicate a certain rack location. 6. An employee will scan the product and the barcode of the shelf that is given by the scanner. 7. The employee will unpack the products from their cases and places them loose on this shelf. 8. When finish with that product, the employee will scan the next product and will move the roller cage to that location. He will repeat number 7 to 9 until the roller cage is empty.
Pick product/tote from storage	9. An employee requests an assignment from the portable scanner. 10. He or she will scan a cart of 12 or 18 totes and the scanner will give him a certain assignment. The scanner will give the first product, location of the product and total to-be-picked quantity. 11. The employee will scan the product and one of the totes. This will let the system link an order for which that product is needed to that specific tote.
Place product in box/tote	12. He will place the product in the tote. 13. If multiple items of that product are needed he will scan another one. 14. The system will either give him the tote he will need to put it in or will ask him to scan an empty tote, which will create a new link between an unlinked order and a tote. 15. When all items of the product are picked, the scanner will give the next location and the process will be repeated. The products are sorted on heavy first and light last and on the risk of breakage. Every order picker will walk the exact same route.
Place products in sorting machine	*Not applicable*

Sort the products per order	*Not applicable*
Control of picked products	*Not applicable*
Pack the picked products	*Not applicable: insight the totes are three plastic bags. The totes will be transported to the customer's home where the customer will receive the plastic bags and the totes will be returned to the vehicle.*
Place label on the box	*Not applicable: the totes have a barcode, which is linked to a specific order at the moment the first products has been picked.*
Place products in sorting machine	*Not applicable*
Sort the products on postal code	*Not applicable: the 12 to 18 orders received by an order picker are already sorted on postal code and deliver time frame by the system*
Place case/ box in transport device	16. An employee will scan a tote, after which the system will give the loading dock it needs to go to, the electric vehicle rack it needs to go in and the position in the rack. All 12 or 18 orders will go into the same rack, so only the position will change between these totes.
Seal the transport device	*Not applicable*
Place label on transport device	*Not applicable*
Place transport device in truck	17. The racks, equipped with wheels, are placed in a truck manually. First they will be shipped to the smaller in town crossdock centres, where each rack will be placed in small electrical vehicle, which bring the groceries to the customers. These vehicles can handle 36 orders, so each rack can consist of 36 totes

Table 26: Process description of the warehouse activities at the Picnic fulfilment centre in Utrecht

In Table 27, the process description of the warehouse activities of the PostNL fulfilment centre in Houten is provided. This warehouse has been visited in the begin stage of the research.

	Process description of the warehouse activities at the PostNL fulfilment centre in Houten, manual piece picking
Unloading truck	1. Full pallets, roller cages and loose boxes are unloaded from the truck by employees supported by forklift trucks.
Control input	2. The input is controlled manually
Bulk storage and retrieval	3. When loose boxes or boxes on roller cages need to go into the bulk storage, they will be palletized first or placed on ground floor level underneath the pallet rack. 4. The pallets will be brought to and placed in the bulk storage with a semi-automated crane. An employee drives the crane but when on a path between two pallet racks, it can only move forwards, backwards, up and down and not to the sides. This lowers the risk of collision and therefore allows smaller paths. On the area where the crane can switch to another path, the crane is fully under control of the driver, but its maximum speed is lowered. It is unknown which scans take place for registering the location of the pallet.
Unpacking input	*How this activity is performed is unknown, but it is expected that the unpacking happens after retrieving the pallets from the bulk storage and is done manually.*
Unstack the bulk	5. The boxes are unstacked from the pallets or roller cages manually
Place product/case in tote	Not applicable
Place product/tote in storage	6. An employee will place the products from the box into the shelves of the piece picking area. How the employee knows where to put these products and how this location is registered is unknown.
Pick product/tote from storage	7. An employee requests an assignment from the portable scanner. The assignment will consist of maximum 8 orders and is separated per client of PostNL. The rout is based on the shortest route.

	8. He or she will collect a rack with 8 totes. Each tote representing one order. 9. The portable scanner will mention the location of the product, a description of the product and the to-be-picked amount. 10. The employee will go to this certain location and scans the barcode on the shelf of the location of the product. He will pick the product(s).
Place product in box/tote	11. The employee will then scan the tote, given by the portable scanner and place the product(s) in the correct tote. 12. Next, he will go on towards the following given location. The amount of products that are placed in the tote is not controlled in this stage. 13. When the order picker is finished he will bring the rack with the totes to the packing station.
Place products in sorting machine	Not applicable
Sort the products per order	Not applicable
Control of picked products	14. The employee at the packing station controls the picked products manually. He or she prints the delivery note with the products on it and checks whether all products are present and in good state.
Pack the picked products	15. The products are placed in a box manually. The delivery note is added inside the box. Because all orders are per client, it is possible to pack the orders in special boxes of that client.
Place label on the box	16. The employee places a label on the box. 17. The box is placed on a conveyor belt, which will transport it to the stacking area at the dock.
Place products in sorting machine	Not applicable
Sort the products on postal code	Not applicable: *all the packages are brought to the sorting centre in Utrecht, from where it will be distributed.*
Place case/ box in transport device	18. An employee places all the boxes on roller cages
Seal the transport device	19. Whether the roller cages are sealed with foil is not known. If this is done, it is expected to be done manually.
Place label on transport device	20. Whether a label is placed on the roller cages is unknown. It is expected that if performed, this is done manually
Place transport device in truck	21. The roller cages are placed manually in the truck.

Table 27: Process description of the warehouse activities at the PostNL fulfilment centre in Houten

In Table 28, the process description of the warehouse activities of Webshop Service Nederland are given. This warehouse has provided a visit, during the conceptual design stage of the research.

Process description of the warehouse activities at the Webshop Service Nederland (WSSN) fulfilment centre in Nieuwveen, manual piece picking	
Unloading truck	1. Full pallets, roller cages and loose boxes are unloaded from the truck by employees supported by forklift trucks.
Control input	2. The input is controlled manually
Bulk storage and retrieval	3. When loose boxes or boxes on roller cages need to go into the bulk storage, they will be palletized first or placed on ground floor level underneath the pallet rack. 4. The pallets will be brought to and placed in the bulk storage with a reachtruck. It is unknown which scans take place for registering the location of the pallet.
Unpacking input	*How this activity is performed is unknown, but it is expected that the unpacking happens after retrieving the pallets from the bulk storage and is done manually.*
Unstack the bulk	5. The boxes are unstacked from the pallets or roller cages manually
Place product/case in tote	Not applicable
Place product/tote in storage	6. An employee will place the products from the box into the shelves of the piece picking area. The location is given on the replenishment order, on paper. A confirmation on whether it is placed at the correct location is not provided.

Pick product/tote from storage	7. An employee receives an assignment from the team leader (on paper). The assignment will consist of maximum 8 orders and is separated per client of WSSN. The route is based on the shortest route. 8. He or she will collect a rack with 8 totes. Each tote representing one order. 9. The pick order (on paper) will mention the location of the product, a description of the product and the to-be-picked amount. 10. The employee will go to this certain location, checks the barcode of the product and compares these with the code on the pick order. He will pick the product(s).
Place product in box/tote	11. The employee will then place the product(s) in the tote number stated on the paper. 12. Next, he will go on towards the following given location. 13. When the order picker is finished he will bring the rack with the totes to the control station.
Place products in sorting machine	Not applicable
Sort the products per order	Not applicable
Control of picked products	14. The employee at the packing station controls the picked products manually. He or she picks every product, scans it and places it in the transport device (box) and checks whether all products are present and in good state.
Pack the picked products	15. The products are placed in a box manually. The delivery note is added inside the box.
Place label on the box	16. The employee places a label on the box. 17. The box is placed on a conveyor belt, which will transport it to the sorting and stacking area.
Place products in sorting machine	Not applicable
Sort the products on postal code	18. The boxes are sorted on distributor and placed on a pallet. 19. When the pallet is complete, all boxes will be checked ones more and placed on another pallet, to make sure the correct boxes go with the correct external distributor
Place case/ box in transport device	Not applicable
Seal the transport device	20. Whether the roller cages are sealed with foil is not known. If this is done, it is expected to be done manually.
Place label on transport device	21. Whether a label is placed on the roller cages is unknown. It is expected that if performed, this is done manually
Place transport device in truck	22. The roller cages are placed manually in the truck.

Table 28: Process description of the warehouse activities at the Webshop Service Nederland fulfilment centre in Nieuwveen

APPENDIX E: DESIGN ALTERNATIVES

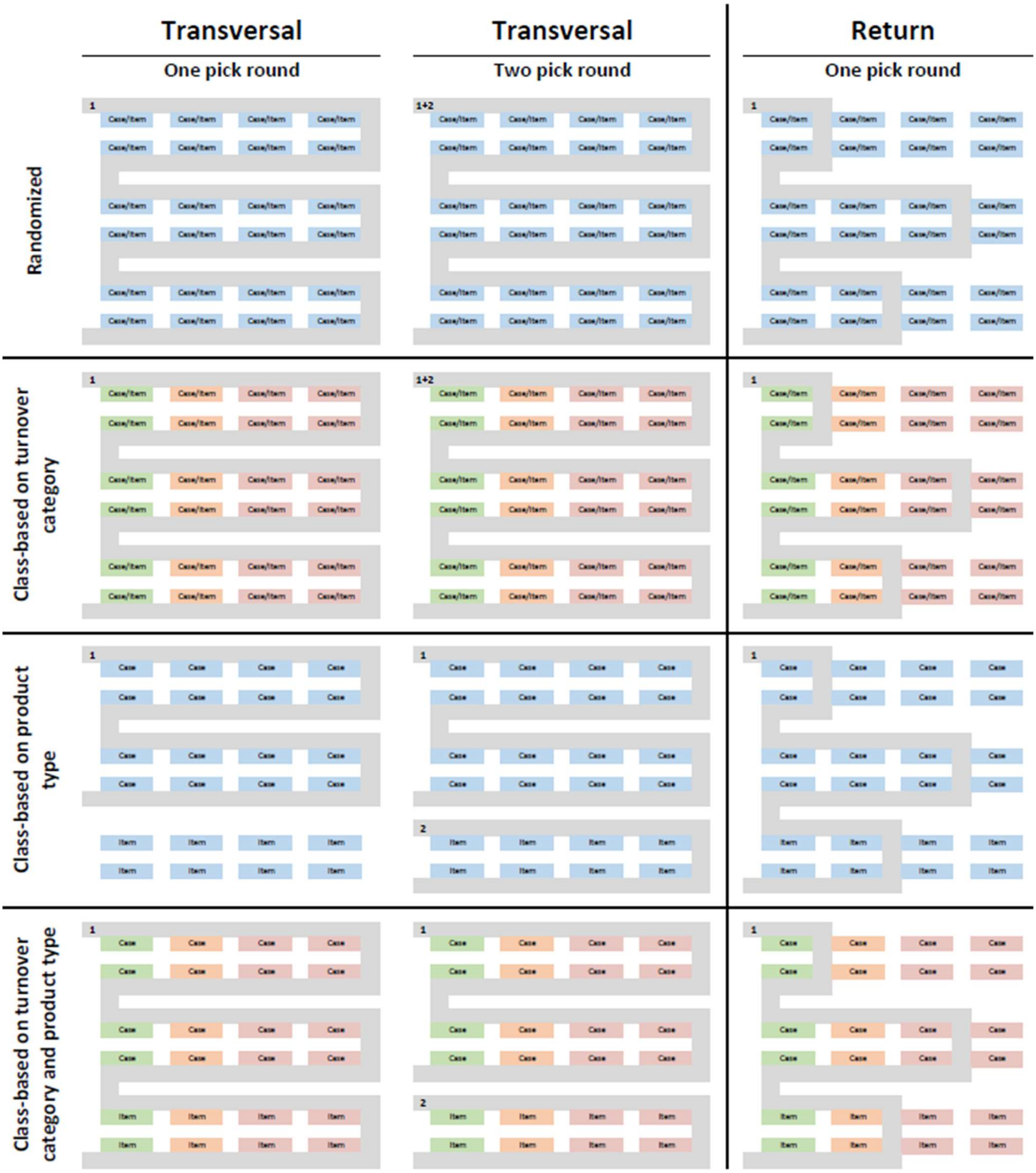


Figure 50: Visualization of design alternatives (part 1)

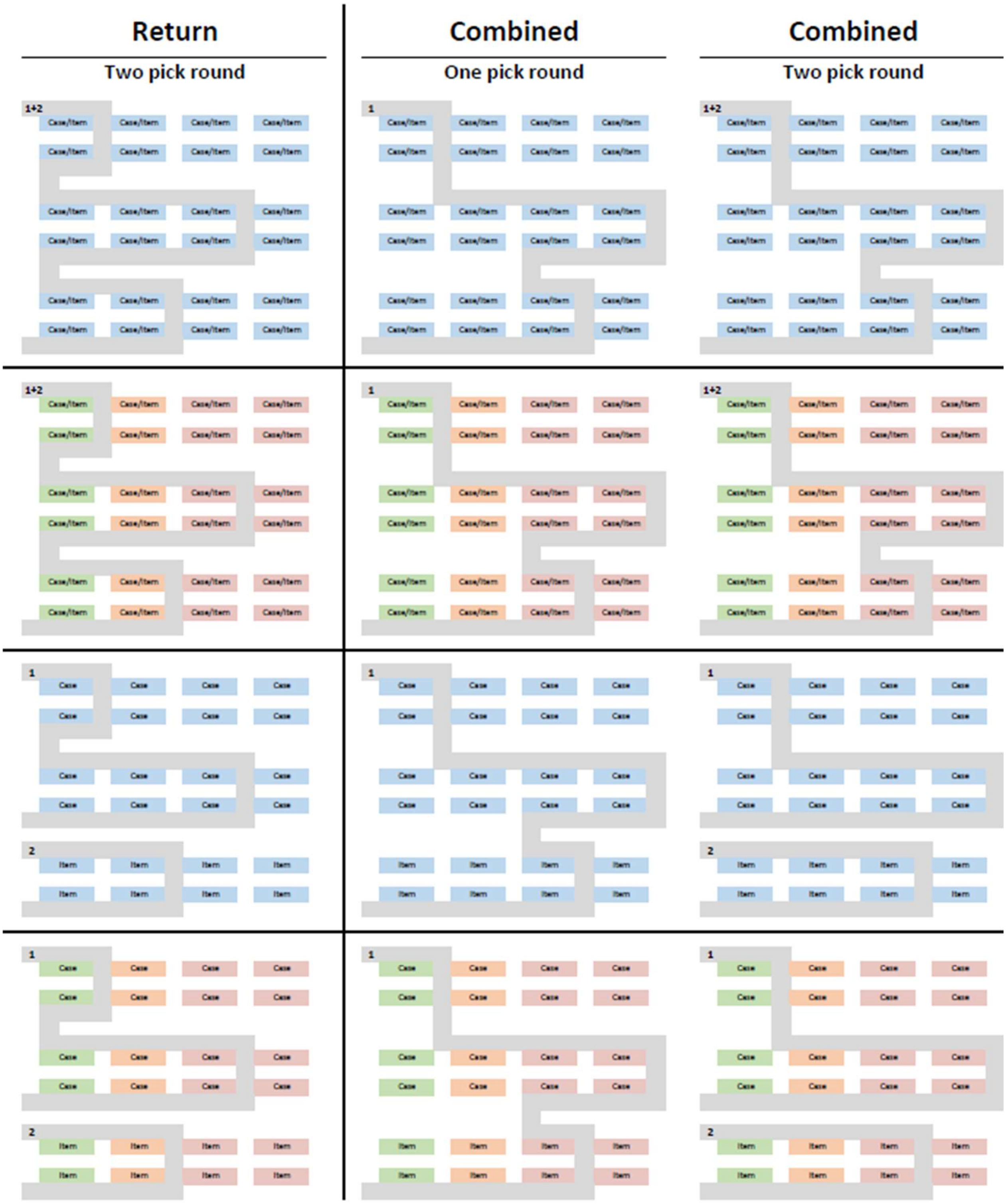


Figure 51: Visualisation of design alternatives (part 2)

APPENDIX F: INPUT TABLES FOR THE SIMULATION MODEL

This appendix provides all tables with input data used in the simulation model. These tables represent the distribution in turnover category, the probability of the amount of SKUs per turnover category, the probability of the order configuration per turnover category and the picking times per order configuration.

Table 29: Turnover category distribution over the orders

Order type	Meaning	Proportion (%)
A	Order consisting of only fast-moving product types	68,1
B	Order consisting of only medium moving product types	2,9
C	Order consisting of only slow-moving product types	0,9
AB	Order consisting of fast and medium moving product types	22,0
AC	Order consisting of fast and slow-moving product types	1,7
BC	Order consisting of medium and slow-moving product types	0,7
ABC	Order consisting of fast, medium and slow-moving product types	3,7

Table 30: Order definition: amount of SKUs per turnover category

Entity Definition: Turnover category						
Turnover Category	Amount of SKUs	% of orders	Cumulative probability	Stops at A	Stops at B	Stops at C
A	1	32,8	0,328	1	0	0
A	2	15,2	0,226	2	0	0
A	3	11	0,211	3	0	0
A	4	9	0,219	4	0	0
A	5	7,2	0,224	5	0	0
A	6	6	0,243	6	0	0
A	7	4,7	0,25	7	0	0
A	8	3,4	0,241	8	0	0
A	9	2,6	0,243	9	0	0
A	10	1,6	0,192	10	0	0
A	15	6,5	1	15	0	0
B	1	59,7	0,597	0	1	0
B	2	9,7	0,24	0	2	0
B	3	6,5	0,211	0	3	0
B	4	5,3	0,219	0	4	0
B	5	4,2	0,224	0	5	0
B	6	3,6	0,243	0	6	0
B	7	2,8	0,25	0	7	0
B	8	2	0,241	0	8	0
B	9	1,5	0,243	0	9	0
B	10	0,9	0,192	0	10	0
B	15	3,9	1	0	15	0
C	1	60	0,6	0	0	1
C	2	9,2	0,231	0	0	2
C	3	6,5	0,211	0	0	3
C	4	5,3	0,219	0	0	4
C	5	4,2	0,224	0	0	5
C	6	2,6	0,243	0	0	6
C	7	2,8	0,25	0	0	7
C	8	2	0,241	0	0	8
C	9	1,5	0,243	0	0	9
C	10	0,9	0,192	0	0	10

C	15	3,9	1	0	0	15
AB	1	0	0	0	0	0
AB	2	21,4	0,214	1	1	0
AB	3	16,6	0,211	2	1	0
AB	4	13,6	0,219	3	1	0
AB	5	10,8	0,224	4	1	0
AB	6	9,1	0,243	5	1	0
AB	7	7,1	0,25	5	2	0
AB	8	5,1	0,241	6	2	0
AB	9	3,9	0,243	7	2	0
AB	10	2,4	0,192	8	2	0
AB	15	9,9	1	13	2	0
AC	1	0	0	0	0	0
AC	2	20,4	0,204	1	0	1
AC	3	16,8	0,211	2	0	1
AC	4	13,7	0,219	3	0	1
AC	5	11	0,224	4	0	1
AC	6	9,3	0,243	5	0	1
AC	7	7,2	0,25	6	0	1
AC	8	5,2	0,241	7	0	1
AC	9	4	0,243	8	0	1
AC	10	2,4	0,192	9	0	1
AC	15	10	1	13	0	2
BC	1	0	0	0	0	0
BC	2	21	0,21	0	1	1
BC	3	16,7	0,211	0	2	1
BC	4	13,6	0,219	0	2	2
BC	5	10,9	0,224	0	3	2
BC	6	9,2	0,243	0	4	2
BC	7	7,2	0,25	0	2	5
BC	8	5,2	0,241	0	3	5
BC	9	4	0,243	0	4	5
BC	10	2,4	0,192	0	1	9
BC	15	10	1	0	4	11
ABC	1	0	0	0	0	0
ABC	2	0	0	0	0	0
ABC	3	21,1	0,211	1	1	1
ABC	4	17,3	0,219	2	1	1
ABC	5	13,8	0,224	2	2	1
ABC	6	11,6	0,243	3	2	1
ABC	7	9,1	0,25	4	2	1
ABC	8	6,5	0,241	4	2	2
ABC	9	5	0,243	4	3	2
ABC	10	3	0,192	6	3	1
ABC	15	12,6	1	10	3	2

In the following graph, some abbreviations have been used to let the graph fit on the page. The meaning of the abbreviations is as follows:

- Turn. Cat. = turnover category
- Order Config. = order configuration
- Prob_O = original probability; probability of orders in 2016
- Prob. = probability used in the experiments
- P.C = probability of cases within the order
- P.CI = probability of case-items within the order
- P.I = probability of items within the order

Table 31: Order definition: probability of order configuration per turnover category

Entity Definition: Order configuration								
Turn. Cat.	Order Config.	Prob_O (%)	Prob. (%)	Cumulative probability (%)	Cumulative probability/100	P.C	P.CI	P.I
A	Case	35,1	A_PCase	ED.CI[1].Prob	ED.CI[1].Prob/100	1	0	0
A	CaseItem	3,1	ED.CI[2].Prob_O.	ED.CI[1].Cum. + ED.CI[2].Prob.	ED.CI[2].Prob/(100 – ED.CI[1].Cum.)	0	1	0
A	Item	13,2	A_PItem	ED.CI[2].Cum. + ED.CI[3].Prob.	ED.CI[3].Prob/(100 – ED.CI[2].Cum.)	0	0	1
A	C + CI	2,8	ED.CI[4].Prob_O.	ED.CI[3].Cum. + ED.CI[4].Prob.	ED.CI[4].Prob/(100 – ED.CI[3].Cum.)	0,68	0,32	0
A	C + I	40,6	A_PCaseItem	ED.CI[4].Cum. + ED.CI[5].Prob.	ED.CI[5].Prob/(100 – ED.CI[4].Cum.)	0,62	0	0,38
A	CI + I	1,4	ED.CI[6].Prob_O.	ED.CI[5].Cum. + ED.CI[6].Prob.	ED.CI[6].Prob/(100 – ED.CI[5].Cum.)	0	0,32	0,68
A	C + CI + I	3,8	ED.CI[7].Prob_O.	ED.CI[6].Cum. + ED.CI[7].Prob.	ED.CI[7].Prob/(100 – ED.CI[6].Cum.)	0,44	0,18	0,38
B	Case	35,7	B_PCase	ED.CI[8].Prob	ED.CI[8].Prob/100	1	0	0
B	CaseItem	7,6	ED.CI[9].Prob_O.	ED.CI[8].Cum. + ED.CI[9].Prob.	ED.CI[9].Prob/(100 – ED.CI[8].Cum.)	0	1	0
B	Item	50	B_PItem	ED.CI[9].Cum. + ED.CI[10].Prob.	ED.CI[10].Prob/(100 – ED.CI[9].Cum.)	0	0	1
B	C + CI	1,4	ED.CI[11].Prob_O.	ED.CI[10].Cum. + ED.CI[11].Prob.	ED.CI[11].Prob/(100 – ED.CI[10].Cum.)	0,43	0,57	0
B	C + I	4,8	B_PCaseItem	ED.CI[11].Cum. + ED.CI[12].Prob.	ED.CI[12].Prob/(100 – ED.CI[11].Cum.)	0,54	0	0,46
B	CI + I	0,5	ED.CI[13].Prob_O.	ED.CI[12].Cum. + ED.CI[13].Prob.	ED.CI[13].Prob/(100 – ED.CI[12].Cum.)	0	0,5	0,5
B	C + CI + I	0	ED.CI[14].Prob_O.	ED.CI[13].Cum. + ED.CI[14].Prob.	ED.CI[14].Prob/(100 – ED.CI[13].Cum.)	0,33	0,33	0,33
C	Case	18,5	C_PCase	ED.CI[15].Prob	ED.CI[15].Prob/100	1	0	0
C	CaseItem	3,1	ED.CI[16].Prob_O.	ED.CI[15].Cum. + ED.CI[16].Prob.	ED.CI[16].Prob/(100 – ED.CI[15].Cum.)	0	1	0
C	Item	72,3	C_PItem	ED.CI[16].Cum. + ED.CI[17].Prob.	ED.CI[17].Prob/(100 – ED.CI[16].Cum.)	0	0	1
C	C + CI	0	ED.CI[18].Prob_O.	ED.CI[17].Cum. + ED.CI[18].Prob.	ED.CI[18].Prob/(100 – ED.CI[17].Cum.)	0,5	0,5	0
C	C + I	4,6	C_PCaseItem	ED.CI[18].Cum. + ED.CI[19].Prob.	ED.CI[19].Prob/(100 – ED.CI[18].Cum.)	0,75	0	0,25
C	CI + I	0	ED.CI[20].Prob_O.	ED.CI[19].Cum. + ED.CI[20].Prob.	ED.CI[20].Prob/(100 – ED.CI[19].Cum.)	0	0,5	0,5
C	C + CI + I	1,5	ED.CI[21].Prob_O.	ED.CI[20].Cum. + ED.CI[21].Prob.	ED.CI[21].Prob/(100 – ED.CI[20].Cum.)	0,33	0,33	0,33
AB	Case	4,6	AB_PCase	ED.CI[22].Prob	ED.CI[22].Prob/100	1	0	0
AB	CaseItem	0,1	ED.CI[23].Prob_O.	ED.CI[22].Cum. + ED.CI[23].Prob.	ED.CI[23].Prob/(100 – ED.CI[22].Cum.)	0	1	0
AB	Item	7,7	AB_PItem	ED.CI[23].Cum. + ED.CI[24].Prob.	ED.CI[24].Prob/(100 – ED.CI[23].Cum.)	0	0	1
AB	C + CI	3,1	ED.CI[25].Prob_O.	ED.CI[24].Cum. + ED.CI[25].Prob.	ED.CI[25].Prob/(100 – ED.CI[24].Cum.)	0,46	0,54	0
AB	C + I	71,7	AB_PCaseItem	ED.CI[25].Cum. + ED.CI[26].Prob.	ED.CI[26].Prob/(100 – ED.CI[25].Cum.)	0,59	0	0,41
AB	CI + I	1,8	ED.CI[27].Prob_O.	ED.CI[26].Cum. + ED.CI[27].Prob.	ED.CI[27].Prob/(100 – ED.CI[26].Cum.)	0	0,24	0,76
AB	C + CI + I	11	ED.CI[28].Prob_O.	ED.CI[27].Cum. + ED.CI[28].Prob.	ED.CI[28].Prob/(100 – ED.CI[27].Cum.)	0,49	0,15	0,36
AC	Case	1,6	AC_PCase	ED.CI[29].Prob	ED.CI[29].Prob/100	1	0	0

AC	CaseItem	0	ED.CI[30].Prob_O.	ED.CI[29].Cum. + ED.CI[30].Prob.	ED.CI[30].Prob/(100 – ED.CI[29].Cum.)	0	1	0
AC	Item	7,1	AC_PItem	ED.CI[30].Cum. + ED.CI[31].Prob.	ED.CI[31].Prob/(100 – ED.CI[30].Cum.)	0	0	1
AC	C + CI	6,3	ED.CI[32].Prob_O.	ED.CI[31].Cum. + ED.CI[32].Prob.	ED.CI[32].Prob/(100 – ED.CI[31].Cum.)	0,5	0,5	0
AC	C + I	67,7	AC_PCaseItem	ED.CI[32].Cum. + ED.CI[33].Prob.	ED.CI[33].Prob/(100 – ED.CI[32].Cum.)	0,54	0	0,46
AC	CI + I	2,4	ED.CI[34].Prob_O.	ED.CI[33].Cum. + ED.CI[34].Prob.	ED.CI[34].Prob/(100 – ED.CI[33].Cum.)	0	0,36	0,64
AC	C + CI + I	14,9	ED.CI[35].Prob_O.	ED.CI[34].Cum. + ED.CI[35].Prob.	ED.CI[35].Prob/(100 – ED.CI[34].Cum.)	0,53	0,17	0,3
BC	Case	10,9	BC_PCase	ED.CI[36].Prob	ED.CI[36].Prob/100	1	0	0
BC	CaseItem	0	ED.CI[37].Prob_O.	ED.CI[36].Cum. + ED.CI[37].Prob.	ED.CI[37].Prob/(100 – ED.CI[36].Cum.)	0	1	0
BC	Item	36,4	BC_PItem	ED.CI[37].Cum. + ED.CI[38].Prob.	ED.CI[38].Prob/(100 – ED.CI[37].Cum.)	0	0	1
BC	C + CI	0	ED.CI[39].Prob_O.	ED.CI[38].Cum. + ED.CI[39].Prob.	ED.CI[39].Prob/(100 – ED.CI[38].Cum.)	0,5	0,5	0
BC	C + I	36,4	BC_PCaseItem	ED.CI[39].Cum. + ED.CI[40].Prob.	ED.CI[40].Prob/(100 – ED.CI[39].Cum.)	0,48	0	0,52
BC	CI + I	3,6	ED.CI[41].Prob_O.	ED.CI[40].Cum. + ED.CI[41].Prob.	ED.CI[41].Prob/(100 – ED.CI[40].Cum.)	0	0,25	0,75
BC	C + CI + I	12,7	ED.CI[42].Prob_O.	ED.CI[41].Cum. + ED.CI[42].Prob.	ED.CI[42].Prob/(100 – ED.CI[41].Cum.)	0,38	0,17	0,45
ABC	Case	0,7	ABC_PCase	ED.CI[43].Prob	ED.CI[43].Prob/100	1	0	0
ABC	CaseItem	0	ED.CI[44].Prob_O.	ED.CI[43].Cum. + ED.CI[44].Prob.	ED.CI[44].Prob/(100 – ED.CI[43].Cum.)	0	1	0
ABC	Item	6,3	ABC_PItem	ED.CI[44].Cum. + ED.CI[45].Prob.	ED.CI[45].Prob/(100 – ED.CI[44].Cum.)	0	0	1
ABC	C + CI	1,8	ED.CI[46].Prob_O.	ED.CI[45].Cum. + ED.CI[46].Prob.	ED.CI[46].Prob/(100 – ED.CI[45].Cum.)	0,17	0,83	0
ABC	C + I	66,8	ABC_PCaseItem	ED.CI[46].Cum. + ED.CI[47].Prob.	ED.CI[47].Prob/(100 – ED.CI[46].Cum.)	0,57	0	0,43
ABC	CI + I	2,2	ED.CI[48].Prob_O.	ED.CI[47].Cum. + ED.CI[48].Prob.	ED.CI[48].Prob/(100 – ED.CI[47].Cum.)	0	0,22	0,78
ABC	C + CI + I	22,2	ED.CI[49].Prob_O.	ED.CI[49].Cum. + ED.CI[50].Prob.	ED.CI[49].Prob/(100 – ED.CI[48].Cum.)	0,51	0,15	0,34

Table 32: Picking times per order configuration

Picking times	
Picked products	Picking time per pick (sec)
Case	34
Case-Item	50
Item	20

Appendix G: Simulation Process

In this appendix all tables and process descriptions referred to in chapter 0 paragraph 4.2 are stated.

Order entry – process description

The process description of the order definition is explained in the steps below. In these steps an order gets a picking time assigned and the amount of stops per flowrack section for each of the scenarios.

4. Decide: Order type = A ?

$$Condition: ModelEntity.DisplayName = A$$

   a. True: continue at step 2
   b. False: continue with → Decide: Order Type = B ?

5. Decide: Amount of article types = 1 ?

$$Probability: Probability\ of\ number\ of\ articles = 1, within\ order\ type = A$$

   a. True: continue at step 3
   b. False: continue with → Decide: Amount of article types = 2?

6. Assign: Amount of Stops at A = 1

$$ModelEntity.StopsA = 1$$

7. Decide: Order consist of only cases ? Probability: referred to specific table column and row.

$$Probability: Probability\ of\ order\ with\ only\ cases\ within\ order\ type = A$$

   a. True: continue at step 5
   b. False: continue with → Order consist of only case and items combined ?

8. Assign: Picking time per stop Referred to a specific table column and row.

$$Picking\ Time\ at\ Stops = PCase * GPTCase + PCaseItem * GPTCaseItem + PItem * GPTItem$$

9. Assign: Amount of Stops of Cases picked from A

$$1)\ Case\ stops\ at\ A = StopsCaseA = PCase^X * StopsA$$

$$2)\ Case\ stops\ at\ A = StopsCaseA = (PCase^X + PCaseItem^X) * StopsA$$

10. Assign: Amount of Stops of Cases picked from B

$$1)\ Case\ stops\ at\ B = StopsCaseB = PCase^X * StopsB$$

$$2)\ Case\ stops\ at\ B = StopsCaseB = (PCase^X + PCaseItem^X) * StopsB$$

11. Assign: Amount of Stops of Cases picked from C

$$1)\ Case\ stops\ at\ C = StopsCaseC = PCase^X * StopsC$$

$$2)\ Case\ stops\ at\ C = StopsCaseC = (PCase^X + PCaseItem^X) * StopsC$$

12. Assign: Amount of Stops of Items picked from A

$$1)\ CaseItem\ stops\ at\ A = StopsCaseItemA = PCaseItem^X * StopsA$$

13. Assign: Amount of Stops of Items picked from B

$$1)\ CaseItem\ stops\ at\ B = StopsCaseItemB = PCaseItem^X * StopsB$$

14. Assign: Amount of Stops of Items picked from C

$$1)\ CaseItem\ stops\ at\ C = StopsCaseItemC = PCaseItem^X * StopsC$$

15. Assign: Amount of Stops of Items picked from A

$$1)\ Item\ stops\ at\ A = StopsItemA = PItem^X * StopsA$$

$$2)\ Item\ stops\ at\ A = StopsItemA = (PItem^X + PCaseItem^X) * StopsA$$

16. Assign: Amount of Stops of Items picked from B

$$1)\ Item\ stops\ at\ B = StopsItemB = PItem^X * StopsB$$

$$2)\ Item\ stops\ at\ B = StopsItemB = (PItem^X + PCaseItem^X) * StopsB$$

17. Assign: Amount of Stops of Items picked from C

$$1)\ Item\ stops\ at\ C = StopsItemC = PItem^X * StopsC$$

$$2)\ Item\ stops\ at\ C = StopsItemC = (PItem^X + PCaseItem^X) * StopsC$$

18. Assign: Amount of Stops of Cases

$$Total\ number\ of\ case\ stops = StopsCase = StopsCaseA + StopsCaseB + StopsCaseC$$

19. Assign: Amount of Stops of CaseItems

$$1)\ Total\ number\ of\ caseitem\ stops = StopsCaseItem$$
$$= StopsCaseItemA + StopsCaseItemB + StopsCaseItemC$$

20. Assign: Amount of Stops of Items

$$Total\ number\ of\ item\ stops = StopsItem = StopsItemA + StopsItemB + StopsItemC$$

21. Assign: Amount of Stops in A

$$Total\ number\ of\ stops\ at\ A = StopsA = StopsCaseA + StopsCaseIte \quad + StopsItemA$$

22. Assign: Amount of Stops in B

$$Total\ number\ of\ stops\ at\ B = StopsB = StopsCaseB + StopsCaseItemB + StopsItemB$$

23. Assign: Amount of Stops in C

$$Total\ number\ of\ stops\ at\ C = StopsC = StopsCaseC + StopsCaseItemC + StopsItemC$$

24. Assign: Amount of Stops

$$Total\ number\ of\ stops = Stops = StopsA + StopsB + StopsC$$

- $X = A, B, C, AB, AC, BC\ or\ ABC\ (example{:}\ PCase^A = probability\ of\ cases\ in\ order\ type = A$
- $For\ scenarios\ in\ which\ cases\ and\ items\ of\ the\ same\ producttype\ are\ stored\ next\ eachother$
- $For\ scenarios\ in\ which\ cases\ and\ items\ of\ the\ same\ producttype\ are\ stored\ separated$

Entering the picking area

The formulas used for entering the picking area are given in the following four tables, each table represents a storage strategy applied in the alternatives.

Table 33: Formulas for entering the storage area with randomized storage

RANDOMIZED STORAGE

ENTER_1	$S \le (108 * MSPF)$
ENTER _2	$S \le (72 * MSPF)$
ENTER _3	$S \le (36 * MSPF)$
Complete	$(S - SD) = 0$
Not Complete	$1 - ((S - SD) = 0)$

Table 34: Formulas for entering the storage area with class-based storage on turnover category

CLASS-BASED STORAGE ON TURNOVER CATEGORY	
ENTER_1	$(SA \le (24 * MSPF)) * (SB \le (30 * MSPF)) * (SC \le (54 * MSPF))$
ENTER _2	$(SA \le (16 * MSPF)) * (SB \le (20 * MSPF)) * (SC \le (36 * MSPF))$
ENTER _3	$(SA \le (8 * MSPF)) * (SB \le (10 * MSPF)) * (SC \le (18 * MSPF))$
Complete	$((SA - SDA) = 0) * ((SB - SDB) = 0) * ((SC - SDC) = 0)$
Not Complete	$1 - ((SA - SDA) = 0) * ((SB - SDB) = 0) * ((SC - SDC) = 0)$

Table 35: Formulas for entering the storage area with class-based storage on product type

CLASS-BASED STORAGE ON PRODUCT TYPE	
ENTER_1	$S^{Case} \le (72 * MSPF)$
ENTER _2	$S^{Case} \le (36 * MSPF)$
ENTER _3	$S^{Case} = 0$
Complete	$(S^{Case} - SD^{Case}) = 0) * ((S^{Item} - SD^{Item}) = 0)$
Not Complete	$1 - (S^{Case} - SD^{Case}) = 0) * ((S^{Item} - SD^{Item}) = 0)$

Table 36: Formulas for entering the storage area with class-based storage on product type and turnover category

CLASS-BASED STORAGE ON TURNOVER CATEGORY AND PRODUCT TYPE	
ENTER_1	$(SA^{Case} \le (16 * MSPF)) * (SB^{Case} \le (20 * MSPF)) * (SB^{Case} \le (36 * MSPF))$
ENTER _2	$(SA^{Case} \le (8 * MSPF)) * (SB^{Case} \le (10 * MSPF)) * (SB^{Case} \le (18 * MSPF))$
ENTER _3	$(SA^{Case} = 0) * (SB^{Case} = 0) * (SB^{Case} = 0)$
Complete	$(SA^{Case} - SDA^{Case}) = 0) * ((SA^{Item} - SDA^{Item}) = 0) * (SB^{Case} - SDB^{Case}) = 0) * ((SB^{Item} - SDB^{Item}) = 0) * (SC^{Case} - SDC^{Case}) = 0) * ((SC^{Item} - SDC^{Item}) = 0)$
Not Complete	$1 - (SA^{Case} - SDA^{Case}) = 0) * ((SA^{Item} - SDA^{Item}) = 0) * (SB^{Case} - SDB^{Case}) = 0) * ((SB^{Item} - SDB^{Item}) = 0) * (SC^{Case} - SDC^{Case}) = 0) * ((SC^{Item} - SDC^{Item}) = 0)$

(Re)-Entering a flowrack

The formulas used for entering or not and re-entering or not a flowrack are given in the following for tables. Again these are sorted on storage strategy applied. In these tables 'Yes_1' represents 1B, 'Yes_2' represents 2A, 'Yes_3' represents 3A and 'Yes_4' represents 4A. The opposite direction have a selection weight of one minus the formula.

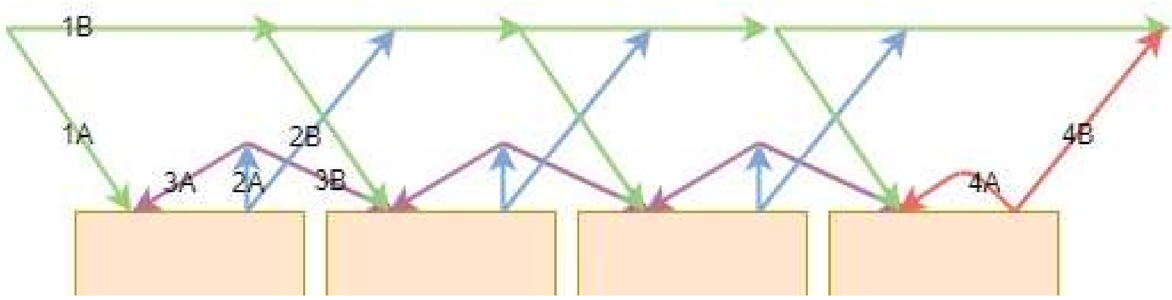


Table 37: Formulas for (re)-entering a flowrack with randomized storage

RANDOMIZED STORAGE	
YES_1	$1-(0.5*\left(((SIS-SP)-(S-SD))\geq MSPF\right)+0.5*((S-SD)=0))$
YES_2	$1-(0.5*\left(((SIS-SP)-(S-SD))\geq(2*MSPF-SPF)\right)+0.5*((S-SD)=0))$
YES_3	$1-(0.5*\left(((SIS-SP)-(S-SD))\geq(MSPF-SPF)\right)+0.5*(MSPF-SPF)=0))$
YES_4	$1-(0.5*\left(((SIS-SP)-(S-SD))\geq(MSPF-SPF)\right)+0.5*\left(\left(((S-SD)=0)+((MSPF-SPF)=0)\right)>0\right))$

Table 38: Formulas for (re)-entering a flowrack with class-based storage on turnover category

CLASS-BASED STORAGE ON TURNOVER CATEGORY	
YES_1_A	$1-(0.5*\left(((SISA-SPA)-(SA-SDA))\geq MSPF\right)+0.5*((SA-SDA)=0))$
YES_2_A	$1-(0.5*\left(((SISA-SPA)-(SA-SDA))\geq(2*MSPF-SPF)\right)+0.5*((SA-SDA)=0))$
YES_3_A	$1-(0.5*\left(((SISA-SPA)-(SA-SDA))\geq(MSPF-SPF)\right)+0.5*(MSPF-SPF)=0))$
YES_4_A	$1-(0.5*\left(((SISA-SPA)-(SA-SDA))\geq(MSPF-SPF)\right)+0.5*\left(\left(((SA-SDA)=0)+((MSPF-SPF)=0)\right)>0\right))$
YES_1_B	$1-(0.5*\left(((SISB-SPB)-(SB-SDB))\geq MSPF\right)+0.5*((SB-SDB)=0))$
YES_2_B	$1-(0.5*\left(((SISB-SPB)-(SB-SDB))\geq(2*MSPF-SPF)\right)+0.5*((SB-SDB)=0))$
YES_3_B	$1-(0.5*\left(((SISB-SPB)-(SB-SDB))\geq(MSPF-SPF)\right)+0.5*(MSPF-SPF)=0))$
YES_4_B	$1-(0.5*\left(((SISB-SPB)-(SB-SDB))\geq(MSPF-SPF)\right)+0.5*\left(\left(((SB-SDB)=0)+((MSPF-SPF)=0)\right)>0\right))$
YES_1_C	$1-(0.5*\left(((SISC-SPC)-(SC-SDC))\geq MSPF\right)+0.5*((SC-SDC)=0))$
YES_2_C	$1-(0.5*\left(((SISC-SPC)-(SC-SDC))\geq(2*MSPF-SPF)\right)+0.5*((SC-SDC)=0))$
YES_3_C	$1-(0.5*\left(((SISC-SPC)-(SC-SDC))\geq(MSPF-SPF)\right)+0.5*(MSPF-SPF)=0))$
YES_4_C	$1-(0.5*\left(((SISC-SPC)-(SC-SDC))\geq(MSPF-SPF)\right)+0.5*\left(\left(((SC-SDC)=0)+((MSPF-SPF)=0)\right)>0\right))$

Table 39: Formulas for (re)-entering a flowrack with class-based storage on product type

CLASS-BASED STORAGE ON PRODUCT TYPE	
YES_1_Case	$1-(0.5*\left(((SIS^{Case}-SP^{Case})-(S^{Case}-SD^{Case}))\geq MSPF\right)+0.5*((S^{Case}-SD^{Case})=0))$
YES_2_Case	$1-(0.5*\left(((SIS^{Case}-SP^{Case})-(S^{Case}-SD^{Case}))\geq(2*MSPF-SPF)\right)+0.5*((S^{Case}-SD^{Case})=0))$
YES_3_Case	$1-(0.5*\left(((SIS^{Case}-SP^{Case})-(S^{Case}-SD^{Case}))\geq(MSPF-SPF)\right)+0.5*(MSPF-SPF)=0))$

YES_4_Case	$1-(0.5\ast\left(\left((SIS^{Case}-SP^{Case})-(S^{Case}-SD^{Case})\right)\geq(MSPF-SPF)\right)+0.5\ast\left(\left(\left((S^{Case}-SD^{Case})=0\right)+\left((MSPF-SPF)=0\right)\right)>0\right))$
YES_1_Item	$1-(0.5\ast\left(\left((SIS^{Item}-SP^{Item})-(S^{Item}-SD^{Item})\right)\geq MSPF\right)+0.5\ast\left((S^{Item}-SD^{Item})=0\right))$
YES_2_Item	$1-(0.5\ast\left(\left((SIS^{Item}-SP^{Item})-(S^{Item}-SD^{Item})\right)\geq(2\ast MSPF-SPF)\right)+0.5\ast\left((S^{Item}-SD^{Item})=0\right))$
YES_3_Item	$1-(0.5\ast\left(\left((SIS^{Item}-SP^{Item})-(S^{Case}-SD^{Case})\right)\geq(MSPF-SPF)\right)+0.5\ast(MSPF-SPF)=0))$
YES_4_Item	$1-(0.5\ast\left(\left((SIS^{Item}-SP^{Item})-(S^{Item}-SD^{Item})\right)\geq(MSPF-SPF)\right)+0.5\ast\left(\left(\left((S^{Item}-SD^{Item})=0\right)+\left((MSPF-SPF)=0\right)\right)>0\right))$

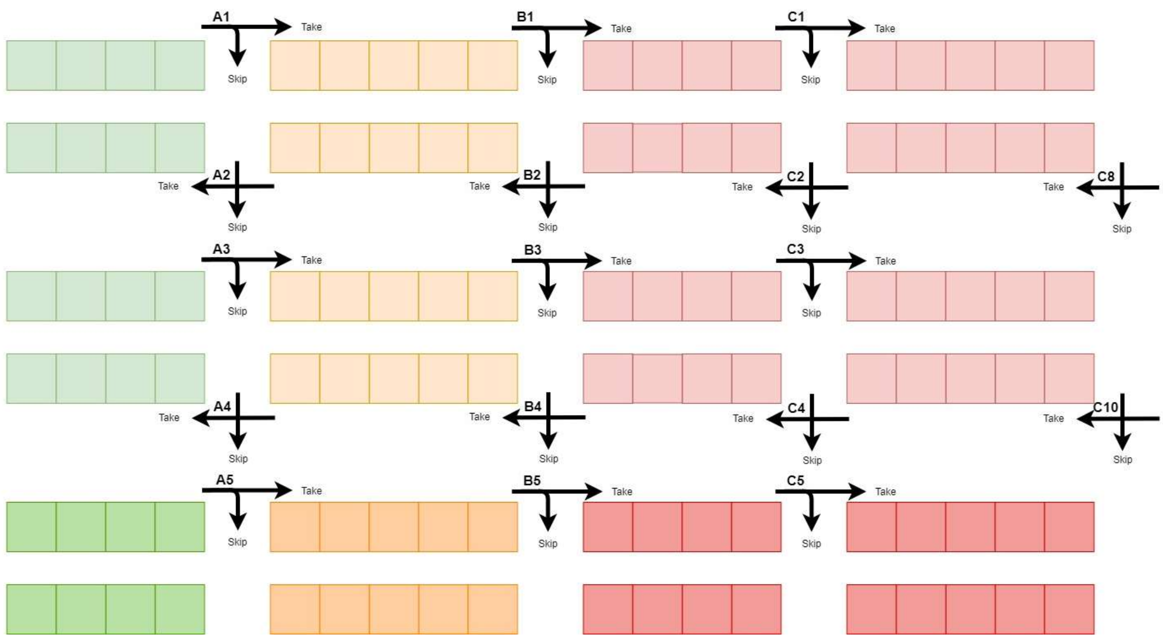
Table 40: Formulas for (re)-entering a flowrack with class-based storage on product type and turnover category

CLASS-BASED STORAGE ON TURNOVER CATEGORY AND PRODUCT TYPE	
YES_1_A_Case	$1-(0.5\ast\left(\left((SISA^{Case}-SPA^{Case})-(SA^{Case}-SDA^{Case})\right)\geq MSPF\right)+0.5\ast\left((SA^{Case}-SDA^{Case})=0\right))$
YES_2_A_Case	$1-(0.5\ast\left(\left((SISA^{Case}-SPA^{Case})-(SA^{Case}-SDA^{Case})\right)\geq(2\ast MSPF-SPF)\right)+0.5\ast\left((SA^{Case}-SDA^{Case})=0\right))$
YES_3_A_Case	$1-(0.5\ast\left(\left((SISA^{Case}-SPA^{Case})-(SA^{Case}-SDA^{Case})\right)\geq(MSPF-SPF)\right)+0.5\ast(MSPF-SPF)=0))$
YES_4_A_Case	$1-(0.5\ast\left(\left((SISA^{Case}-SPA^{Case})-(SA^{Case}-SDA^{Case})\right)\geq(MSPF-SPF)\right)+0.5\ast\left(\left(\left((SA^{Case}-SDA^{Case})=0\right)+\left((MSPF-SPF)=0\right)\right)>0\right))$
YES_1_A_Item	$1-(0.5\ast\left(\left((SISA^{Item}-SPA^{Item})-(SA^{Item}-SDA^{Item})\right)\geq MSPF\right)+0.5\ast\left((SA^{Item}-SDA^{Item})=0\right))$
YES_2_A_Item	$1-(0.5\ast\left(\left((SISA^{Item}-SPA^{Item})-(SA^{Item}-SDA^{Item})\right)\geq(2\ast MSPF-SPF)\right)+0.5\ast\left((SA^{Item}-SDA^{Item})=0\right))$
YES_3_A_Item	$1-(0.5\ast\left(\left((SISA^{Item}-SPA^{Item})-(SA^{Item}-SDA^{Item})\right)\geq(MSPF-SPF)\right)+0.5\ast(MSPF-SPF)=0))$
YES_4_A_Item	$1-(0.5\ast\left(\left((SISA^{Item}-SPA^{Item})-(SA^{Item}-SDA^{Item})\right)\geq(MSPF-SPF)\right)+0.5\ast\left(\left(\left((SA^{Item}-SDA^{Item})=0\right)+\left((MSPF-SPF)=0\right)\right)>0\right))$
YES_1_B_Case	$1-(0.5\ast\left(\left((SISB^{Case}-SPB^{Case})-(SB^{Case}-SDB^{Case})\right)\geq MSPF\right)+0.5\ast\left((SB^{Case}-SDB^{Case})=0\right))$
YES_2_B_Case	$1-(0.5\ast\left(\left((SISB^{Case}-SPB^{Case})-(SB^{Case}-SDB^{Case})\right)\geq(2\ast MSPF-SPF)\right)+0.5\ast\left((SB^{Case}-SDB^{Case})=0\right))$
YES_3_B_Case	$1-(0.5\ast\left(\left((SISB^{Case}-SPB^{Case})-(SB^{Case}-SDB^{Case})\right)\geq(MSPF-SPF)\right)+0.5\ast(MSPF-SPF)=0))$
YES_4_B_Case	$1-(0.5\ast\left(\left((SISB^{Case}-SPB^{Case})-(SB^{Case}-SDB^{Case})\right)\geq(MSPF-SPF)\right)+0.5\ast\left(\left(\left((SB^{Case}-SDB^{Case})=0\right)+\left((MSPF-SPF)=0\right)\right)>0\right))$
YES_1_B_Item	$1-(0.5\ast\left(\left((SISB^{Item}-SPB^{Item})-(SB^{Item}-SDB^{Item})\right)\geq MSPF\right)+0.5\ast\left((SB^{Item}-SDB^{Item})=0\right))$
YES_2_B_Item	$1-(0.5\ast\left(\left((SISB^{Item}-SPB^{Item})-(SB^{Item}-SDB^{Item})\right)\geq(2\ast MSPF-SPF)\right)+0.5\ast\left((SB^{Item}-SDB^{Item})=0\right))$
YES_3_B_Item	$1-(0.5\ast\left(\left((SISB^{Item}-SPB^{Item})-(SB^{Item}-SDB^{Item})\right)\geq(MSPF-SPF)\right)+0.5\ast(MSPF-SPF)=0))$
YES_4_B_Item	$1-(0.5\ast\left(\left((SISB^{Item}-SPB^{Item})-(SB^{Item}-SDB^{Item})\right)\geq(MSPF-SPF)\right)+0.5\ast\left(\left(\left((SB^{Item}-SDB^{Item})=0\right)+\left((MSPF-SPF)=0\right)\right)>0\right))$
YES_1_C_Case	$1-(0.5\ast\left(\left((SISC^{Case}-SPC^{Case})-(SC^{Case}-SDC^{Case})\right)\geq MSPF\right)+0.5\ast\left((SC^{Case}-SDC^{Case})=0\right))$
YES_2_C_Case	$1-(0.5\ast\left(\left((SISC^{Case}-SPC^{Case})-(SC^{Case}-SDC^{Case})\right)\geq(2\ast MSPF-SPF)\right)+0.5\ast\left((SC^{Case}-SDC^{Case})=0\right))$

YES_3_C_Case	$1-(0.5*\left(\left((SISC^{Case}-SPC^{Case})-(SC^{Case}-SDC^{Case})\right)\geq(MSPF-SPF)\right)+0.5*(MSPF-SPF)=0))$
YES_4_C_Case	$1-(0.5*\left(\left((SISC^{Case}-SPC^{Case})-(SC^{Case}-SDC^{Case})\right)\geq(MSPF-SPF)\right)+0.5*\left(\left(((SC^{Case}-SDC^{Case})=0)+((MSPF-SPF)=0)\right)>0\right))$
YES_1_C_Item	$1-(0.5*\left(\left((SISC^{Item}-SPC^{Item})-(SC^{Item}-SDC^{Item})\right)\geq MSPF\right)+0.5*((SC^{Item}-SDC^{Item})=0))$
YES_2_C_Item	$1-(0.5*\left(\left((SISC^{Item}-SPC^{Item})-((SC^{Item}-SDC^{Item}))\right)\geq(2*MSPF-SPF)\right)+0.5*\left(((SC^{Item}-SDC^{Item}))=0\right))$
YES_3_C_Item	$1-(0.5*\left(\left((SISC^{Item}-SPC^{Item})-(SC^{Item}-SDC^{Item})\right)\geq(MSPF-SPF)\right)+0.5*(MSPF-SPF)=0))$
YES_4_C_Item	$1-(0.5*\left(\left((SISC^{Item}-SPC^{Item})-(SC^{Item}-SDC^{Item})\right)\geq(MSPF-SPF)\right)+0.5*\left(\left(((SC^{Item}-SDC^{Item})=0)+((MSPF-SPF)=0)\right)>0\right))$

Passing a flowrack section

The formulas used for passing certain flowrack section are given in the table below. The intersection where a formula is applied are given in the figure below. The formulas are based on the probability of 0%, 50% of 100% entering a shortcut. In the table the formulas for entering a flowrack are given. The formula for not entering the shortcut is one minus the formula for entering the shortcut.



Again, the tables are sorted on storage strategy applied.

Table 41: Formulas for passing a flowrack section with randomized storage

Formulas used for storage strategy scenario: Random --> Percentage of taking shortcut			
Shortcut	0 %	50%	100%
A1	If: S - SD > (76 * MSPF)	If: 0 ≤ S - SD ≤ (76 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5*((S-SD)\leq(76*MSPF))+0.5*((S-SD)=0)$		
Combined	$0.5*((S-SD)\leq(76*MSPF))+0.5*((S-SD)=0)$		
A2	If: S - SD > (64 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (64 * MSPF)	
Transversal	0,0		

Return	0,0		
Combined	$0.5 * ((S - SD) \leq (68 * MSPF)) + 0.5 * ((S - SD) = 0)$		
A3	If: S - SD > (40 * MSPF)	If: 0 ≤ S - SD ≤ (40 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (40 * MSPF)) + 0.5 * ((S - SD) = 0)$		
Combined	$0.5 * ((S - SD) \leq (40 * MSPF)) + 0.5 * ((S - SD) = 0)$		
A4	If: S - SD > (32 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (32 * MSPF)	
Transversal	0,0		
Return	0,0		
Combined	$0.5 * ((S - SD) \leq (32 * MSPF)) + 0.5 * ((S - SD) = 0)$		
A5	If: S - SD > (4 * MSPF)	If: 0 ≤ S - SD ≤ (4 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (4 * MSPF)) + 0.5 * ((S - SD) = 0)$		
Combined	$0.5 * ((S - SD) \leq (4 * MSPF)) + 0.5 * ((S - SD) = 0)$		
B1	If: S - SD > (81* MSPF)	If: 0 ≤ S - SD ≤ (81 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (81 * MSPF)) + 0.5 * ((S - SD) = 0)$		
Combined	$0.5 * ((S - SD) \leq (81 * MSPF)) + 0.5 * ((S - SD) = 0)$		
B2	If: S - SD > (63 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (63 * MSPF)	
Transversal	0,0		
Return	0,0		
Combined	$0.5 * ((S - SD) \leq (63 * MSPF)) + 0.5 * ((S - SD) = 0)$		
B3	If: S - SD > (45 * MSPF)	If: 0 ≤ S - SD ≤ (45 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (45 * MSPF)) + 0.5 * ((S - SD) = 0)$		
Combined	$0.5 * ((S - SD) \leq (45 * MSPF)) + 0.5 * ((S - SD) = 0)$		
B4	If: S - SD > (27 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (27 * MSPF)	
Transversal	0,0		
Return	0,0		
Combined	$0.5 * ((S - SD) \leq (27 * MSPF)) + 0.5 * ((S - SD) = 0)$		
B5	If: S - SD > (9 * MSPF)	If: 0 ≤ S - SD ≤ (9 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (9 * MSPF)) + 0.5 * ((S - SD) = 0)$		
Combined	$0.5 * ((S - SD) \leq (9 * MSPF)) + 0.5 * ((S - SD) = 0)$		
C1	If: S - SD > (85 * MSPF)	If: 0 ≤ S - SD ≤ (85 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (85 * MSPF)) + 0.5 * ((S - SD) = 0)$		
Combined	$0.5 * ((S - SD) \leq (85 * MSPF)) + 0.5 * ((S - SD) = 0)$		
C2	If: S - SD > (59 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (59 * MSPF)	
Transversal	0,0		
Return	0,0		
Combined	$0.5 * ((S - SD) \leq (59 * MSPF)) + 0.5 * ((S - SD) = 0)$		
C3	If: S - SD > (49 * MSPF)	If: 0 ≤ S - SD ≤ (49 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (49 * MSPF)) + 0.5 * ((S - SD) = 0)$		

Combined	$0.5 * ((S - SD) \leq (49 * MSPF)) + 0.5 * ((S - SD) = 0)$		
C4	If: S - SD > (23 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (23 * MSPF)	
Transversal	0,0		
Return	**0, 0**		
Combined	$0.5 * ((S - SD) \leq (23 * MSPF)) + 0.5 * ((S - SD) = 0)$		
C5	If: S - SD > (13 * MSPF)	If: 0 ≤ S - SD ≤ (13 * MSPF)	If: S - SD = 0
Transversal	0,0		
Return	$0.5 * ((S - SD) \leq (13 * MSPF)) + 0.5 * ((S - SD) = 0)$		
Combined	$0.5 * ((S - SD) \leq (13 * MSPF)) + 0.5 * ((S - SD) = 0)$		
C8	If: S - SD > (54 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (54 * MSPF)	
Transversal	0,0		
Return	**0, 0**		
Combined	$0.5 * ((S - SD) \leq (54 * MSPF)) + 0.5 * ((S - SD) = 0)$		
C10	If: S - SD > (18 * MSPF) or if: S - SD = 0	If: 0 ≤ S - SD ≤ (18 * MSPF)	
Transversal	0,0		
Return	**0, 0**		
Combined	$0.5 * ((S - SD) \leq (18 * MSPF)) + 0.5 * ((S - SD) = 0)$		

Table 42: Formulas for passing a flowrack section with class-based storage on turnover category

Formulas used for storage strategy scenario: ABC --> Percentage of taking shortcut			
Shortcut	0 %	50%	100%
A1	If: SB - SDB > (20 * MSPF) Or if: SC - SDC > (36 * MSPF)	If: 0 ≤ SB - SDB ≤ (20 * MSPF) and: 0 ≤ SC - SDC ≤ (36 * MSPF)	If: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0
Transversal	0,0		
Return	$0.5 * ((SB - SDB) \leq (20 * MSPF)) * ((SC - SDC) \leq (36 * MSPF)) + 0.5 * ((SB - SDB) = 0) * ((SC - SDC) = 0)$		
Combined	$0.5 * ((SB - SDB) \leq (20 * MSPF)) * ((SC - SDC) \leq (36 * MSPF)) + 0.5 * ((SB - SDB) = 0) * ((SC - SDC) = 0)$		
A2	If: SA - SDA > (12 * MSPF) Or if: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0	If: 0 ≤ SA - SDA ≤ (12 * MSPF)	If: SA - SDA = 0 and: SB - SDB > 0 Or if: SA - SDA = 0 and: SC - SDC > 0
Transversal	0,0		
Return	**0, 0**		
Combined	$1 - (0.5 * ((SA - SDA) \leq (12 * MSPF)) + 0.5 * ((SA - SDA) = 0) * ((SB - SDB) = 0) * ((SC - SDC) = 0) + ((SA - SDA) > (12 * MSPF)) - 0.5 * ((SA - SDA) = 0) * (((SB - SDB) + (SC - SDC)) > 0))$		
A3	If: SB - SDB > (10 * MSPF) Or if: SC - SDC > (18 * MSPF)	If: 0 ≤ SB - SDB ≤ (10 * MSPF) and: 0 ≤ SC - SDC ≤ (18 * MSPF)	If: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0
Transversal	0,0		
Return	$0.5 * ((SB - SDB) \leq (10 * MSPF)) * ((SC - SDC) \leq (18 * MSPF)) + 0.5 * ((SB - SDB) = 0) * ((SC - SDC) = 0)$		
Combined	$0.5 * ((SB - SDB) \leq (10 * MSPF)) * ((SC - SDC) \leq (18 * MSPF)) + 0.5 * ((SB - SDB) = 0) * ((SC - SDC) = 0)$		
A4	If: SA - SDA > (4 * MSPF) Or if: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0	If: 0 ≤ SA - SDA ≤ (4 * MSPF)	If: SA - SDA = 0 and: SB - SDB > 0 Or if: SA - SDA = 0 and: SC - SDC > 0
Transversal	0,0		

Return	$0,0$		
Combined	$1-(0.5*((SA-SDA)\leq(4*MSPF))+0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)=0)+((SA-SDA)>(4*MSPF))-0.5*((SA-SDA)=0)*(((SB-SDB)+(SC-SDC))>0))$		
A5	If: SB - SDB > 0 Or if: SC - SDC > 0		If: SB - SDB = 0 Or if: SC - SDC = 0
Transversal	0,0		
Return	$((SB-SDB)=0)*((SC-SDC)=0)$		
Combined	$((SB-SDB)=0)*((SC-SDC)=0)$		
B1	If: SC - SDC > (36 * MSPF)	If: 0 ≤ SC - SDC ≤ (36 * MSPF)	If: SC - SDC = 0
Transversal	0,0		
Return	$0.5*((SC-SDC)\ \leq(36*MSPF))+0,5*((SC-SDC)=0)$		
Combined	$0.5*((SC-SDC)\ \leq(36*MSPF))+0,5*((SC-SDC)=0)$		
B2	If: SA - SDA > (12 * MSPF) Or if: SB - SDB > (15 * MSPF) Or if: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0	If: 0 ≤ SA - SDA ≤ (12 * MSPF) and: 0 ≤ SB - SDB ≤ (15 * MSPF)	If: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC > 0
Transversal	0,0		
Return	$0,0$		
Combined	$1-(0.5*((SA-SDA)\leq(12\ *MSPF))*((SB-SDB)\leq(15*MSPF))+0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)=0)+\left(\left(((SA-SDA)>(12*MSPF))+((SB-SCB)>(15*MSPF))\right)>0\right)-0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)>0))$		
B3	If: SC - SDC > (18 * MSPF)	If: 0 ≤ SC - SDC ≤ (18 * MSPF)	If: SC - SDC = 0
Transversal	0,0		
Return	$0.5*((SC-SDC)\ \leq(18*MSPF))+0,5*((SC-SDC)=0)$		
Combined	$0.5*((SC-SDC)\ \leq(18*MSPF))+0,5*((SC-SDC)=0)$		
B4	If: SA - SDA > (4 * MSPF) Or if: SB - SDB > (5 * MSPF) Or if: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0	If: 0 ≤ SA - SDA ≤ (4 * MSPF) and: 0 ≤ SB - SDB ≤ (5 * MSPF)	If: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC > 0
Transversal	0,0		
Return	$0,0$		
Combined	$1-(0.5*((SA-SDA\ \leq(4*MSPF))*((SB-SDB)\leq(5*MSPF))+0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)=0)+\left(\left(((SA-SDA)>(4*MSPF))+((SB-SCB)>(5*MSPF))\right)>0\right)-0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)>0))$		
B5	If: SC - SDC > 0		If: SC - SDC = 0
Transversal	0,0		
Return	$((SC-SDC)=0)$		
Combined	$((SC-SDC)=0)$		
C1	If: SC - SDC > (40 * MSPF)	If: 0 ≤ SC - SDC ≤ (40 * MSPF)	If: SC - SDC = 0
Transversal	0,0		
Return	$0.5*((SC-SDC)\ \leq(40*MSPF))+0,5*((SC-SDC)=0)$		
Combined	$0.5*((SC-SDC)\ \leq(40*MSPF))+0,5*((SC-SDC)=0)$		
C2	If: SA - SDA > (12 * MSPF) Or if: SB - SDB > (15 * MSPF) Or if: SC - SDC > (32 * MSPF) Or if: SA - SDA = 0	If: 0 ≤ SA - SDA ≤ (12 * MSPF) and: 0 ≤ SB - SDB ≤ (15 * MSPF) and: 0 ≤ SB - SDB ≤ (32 * MSPF)	

	and: SB - SDB = 0 and: SC - SDC = 0		
Transversal	0,0		
Return	0,0		
Combined	$1-(0.5*((SA-SDA)\leq(12*MSPF))*((SB-SDB)\leq(15*MSPF))*((SC-SDC)\leq(32*MSPF))$ $+0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)=0)$ $+\left(\left(((SA-SDA)>(12*MSPF))+((SB-SCB)>(15*MSPF))+((SC-SDC)>(32*MSPF))\right)>0\right)$		
C3	If: SC - SDC > (22 * MSPF)	If: 0 ≤ SC - SDC ≤ (22 * MSPF)	If: SC - SDC = 0
Transversal	0,0		
Return	$0.5*((SC-SDC)\ \leq(22*MSPF))+0,5*((SC-SDC)=0)$		
Combined	$0.5*((SC-SDC)\ \leq(22*MSPF))+0,5*((SC-SDC)=0)$		
C4	If: SA - SDA > (4 * MSPF) Or if: SB - SDB > (5 * MSPF) Or if: SC - SDC > (14 * MSPF) Or if: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0	If: 0 ≤ SA - SDA ≤ (4 * MSPF) and: 0 ≤ SB - SDB ≤ (5 * MSPF) and: 0 ≤ SB - SDB ≤ (14 * MSPF)	
Transversal	0,0		
Return	$\mathbf{0,0}$		
Combined	$1-(0.5*((SA-SDA)\leq(4*MSPF))*((SB-SDB)\leq(5*MSPF))*((SC-SDC)\leq(14*MSPF))$ $+0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)=0)$ $+\left(\left(((SA-SDA)>(4*MSPF))+((SB-SCB)>(5*MSPF))+((SC-SDC)>(14*MSPF))\right)>0\right)$		
C5	If: SC - SDC > (4 * MSPF)	If: 0 ≤ SC - SDC ≤ (4 * MSPF)	If: SC - SDC = 0
Transversal	0,0		
Return	$0.5*((SC-SDC)\ \leq(4*MSPF))+0,5*((SC-SDC)=0)$		
Combined	$0.5*((SC-SDC)\ \leq(4*MSPF))+0,5*((SC-SDC)=0)$		
C8	If: SA - SDA > (12 * MSPF) Or if: SB - SDB > (15 * MSPF) Or if: SC - SDC > (27 * MSPF) Or if: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0	If: 0 ≤ SA - SDA ≤ (12 * MSPF) and: 0 ≤ SB - SDB ≤ (15 * MSPF) and: 0 ≤ SB - SDB ≤ (27 * MSPF)	
Transversal	0,0		
Return	$\mathbf{0,0}$		
Combined	$1-(0.5*((SA-SDA)\leq(12*MSPF))*((SB-SDB)\leq(15*MSPF))*((SC-SDC)\leq(27*MSPF))$ $+0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)=0)$ $+\left(\left(((SA-SDA)>(12*MSPF))+((SB-SCB)>(15*MSPF))+((SC-SDC)>(27*MSPF))\right)>0\right)$		
C10	If: SA - SDA > (4 * MSPF) Or if: SB - SDB > (5 * MSPF) Or if: SC - SDC > (9 * MSPF) Or if: SA - SDA = 0 and: SB - SDB = 0 and: SC - SDC = 0	If: 0 ≤ SA - SDA ≤ (4 * MSPF) and: 0 ≤ SB - SDB ≤ (5 * MSPF) and: 0 ≤ SB - SDB ≤ (9 * MSPF)	
Transversal	0,0		
Return	$\mathbf{0,0}$		
Combined	$1-(0.5*((SA-SDA)\leq(4*MSPF))*((SB-SDB)\leq(5*MSPF))*((SC-SDC)\leq(9*MSPF))$ $+0.5*((SA-SDA)=0)*((SB-SDB)=0)*((SC-SDC)=0)$ $+\left(\left(((SA-SDA)>(4*MSPF))+((SB-SCB)>(5*MSPF))+((SC-SDC)>(9*MSPF))\right)>0\right)$		

Table 43: Formulas for passing a flowrack section with class-based storage on product type

Formulas used for storage strategy scenario: CI --> Percentage of taking shortcut			
	0 %	50%	100%
A1	If: S^{Case} - SD^{Case} > (68 * MSPF)	If: 0 ≤ S^{Case} - SD^{Case} ≤ (68 * MSPF)	If: S^{Case} - SD^{Case} = 0
Transversal	0,0		
Return	$0.5*((S^{Case}-SD^{Case}) \le (40*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
Combined	$0.5*((S^{Case}-SD^{Case}) \le (40*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
A2	If: S^{Case} - SD^{Case} > (32 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Case} - SD^{Case} ≤ (32 * MSPF)	if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} > 0
Transversal	0,0		
Return	**0, 0**		
Combined	$1-(0.5*((S^{Case}-SD^{Case}) \le (32*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})=0)$ $+((S^{Case}-SD^{Case}) > (32*MSPF)) - 0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})>0)$		
A3	If: S^{Case} - SD^{Case} > (4 * MSPF)	If: 0 ≤ S^{Case} - SD^{Case} ≤ (4 * MSPF)	If: S^{Case} - SD^{Case} = 0
Transversal	0,0		
Return	$0.5*((S^{Case}-SD^{Case}) \le (4*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
Combined	$0.5*((S^{Case}-SD^{Case}) \le (4*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
A4	If: S^{Case} - SD^{Case} > 0 or if: S^{Item} - SD^{Item} > (32 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Item} - SD^{Item} ≤ (32 * MSPF) and: S^{Case} - SD^{Case} = 0	
Transversal	0,0		
Return	**0, 0**		
Combined	$1-(0.5*((S^{Item}-SD^{Item}) \le (32*MSPF)) + 0.5*((S^{Case}-SD^{Case})>0)$ $+0.5*((S^{Item}-SD^{Item})=0)*((S^{Case}-SD^{Case})=0) + ((S^{Item}-SD^{Item}) > (32*MSPF))$ $+0.5*((S^{Item}-SD^{Item}) > (32*MSPF))*((S^{Case}-SD^{Case})=0)$		
A5	If: S^{Item} - SD^{Item} > (4 * MSPF)	If: 0 ≤ S^{Item} - SD^{Item} ≤ (4 * MSPF)	If: S^{Item} - SD^{Item} = 0
Transversal	0,0		
Return	$0.5*((S^{Item}-SD^{Item}) \le (4*MSPF)) + 0.5*(S^{Item}-SD^{Item}=0)$		
Combined	$0.5*((S^{Item}-SD^{Item}) \le (4*MSPF)) + 0.5*((S^{Item}-SD^{Item})=0)$		
B1	If: S^{Case} - SD^{Case} > (45 * MSPF)	If: 0 ≤ S^{Case} - SD^{Case} ≤ (45 * MSPF)	If: S^{Case} - SD^{Case} = 0
Transversal	0,0		
Return	$0.5*((S^{Case}-SD^{Case}) \le (45*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
Combined	$0.5*((S^{Case}-SD^{Case}) \le (45*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
B2	If: S^{Case} - SD^{Case} > (27 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Case} - SD^{Case} ≤ (27 * MSPF)	if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} > 0
Transversal	0,0		
Return	**0, 0**		
Combined	$1-(0.5*((S^{Case}-SD^{Case}) \le (27*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})=0)$ $+((S^{Case}-SD^{Case}) > (27*MSPF)) - 0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})>0)$		
B3	If: S^{Case} - SD^{Case} > (9 * MSPF)	If: 0 ≤ S^{Case} - SD^{Case} ≤ (9 * MSPF)	If: S^{Case} - SD^{Case} = 0
Transversal	0,0		
Return	$0.5*((S^{Case}-SD^{Case}) \le (9*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
Combined	$0.5*((S^{Case}-SD^{Case}) \le (9*MSPF)) + 0.5*((S^{Case}-SD^{Case})=0)$		
B4	If: S^{Case} - SD^{Case} > 0 or if: S^{Item} - SD^{Item} > (27 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Item} - SD^{Item} ≤ (27 * MSPF) and: S^{Case} - SD^{Case} = 0	
Transversal	0,0		

Return	**0, 0**		
Combined	$1-(0.5*((S^{Item}-SD^{Item}) \le (27*MSPF))+0.5*((S^{Case}-SD^{Case})>0)$ $+0.5*((S^{Item}-SD^{Item})=0)*((S^{Case}-SD^{Case})=0)+((S^{Item}-SD^{Item})>(27*MSPF))$ $+0.5*((S^{Item}-SD^{Item})>(27*MSPF))*((S^{Case}-SD^{Case})=0)$		
B5	If: S^{Item} - SD^{Item} > (9 * MSPF)	If: 0 ≤ S^{Item} - SD^{Item} ≤ (9 * MSPF)	If: S^{Item} - SD^{Item} = 0
Transversal	0,0		
Return	$0.5*((S^{Item}-SD^{Item}) \le (9*MSPF))+0.5*(S^{Item}-SD^{Item}=0)$		
Combined	$0.5*((S^{Item}-SD^{Item}) \le (9*MSPF))+0.5*((S^{Item}-SD^{Item})=0)$		
C1	If: S^{Case} - SD^{Case} > (49 * MSPF)	If: 0 ≤ S^{Case} - SD^{Case} ≤ (49 * MSPF)	If: S^{Case} - SD^{Case} = 0
Transversal	0,0		
Return	$0.5*((S^{Case}-SD^{Case}) \le (49*MSPF))+0.5*((S^{Case}-SD^{Case})=0)$		
Combined	$0.5*((S^{Case}-SD^{Case}) \le (49*MSPF))+0.5*((S^{Case}-SD^{Case})=0)$		
C2	If: S^{Case} - SD^{Case} > (23 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Case} - SD^{Case} ≤ (23 * MSPF)	if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} > 0
Transversal	0,0		
Return	**0, 0**		
Combined	$1-(0.5*((S^{Case}-SD^{Case}) \le (23*MSPF))+0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})=0)$ $+((S^{Case}-SD^{Case})>(23*MSPF))-0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})>0)$		
C3	If: S^{Case} - SD^{Case} > (13 * MSPF)	If: 0 ≤ S^{Case} - SD^{Case} ≤ (13 * MSPF)	If: S^{Case} - SD^{Case} = 0
Transversal	0,0		
Return	$0.5*((S^{Case}-SD^{Case}) \le (13*MSPF))+0.5*((S^{Case}-SD^{Case})=0)$		
Combined	$0.5*((S^{Case}-SD^{Case}) \le (13*MSPF))+0.5*((S^{Case}-SD^{Case})=0)$		
C4	If: S^{Case} - SD^{Case} > 0 or if: S^{Item} - SD^{Item} > (23 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Item} - SD^{Item} ≤ (23 * MSPF) and: S^{Case} - SD^{Case} = 0	
Transversal	0,0		
Return	**0, 0**		
Combined	$1-(0.5*((S^{Item}-SD^{Item}) \le (23*MSPF))+0.5*((S^{Case}-SD^{Case})>0)$ $+0.5*((S^{Item}-SD^{Item})=0)*((S^{Case}-SD^{Case})=0)+((S^{Item}-SD^{Item})>(23*MSPF))$ $+0.5*((S^{Item}-SD^{Item})>(23*MSPF))*((S^{Case}-SD^{Case})=0)$		
C5	If: S^{Item} - SD^{Item} > (13 * MSPF)	If: 0 ≤ S^{Item} - SD^{Item} ≤ (13 * MSPF)	If: S^{Item} - SD^{Item} = 0
Transversal	0,0		
Return	$0.5*((S^{Item}-SD^{Item}) \le (13*MSPF))+0.5*(S^{Item}-SD^{Item}=0)$		
Combined	$0.5*((S^{Item}-SD^{Item}) \le (13*MSPF))+0.5*((S^{Item}-SD^{Item})=0)$		
C8	If: S^{Case} - SD^{Case} > (18 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Case} - SD^{Case} ≤ (18 * MSPF)	if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} > 0
Transversal	0,0		
Return	**0, 0**		
Combined	$1-(0.5*((S^{Case}-SD^{Case}) \le (18*MSPF))+0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})=0)$ $+((S^{Case}-SD^{Case})>(18*MSPF))-0.5*((S^{Case}-SD^{Case})=0)*((S^{Item}-SD^{Item})>0)$		
C10	If: S^{Case} - SD^{Case} > 0 or if: S^{Item} - SD^{Item} > (18 * MSPF) or if: S^{Case} - SD^{Case} = 0 and: S^{Item} - SD^{Item} = 0	If: 0 ≤ S^{Item} - SD^{Item} ≤ (18 * MSPF) and: S^{Case} - SD^{Case} = 0	
Transversal	0,0		
Return	**0, 0**		
Combined	$1-(0.5*((S^{Item}-SD^{Item}) \le (18*MSPF))+0.5*((S^{Case}-SD^{Case})>0)$ $+0.5*((S^{Item}-SD^{Item})=0)*((S^{Case}-SD^{Case})=0)+((S^{Item}-SD^{Item})>(18*MSPF))$ $+0.5*((S^{Item}-SD^{Item})>(18*MSPF))*((S^{Case}-SD^{Case})=0)$		

Table 44: Formulas for passing a flowrack section with class-based storage on turnover category and product type

Formulas used for storage strategy scenario: ABC & CI --> Percentage of taking shortcut			
	0 %	50%	100%
A1	If: $SB^{Case} - SDB^{Case} > (10 * MSPF)$ Or if: $SC^{Case} - SDC^{Case} > (18 * MSPF)$	If: $0 \leq SB^{Case} - SDB^{Case} \leq (10 * MSPF)$ and: $0 \leq SC^{Case} - SDC^{Case} \leq (18 * MSPF)$	If: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$
Transversal	0,0		
Return	$0.5 * ((SB^{Case} - SDB^{Case}) \leq (10 * MSPF)) * ((SC^{Case} - SDC^{Case}) \leq (18 * MSPF)) + 0.5 * ((SB^{Case} - SDB^{Case}) = 0) * ((SC^{Case} - SDC^{Case}) = 0)$		
Combined	$0.5 * ((SB^{Case} - SDB^{Case}) \leq (10 * MSPF)) * ((SC^{Case} - SDC^{Case}) \leq (18 * MSPF)) + 0.5 * ((SB^{Case} - SDB^{Case}) = 0) * ((SC^{Case} - SDC^{Case}) = 0)$		
A2	If: $SA^{Case} - SDA^{Case} > (4 * MSPF)$ Or if: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$ and: $SA^{Item} - SDA^{Item} = 0$ and: $SB^{Item} - SDB^{Item} = 0$ and: $SC^{Item} - SDC^{Item} = 0$	If: $0 \leq SA^{Case} - SDA^{Case} \leq (4 * MSPF)$	If: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} > 0$ o/a: $SC^{Case} - SDC^{Case} > 0$ o/a: $SA^{Item} - SDA^{Item} > 0$ o/a: $SB^{Item} - SDB^{Item} > 0$ o/a: $SC^{Item} - SDC^{Item} > 0$
Transversal	0,0		
Return	0,0		
Combined	$1 - (0.5 * ((SA^{Case} - SDA^{Case}) \leq (4 * MSPF)) + 0.5 * ((SA^{Case} - SDA^{Case}) = 0) * ((SB^{Case} - SDB^{Case}) = 0) * ((SC^{Case} - SDC^{Case}) = 0) * ((SA^{Item} - SDA^{Item}) = 0) * ((SB^{Item} - SDB^{Item}) = 0) * ((SC^{Item} - SDC^{Item}) = 0) + ((SA^{Case} - SDA^{Case}) > (4 * MSPF)) - ((SA^{Case} - SDA^{Case}) = 0) * (((SB^{Case} - SDB^{Case}) + (SC^{Case} - SDC^{Case})) > 0))$		
A3	If: $SB^{Case} - SDB^{Case} > 0$ Or if: $SC^{Case} - SDC^{Case} > 0$		If: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$
Transversal	0,0		
Return	$((SB^{Case} - SDB^{Case}) = 0) * ((SC^{Case} - SDC^{Case}) = 0)$		
Combined	$((SB^{Case} - SDB^{Case}) = 0) * ((SC^{Case} - SDC^{Case}) = 0)$		
A4	If: $SA^{Item} - SDA^{Item} > (4 * MSPF)$ Or if: $SA^{Case} - SDA^{Case} > 0$ Or if: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$ and: $SA^{Item} - SDA^{Item} = 0$ and: $SB^{Item} - SDB^{Item} = 0$ and: $SC^{Item} - SDC^{Item} = 0$	If: $0 \leq SA^{Item} - SDA^{Item} \leq (4 * MSPF)$	If: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} > 0$ o/a: $SC^{Case} - SDC^{Case} > 0$ o/a: $SA^{Item} - SDA^{Item} > 0$ o/a: $SB^{Item} - SDB^{Item} > 0$ o/a: $SC^{Item} - SDC^{Item} > 0$
Transversal	0,0		
Return	0,0		
Combined	$1 - (0.5 * ((SA^{Item} - SDA^{Item}) \leq (4 * MSPF)) + 0.5 * ((SA^{Case} - SDA^{Case}) > 0) + 0.5 * ((SA^{Case} - SDA^{Case}) = 0) * ((SA^{Item} - SDA^{Item}) = 0) * ((SB^{Item} - SDB^{Item}) = 0) * ((SC^{Item} - SDC^{Item}) = 0) + ((SA^{Item} - SDA^{Item}) > (4 * MSPF)) + ((SA^{Item} - SDA^{Item}) > (4 * MSPF)) * ((SA^{Case} - SDA^{Case}) = 0) - ((SA^{Case} - SDA^{Case}) = 0) * ((SA^{Item} - SDA^{Item}) = 0) * (((SB^{Item} - SDB^{Item}) + (SC^{Item} - SDC^{Item})) > 0))$		
A5	If: $SB^{Item} - SDB^{Item} > 0$ Or if: $SC^{Item} - SDC^{Item} > 0$		If: $SB^{Item} - SDB^{Item} = 0$ and: $SC^{Item} - SDC^{Item} = 0$
Transversal	0,0		
Return	$((SB^{Item} - SDB^{Item}) = 0) * ((SC^{Item} - SDC^{Item}) = 0)$		
Combined	$((SB^{Item} - SDB^{Item}) = 0) * ((SC^{Item} - SDC^{Item}) = 0)$		
B1	If: $SC^{Case} - SDC^{Case} > (18 * MSPF)$	If: $0 \leq SC^{Case} - SDC^{Case} \leq (18 * MSPF)$	If: $SC^{Case} - SDC^{Case} = 0$
Transversal	0,0		
Return	$0.5 * ((SC^{Case} - SDC^{Case}) \leq (18 * MSPF)) + 0.5 * ((SC^{Case} - SDC^{Case}) = 0)$		
Combined	$0.5 * ((SC^{Case} - SDC^{Case}) \leq (18 * MSPF)) + 0.5 * ((SC^{Case} - SDC^{Case}) = 0)$		

B2	If: $SA^{Case} - SDA^{Case} > (4 * MSPF)$ Or if: $SB^{Case} - SDB^{Case} > (5 * MSPF)$ Or if: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$ and: $SA^{Item} - SDA^{Item} = 0$ and: $SB^{Item} - SDB^{Item} = 0$ and: $SC^{Item} - SDC^{Item} = 0$	If: $0 \le SA^{Case} - SDA^{Case} \le (4 * MSPF)$ and: If: $0 \le SB^{Case} - SDB^{Case} \le (5 * MSPF)$	If: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} > 0$ o/a: $SA^{Item} - SDA^{Item} > 0$ o/a: $SB^{Item} - SDB^{Item} > 0$ o/a: $SC^{Item} - SDC^{Item} > 0$
Transversal	0,0		
Return	0,0		
Combined	$1-(0.5*((SA^{Case}-SDA^{Case}) \le (4*MSPF))*((SB^{Case}-SDB^{Case}) \le (5*MSPF))+0.5*((SA^{Case}-SDA^{Case})=0)*((SB^{Case}-SDB^{Case})=0)*((SC^{Case}-SDC^{Case})=0)*((SA^{Item}-SDA^{Item})=0)*((SB^{Item}-SDB^{Item})=0)*((SC^{Item}-SDC^{Item})=0)+((((SA^{Case}-SDA^{Case})>(4*MSPF))+((SB^{Case}-SDB^{Case})>(5*MSPF)))>0)-0.5*((SA^{Case}-SDA^{Case})=0)*((SB^{Case}-SDB^{Case})=0)*((SC^{Case}-SDC^{Case})>0))$		
B3	If: $SC^{Case} - SDC^{Case} > 0$		If: $SC^{Case} - SDC^{Case} = 0$
Transversal	0,0		
Return	$((SC^{Item}-SDC^{Item})=0)$		
Combined	$((SC^{Item}-SDC^{Item})=0)$		
B4	If: $SA^{Item} - SDA^{Item} > (4 * MSPF)$ Or if: $SB^{Item} - SDB^{Item} > (5 * MSPF)$ Or if: $SA^{Case} - SDA^{Case} > 0$ Or if: $SB^{Case} - SDB^{Case} > 0$ Or if: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$ and: $SA^{Item} - SDA^{Item} = 0$ and: $SB^{Item} - SDB^{Item} = 0$ and: $SC^{Item} - SDC^{Item} = 0$	If: $0 \le SA^{Item} - SDA^{Item} \le (4 * MSPF)$ Or if: $0 \le SB^{Item} - SDB^{Item} \le (5 * MSPF)$	If: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SA^{Item} - SDA^{Item} = 0$ and: $SB^{Item} - SDB^{Item} = 0$ and: $SC^{Item} - SDC^{Item} > 0$
Transversal	0,0		
Return	0,0		
Combined	$1-(0.5*((((SA^{Item}-SDA^{item}) \le (4*MSPF))+((SB^{Item}-SDB^{Item}) \le (5*MSPF)))>0)+0.5*(((SA^{Case}-SDA^{Case})+(SB^{Case}-SDB^{Case}))>0)+((SA^{Case}-SDA^{Case})=0)*((SB^{Case}-SDB^{Case})=0)*((SA^{Item}-SDA^{Item})=0)*((SB^{Item}-SDB^{Item})=0)*((SC^{Item}-SDC^{Item})=0)+0.5*((((SA^{Item}-SDA^{Item})>(4*MSPF))+((SB^{Item}-SDB^{Item})>(5*MSPF)))>0)-0.5*((SA^{Case}-SDA^{Case})=0)*((SA^{Item}-SDA^{Item})=0)*((SB^{Item}-SDB^{Item})=0)*((SB^{Case}-SDB^{Case})=0)*((SC^{Case}-SDC^{Case})>0))$		
B5	If: $SC^{Item} - SDC^{Item} > 0$		If: $SC^{Item} - SDC^{Item} = 0$
Transversal	0,0		
Return	$((SC^{Item}-SDC^{Item})=0)$		
Combined	$((SC^{Item}-SDC^{Item})=0)$		
C1	If: $SC^{Case} - SDC^{Case} > (22 * MSPF)$	If: $0 \le SC^{Case} - SDC^{Case} \le (22 * MSPF)$	If: $SC^{Case} - SDC^{Case} = 0$
Transversal	0,0		
Return	$0.5*((SC^{Case}-SDC^{Case}) \le (22*MSPF))+0.5*((SC^{Case}-SDC^{Case})=0)$		
Combined	$0.5*((SC^{Case}-SDC^{Case}) \le (22*MSPF))+0.5*((SC^{Case}-SDC^{Case})=0)$		
C2	If: $SA^{Case} - SDA^{Case} > (4 * MSPF)$ Or if: $SB^{Case} - SDB^{Case} > (5 * MSPF)$ Or if: $SC^{Case} - SDC^{Case} > (14 * MSPF)$ Or if: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$ and: $SA^{Item} - SDA^{Item} = 0$	If: $0 \le SA^{Case} - SDA^{Case} \le (4 * MSPF)$ and: $0 \le SB^{Case} - SDB^{Case} \le (5 * MSPF)$ and: $0 \le SC^{Case} - SDC^{Case} \le (14 * MSPF)$	If: $SA^{Case} - SDA^{Case} = 0$ and: $SB^{Case} - SDB^{Case} = 0$ and: $SC^{Case} - SDC^{Case} = 0$ and: $SA^{Item} - SDA^{Item} > 0$ o/a: $SB^{Item} - SDB^{Item} > 0$ o/a: $SC^{Item} - SDC^{Item} > 0$

	and: SB^{Item} - SDB^{Item} = 0 and: SC^{Item} - SDC^{Item} = 0		
Transversal	0,0		
Return	$\mathbf{0,0}$		
Combined	$1-(0.5*((SA^{Case}-SDA^{Case})\leq(4*MSPF))*((SB^{Case}-SDB^{Case})\leq(5*MSPF))*((SC^{Case}-SDC^{Case})\leq(14*MSPF))+0.5*((SA^{Case}-SDA^{Case})=0)*((SB^{Case}-SDB^{Case})=0)*((SC^{Case}-SDC^{Case})=0)*((SA^{Item}-SDA^{Item})=0)*((SB^{Item}-SDB^{Item})=0)*((SC^{Item}-SDC^{Item})=0)+\left(\left(((SA^{Case}-SDA^{Case})>(4*MSPF))+((SB^{Case}-SDB^{Case})>(5*MSPF))+((SC^{Case}-SDC^{Case})>(14*MSPF))\right)>0\right))$		
C3	If: SC^{Case} - SDC^{Case} > (4 * MSPF)	If: 0 ≤ SC^{Case} - SDC^{Case} ≤ (4 * MSPF)	If: SC^{Case} - SDC^{Case} = 0
Transversal	0,0		
Return	$0.5*((SC^{Case}-SDC^{Case})\leq(4*MSPF))+0.5*((SC^{Case}-SDC^{Case})=0)$		
Combined	$0.5*((SC^{Case}-SDC^{Case})\leq(4*MSPF))+0.5*((SC^{Case}-SDC^{Case})=0)$		
C4	If: SA^{Item} - SDA^{Item} > (4 * MSPF) Or if: SB^{Item} - SDB^{Item} > (5 * MSPF) Or if: SC^{Item} - SDC^{Item} > (14 * MSPF) Or if: SA^{Case} - SDA^{Case} > 0 Or if: SB^{Case} - SDB^{Case} > 0 Or if: SC^{Case} - SDC^{Case} > 0 Or if: SA^{Case} - SDA^{Case} = 0 and: SB^{Case} - SDB^{Case} = 0 and: SC^{Case} - SDC^{Case} = 0 and: SA^{Item} - SDA^{Item} = 0 and: SB^{Item} - SDB^{Item} = 0 and: SC^{Item} - SDC^{Item} = 0	If: 0 ≤ SA^{Item} - SDA^{Item} ≤ (4 * MSPF) Or if: 0 ≤ SB^{Item} - SDB^{Item} ≤ (5 * MSPF) Or if: 0 ≤ SC^{Item} - SDC^{Item} ≤ (14 * MSPF)	
Transversal	0,0		
Return	$\mathbf{0,0}$		
Combined	$1-(0.5*\left(\left(((SA^{Item}-SDA^{Item})\leq(4*MSPF))+((SB^{Item}-SDB^{Item})\leq(5*MSPF))+((SC^{Item}-SDC^{Item})\leq(14*MSPF))\right)>0\right)+0.5*\left(((SA^{Case}-SDA^{Case})+(SB^{Case}-SDB^{Case})+(SC^{Case}-SDC^{Case}))>0\right)+((SA^{Case}-SDA^{Case})=0)*((SB^{Case}-SDB^{Case})=0)*((SC^{Case}-SDC^{Case})=0)*((SA^{Item}-SDA^{Item})=0)*((SB^{Item}-SDB^{Item})=0)*((SC^{Item}-SDC^{Item})=0)+0.5*\left(\left(((SA^{Item}-SDA^{Item})>(4*MSPF))+((SB^{Item}-SDB^{Item})>(5*MSPF))+((SC^{Item}-SDC^{Item})>(14*MSPF))\right)>0\right)$		
C5	If: SC^{Item} - SDC^{Item} > (4 * MSPF)	If: 0 ≤ SC^{Item} - SDC^{Item} ≤ (4 * MSPF)	If: SC^{Item} - SDC^{Item} = 0
Transversal	0,0		
Return	$0.5*((SC^{Item}-SDC^{Item})\leq(4*MSPF))+0.5*((SC^{Item}-SDC^{Item})=0)$		
Combined	$0.5*((SC^{Item}-SDC^{Item})\leq(4*MSPF))+0.5*((SC^{Item}-SDC^{Item})=0)$		
C8	If: SA^{Case} - SDA^{Case} > (4 * MSPF) Or if: SB^{Case} - SDB^{Case} > (5 * MSPF) Or if: SC^{Case} - SDC^{Case} > (9 * MSPF) Or if: SA^{Case} - SDA^{Case} = 0 and: SB^{Case} - SDB^{Case} = 0 and: SC^{Case} - SDC^{Case} = 0 and: SA^{Item} - SDA^{Item} = 0 and: SB^{Item} - SDB^{Item} = 0 and: SC^{Item} - SDC^{Item} = 0	If: 0 ≤ SA^{Case} - SDA^{Case} ≤ (4 * MSPF) and: 0 ≤ SB^{Case} - SDB^{Case} ≤ (5 * MSPF) and: 0 ≤ SC^{Case} - SDC^{Case} ≤ (9 * MSPF)	If: SA^{Case} - SDA^{Case} = 0 and: SB^{Case} - SDB^{Case} = 0 and: SC^{Case} - SDC^{Case} = 0 and: SA^{Item} - SDA^{Item} > 0 o/a: SB^{Item} - SDB^{Item} > 0 o/a: SC^{Item} - SDC^{Item} > 0
Transversal	0,0		
Return	$\mathbf{0,0}$		
Combined	$1-(0.5*((SA^{Case}-SDA^{Case})\leq(4*MSPF))*((SB^{Case}-SDB^{Case})\leq(5*MSPF))*((SC^{Case}-SDC^{Case})\leq(9*MSPF))+0.5*((SA^{Case}-SDA^{Case})=0)*((SB^{Case}-SDB^{Case})=0)*((SC^{Case}-SDC^{Case})=0)*((SA^{Item}-SDA^{Item})=0)*((SB^{Item}-SDB^{Item})=0)*((SC^{Item}-SDC^{Item})=0)$		

	$+\left(\left(\left((SA^{Case}-SDA^{Case})>(4*MSPF)\right)+\left((SB^{Case}-SDB^{Case})>(5*MSPF)\right)+\left((SC^{Case}-SDC^{Case})>(9*MSPF)\right)\right)>0\right))$		
C10	If: SA^{Item} - SDA^{Item} > (4 * MSPF) Or if: SB^{Item} - SDB^{Item} > (5 * MSPF) Or if: SC^{Item} - SDC^{Item} > (9 * MSPF) Or if: SA^{Case} - SDA^{Case} > 0 Or if: SB^{Case} - SDB^{Case} > 0 Or if: SC^{Case} - SDC^{Case} > 0 Or if: SA^{Case} - SDA^{Case} = 0 and: SB^{Case} - SDB^{Case} = 0 and: SC^{Case} - SDC^{Case} = 0 and: SA^{Item} - SDA^{Item} = 0 and: SB^{Item} - SDB^{Item} = 0 and: SC^{Item} - SDC^{Item} = 0	If: 0 ≤ SA^{Item} - SDA^{Item} ≤ (4 * MSPF) Or if: 0 ≤ SB^{Item} - SDB^{Item} ≤ (5 * MSPF) Or if: 0 ≤ SC^{Item} - SDC^{Item} ≤ (9 * MSPF)	
Transversal	$Total\ number\ of\ stops = Stops = StopsA + StopsB + StopsC$		
Return	$Total\ number\ of\ stops = Stops = StopsA + StopsB + StopsC$		
Combined	$1-(0.5*(\left(((SA^{Item}-SDA^{Item})\leq(4*MSPF))+((SB^{Item}-SDB^{Item})\leq(5*MSPF))+((SC^{Item}-SDC^{Item})\leq(9*MSPF))\right)>0)+0.5*\left(((SA^{Case}-SDA^{Case})+(SB^{Case}-SDB^{Case})+(SC^{Case}-SDC^{Case}))>0\right)+((SA^{Case}-SDA^{Case})=0)*((SB^{Case}-SDB^{Case})=0)*((SC^{Case}-SDC^{Case})=0)*((SA^{Item}-SDA^{Item})=0)*((SB^{Item}-SDB^{Item})=0)*((SC^{Item}-SDC^{Item})=0)+0.5*\left(\left(((SA^{Item}-SDA^{Item})>(4*MSPF))+((SB^{Item}-SDB^{Item})>(5*MSPF))+((SC^{Item}-SDC^{Item})>(9*MSPF))\right)>0\right)$		

Appendix H: Verification results

In this appendix, all tables and graphs that support the model verification have been provided.

Table 45: Anti-bugging results test 1

Step-by-step walk through – result test 1												
Amount of stops registered at the entry of the entity												
	S	SA	SB	SC	S^{case}	S^{item}	SA^{case}	SA^{item}	SB^{case}	SB^{item}	SC^{case}	SC^{item}
1	11	11			7	4	7	4				
2	3	3			2	1	2	1				
3	2	1	1		2		1		1			
4	4	4			2	2	2	2				
5	3	3			3		3					
Picker	23	22	1		16	7	15	7	1			
Sim.	23	22	1		16	7	15	7	1			
Workstation							Time in		Time out		Processing time	
Get equipment							06:00:03		06:03:01			
Consolidation							06:10:41		06:11:23			
Get equipment							06:13:01		06:15:38			
Consolidation							06:20:36		06:29:22			
Amount of stops done per flow rack section at sink of order picker												
	SD	SDA	SDB	SDC	SD^{case}	SD^{item}	SDA^{case}	SDA^{item}	SDB^{case}	SDB^{item}	SDC^{case}	SDC^{item}
Picker	23	22	1		16	7	15	7	1			

Table 46: Anti-bugging results test 2

Step-by-step walk through – result test 2												
Amount of stops registered at the entry of the entity												
	S	SA	SB	SC	S^{case}	S^{item}	SA^{case}	SA^{item}	SB^{case}	SB^{item}	SC^{case}	SC^{item}
1	4	4			4		4					
2	16	16			10	6	10	6				
3	2	2			1	1	1	1				
4	6	6			4	2	4	2				
5	7	7			7		7					
Picker	35	35			26	9	26	9				
Sim.	35	35			26	9	26	9				
Workstation							Time in		Time out		Processing time	
Get equipment							06:00:05		06:02:56			
Consolidation							06:13:34		06:14:14			
Get equipment							06:15:52		06:17:33			
Consolidation							06:23:08		06:33:01			
	Amount of stops done per flow rack section at sink of order picker											
	SD	SDA	SDB	SDC	SD^{case}	SD^{item}	SDA^{case}	SDA^{item}	SDB^{case}	SDB^{item}	SDC^{case}	SDC^{item}
Picker	32	32			24	8	24	8				

Table 47: Anti-bugging results test 3

Step-by-step walk through – result test 3

Amount of stops registered at the entry of the entity												
	S	SA	SB	SC	S^{case}	S^{item}	SA^{case}	SA^{item}	SB^{case}	SB^{item}	SC^{case}	SC^{item}
1	3	3			2	1	2	1				
2	2	2			2		2					
3	1	1			1		1					
4	6		6		6				6			
5	2	2			1	1	1		1			
Picker	14	8	6		12	2	6	2	6			
Sim.	14	8	9		12	2	6	2	6			
Workstation							Time in		Time out		Processing time	
Get equipment							07:10:42		07:13:10			
Consolidation							07:19:30		07:20:12			
Get equipment							07:21:49		07:24:00			
Consolidation							07:27:01		07:34:32			
Amount of stops done per flow rack section at sink of order picker												
	SD	SDA	SDB	SDC	SD^{case}	SD^{item}	SDA^{case}	SDA^{item}	SDB^{case}	SDB^{item}	SDC^{case}	SDC^{item}
Picker	14	8	9		12	2	6	2	6			

Table 48: Anti-bugging results test 4

Step-by-step walk through – result test 4												
Amount of stops registered at the entry of the entity												
	S	SA	SB	SC	S^{case}	S^{item}	SA^{case}	SA^{item}	SB^{case}	SB^{item}	SC^{case}	SC^{item}
1	5	3	2		3	2	2	1	1	1		
2	7	7			7		7					
3	2	1	1									
4	11	11			7	4	7	4				
5	8	5	3		3	3	2	2	1	1		
Picker	33	27	6		20	9	18	7	2	2		
Sim.	37	29	8		24	13	20	9	4	4		
Workstation							Time in		Time out		Processing time	
Get equipment							12:15:12		12:17:55			
Consolidation							12:27:53		12:28:35			
Get equipment							12:30:13		12:32:16			
Consolidation							12:40:08		12:49:23			
Amount of stops done per flow rack section at sink of order picker												
	SD	SDA	SDB	SDC	SD^{case}	SD^{item}	SDA^{case}	SDA^{item}	SDB^{case}	SDB^{item}	SDC^{case}	SDC^{item}
Picker	37	29	8		24	13	20	9	4	4		

Table 49: Anti-bugging results test 5

Step-by-step walk through – result test 4												
Amount of stops registered at the entry of the entity												
	S	SA	SB	SC	S^{case}	S^{item}	SA^{case}	SA^{item}	SB^{case}	SB^{item}	SC^{case}	SC^{item}
1	7	7			7		7					
2	6	4	2		3	3	2	2	1	1		
3	17	14	3		10	7	8	6	2	1		
4	4		4		4				4			
5	8	8			5	3	5	3				

	SD	SDA	SDB	SDC	SD^{case}	SD^{item}	SDA^{case}	SDA^{item}	SDB^{case}	SDB^{item}	SDC^{case}	SDC^{item}
Picker	42	33	9		29	13	22	11	7	2		
Sim.	42	33	9		29	13	22	11	7	2		

Workstation	Time in	Time out	Processing time
Get equipment	15:57:15	15:59:44	
Consolidation	16:10:23	16:10:59	
Get equipment	16:12:36	16:15:35	
Consolidation	16:22:23	16:38:12	

Amount of stops done per flow rack section at sink of order picker

	SD	SDA	SDB	SDC	SD^{case}	SD^{item}	SDA^{case}	SDA^{item}	SDB^{case}	SDB^{item}	SDC^{case}	SDC^{item}
Picker	42	33	9		29	13	22	11	7	2		

APPENDIX I: SIMULATION RESULTS

In this appendix the figures of the simulation results of the KPIs total time in system, TIS and the time in system without waiting for batching, TIS - WTB are provided.

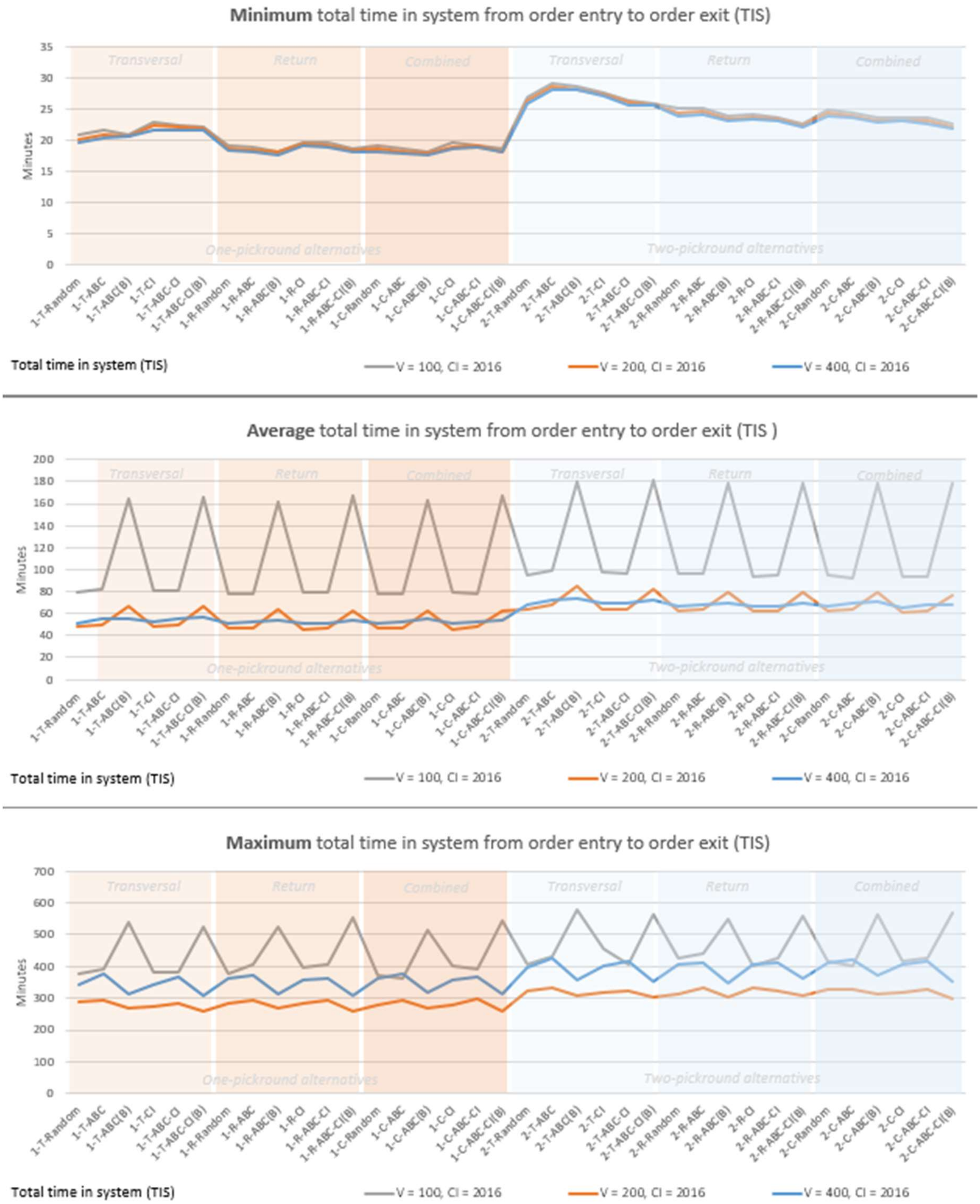


Figure 52: Results experiment 1 to 3: minimum, average and maximum TIS

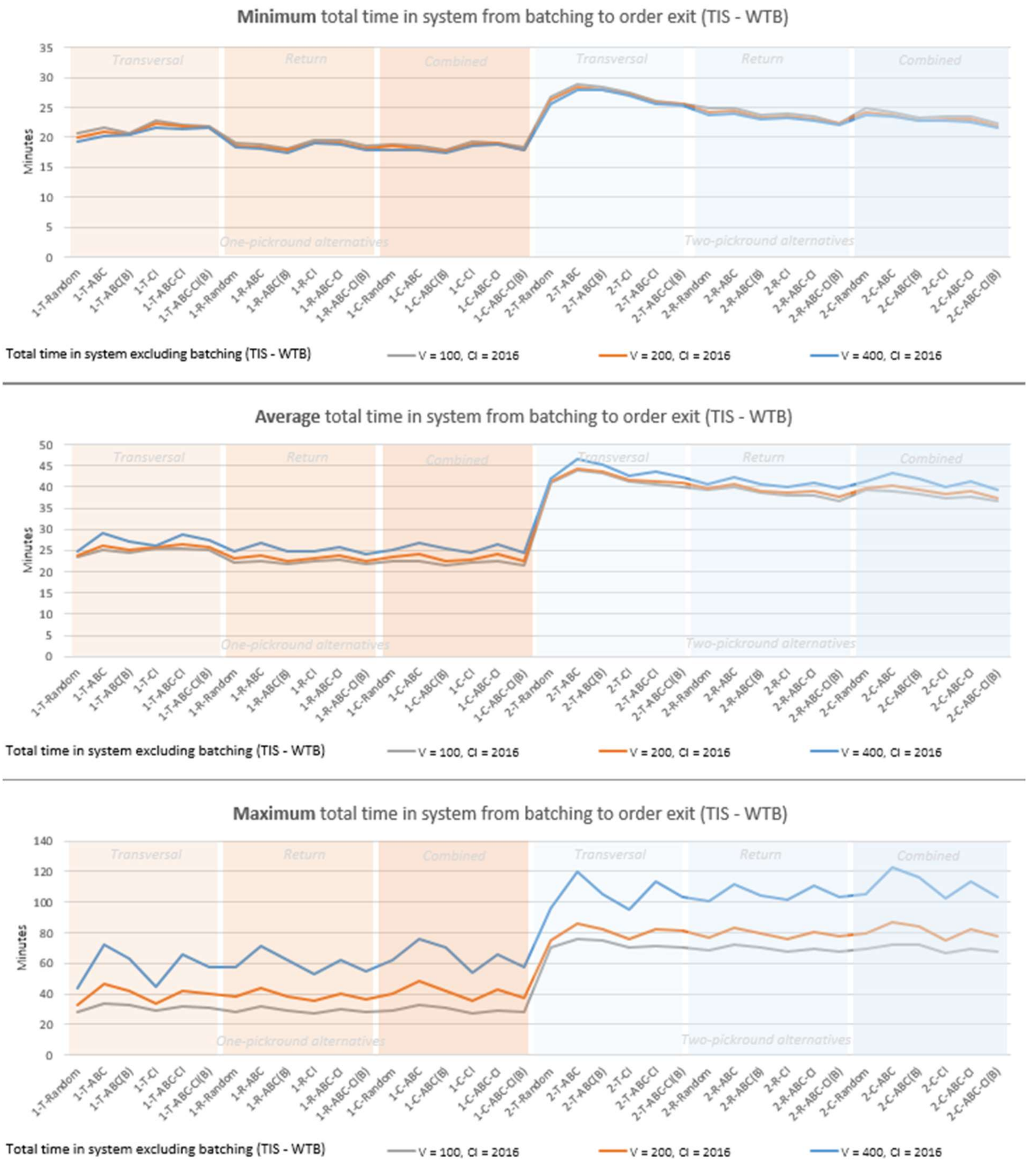
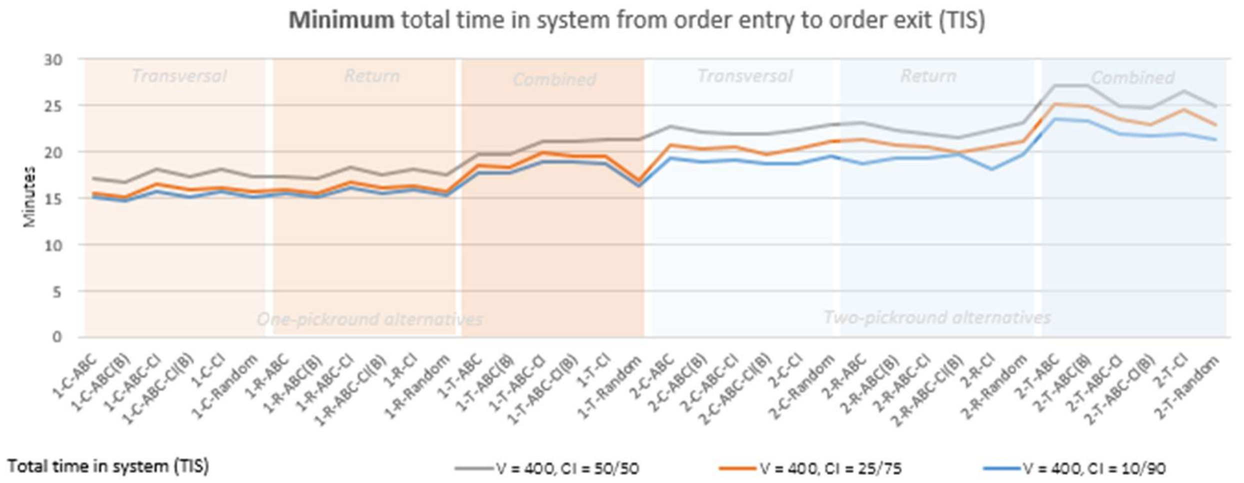
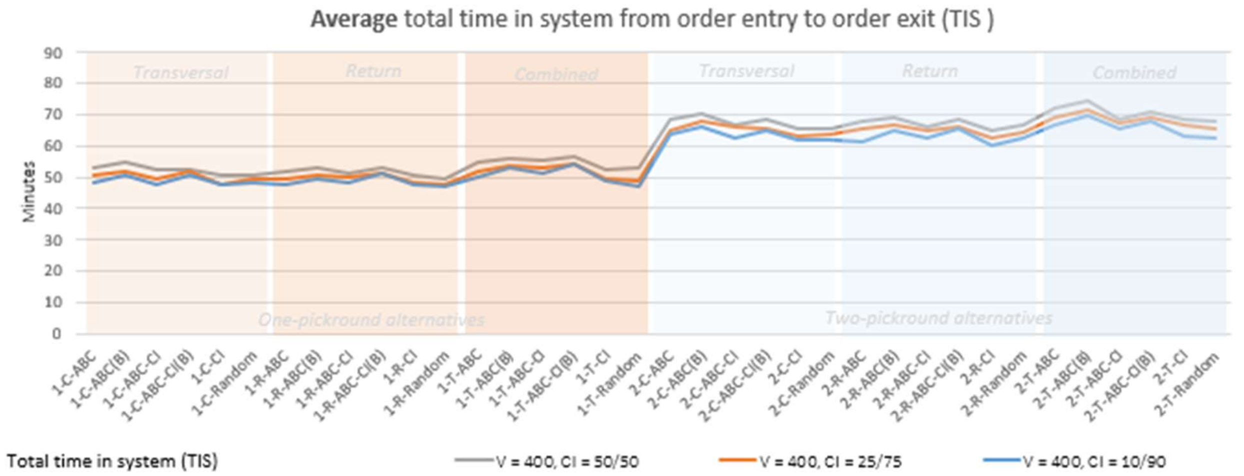


Figure 53: Results experiment 1 to 3: minimum, average and maximum TIS-WTB





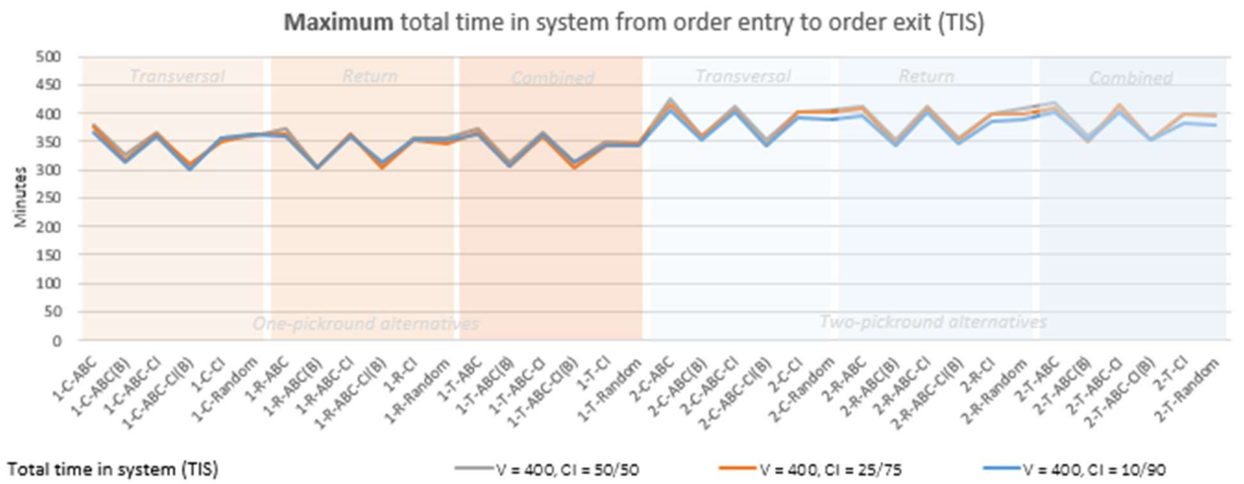


Figure 54: Results experiment 4 to 6: minimum, average and maximum TIS

Figure 55: Results experiment 4 to 6: minimum, average and maximum TIS-WTB

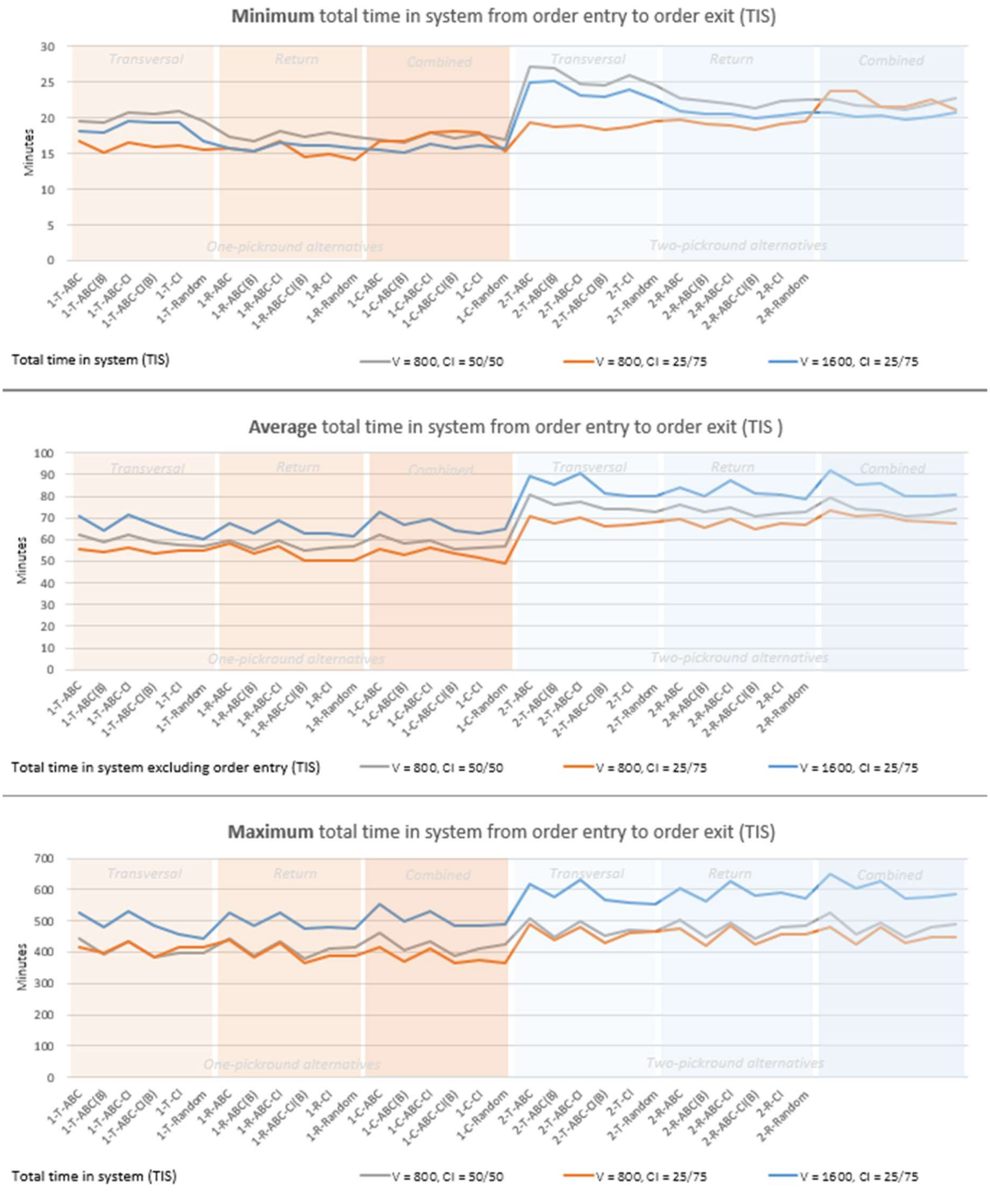


Figure 56: Results experiment 7 to 9: minimum, average and maximum TIS

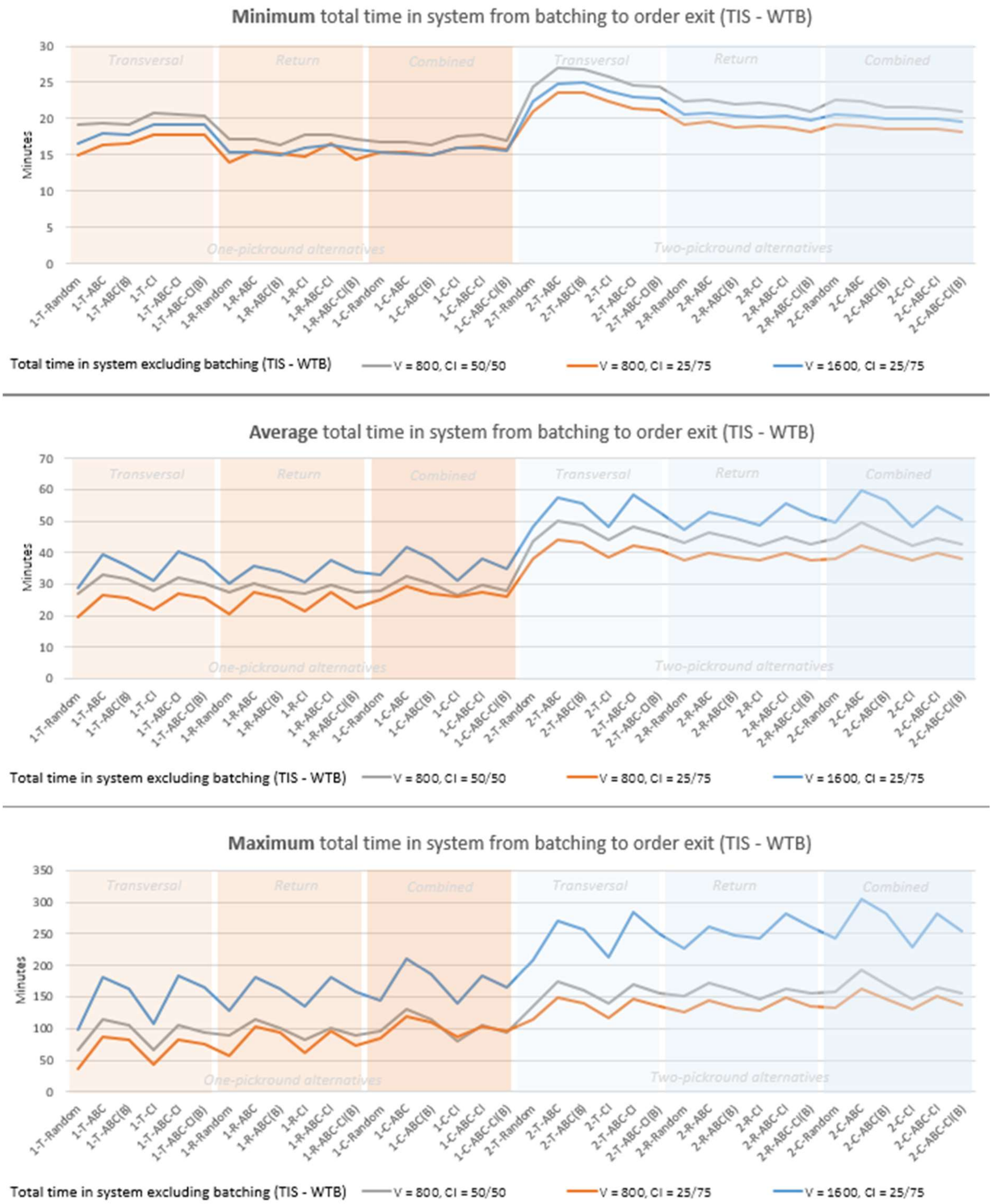


Figure 57: Results experiment 7 to 9: minimum, average and maximum TIS-WTB