

Improving the inbound system at fulfillment centers

What strategies can be
designed to eliminate
non-unloaded rejected trucks
at fulfillment centers?

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by

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Preface

This report presents the results of my research, which is part of the Masters's degree in Transport, Infrastructure and Logistics at the Delft University of Technology. It represents the work I have done during my 7 months graduation internship at bol.com. It marks the end of both my thesis research and time as a student. It has been an amazing period of my life in which I've learned many lessons.

The past few months I was able to conduct my graduation research project at bol.com which has been an incredible opportunity, making the entire process even more enjoyable in which I learned a lot about the complex logistic operations. I had the opportunity to visit the Bol Fulfillment Center in Waalwijk multiple times, which was such a cool experience to witness a part of the logistics world in practice. Also, I now understand precisely how my next order at bol.com is prepared, and I love telling all of you about it! I want to thank the entire 'WRI' team for the warm welcome from the beginning and always willing to help me with answering numerous questions and participate in brainstorm sessions for my research which was very valuable. Their support made my internship very pleasant and I will cherish the moments I've shared with all of you, especially our ping pong games during work hours. Finally, I want to say a huge (!) thanks to my supervisor at bol.com, Joost Hartsink. Your dedication, guidance, valuable feedback, and challenging me to think outside the box (especially the push towards the simulation modeling approach) was very valuable. Thanks for the good talks for keeping me motivated throughout this project. I have couldn't wish for a better supervisor.

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Then lastly, I want to say special thanks to my family and friends for their unconditional support and motivation throughout my thesis research project. First of all, I want to especially thank my parents and my sister. My father, for always willing to think with me about the content of my project at literally any given time. Our brainstorming sessions were gold! My mother, for being my best mental advisor and always helping me to put things into perspective. And finally, my sister, my go-to for venting sessions. Thanks for always answering my endless questions about the process which you've already experienced. Also, big shoutout to my housemates from Schiebroeksestraat in Rotterdam. You were always willing to hear me out and provided me with valuable feedback and support. And to my fellow 'cali' graduation friends - thanks for all the tips and tricks we shared with each other.

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Summary

The continuing growing economy and increase in global trade has led the rapid growth of the e-commerce (Guan and Liu, 2009; Taher, 2021). The covid-19 pandemic has further contributed to this growth since in store-shopping was restricted. (Bhatti et al., 2020; Sardjono et al., 2021; Kawasaki et al., 2022). The growth of the e-commerce has forced logistic companies to continuously improve their supply chain in order to stay competitive (Alvarez-Placencia et al., 2020; Ramaa et al., 2012) and has also led to the increase of truck transportation as they serve as the primary mode of transporting products from suppliers to Fulfillment Centers (FCs) within the inbound system. This highlights the importance of truck logistics, which encompass all the different movements trucks make within a FC. Truck logistics have a significant impact on the flow of the inbound system as they proceed through the processes of the inbound system in chronological order. Therefore, poor organized truck logistics can have many consequences to the operational logistics of the inbound system and therefor impact the system performance of the inbound system. Multiple literature studies have analyzed these consequences and are related to high congestion of trucks, high waiting times, delays in unloading trucks and as a result poor overall system performance. Those studies also show that there are multiple strategies available that can improve the inbound system. However, none of the published research that concerns the improvement of the inbound systems regarding truck logistics is focused on FCs. Furthermore, no research can be found on concerning the consequence of eliminating the rejection of non-unloaded trucks. This research addresses the research gap of improving the inbound system of FCs with the objective of eliminating the rejection of non-unloaded trucks and reducing the pressure on the waiting areas within the inbound system. This is done by developing a Discrete Event Simulation (DES) model for FCs to measure, analyze and evaluate the impact of the increasing truck logistics on the system performance of the inbound system and to design strategies to eliminate the rejection of non-unloaded trucks. The main question of this research was:

"How can fulfillment centers eliminate rejecting non-unloaded trucks, by improving their inbound process?"

A case study was conducted at the logistic company bol.com at one of their FCs: Bol Fulfillment Center (BFC). Recently, during the peak periods of bol.com, BFC faced situations where the municipality forced them to reject non-unloaded trucks that were queued on the road outside. Rejecting trucks means that those trucks can't be unloaded and need to be rescheduled, leading to potential delays in stock replenishment or order processing. By conducting a case study at an e-commerce company facing issues with truck rejections at their FCs, their data can be used to develop a simulation model. This will help identify potential strategies to enhance the performance of the inbound system and eliminate truck rejections.

A current state analysis, encompassing both qualitative and quantitative method, has been performed of the inbound system of BFC in order to identify the logistic bottlenecks. The inbound system consist of four main processes which is arrival, enter, unload and departure of which truck logistics are a part of. Two waiting areas, associated with the arrival and enter process, accommodate parked an waiting trucks. When these waiting areas get too full, it can lead the queuing outside on the road which lead to the rejection of non-unloaded trucks. The logistic bottlenecks are the following. First, having no official capacity set by BFC to the waiting areas results in the possibility of endless queue forming. Second, the inconsistent paperwork received from the carriers and varying service times during the arrival process is a result of non-standardized carrier documentation and working procedures for port operators. This leads to higher and varying service times which leads to lower processing rate of trucks in the arrival process which results in more congestion of trucks in the waiting area. Third, 56.6% of daily arriving trucks concentrate in the morning, causing congestion, longer waiting times, and delays in dock assignment in the morning. Fourth, many trucks are arriving with a underutilized truckload, increasing the overall number of trucks arriving. Finally, during the unloading of trucks, there is a high unloading time for trucks due to high preparation time of truck drivers since they need to unload the trucks themselves and double checking the paperwork. These identified logistic bottlenecks contribute to higher waiting times and high congestion in the two waiting areas, and therefore a higher probability of rejecting non-unloaded trucks. This resulted in the identification of three Key Performance Indicators which will be used for the assessment of the system performance. These are: the probability of exceeding the capacity of the waiting area at the port and dock (KPI 1); Number of trucks parked at the waiting area at the port and dock (KPI 2); Waiting time per truck in queue during arrival and enter

process (KPI 3).

A simulation model was developed using the DES modelling technique, integrated with the Monte Carlo Simulation (MCS). With this model it was able to design and assess the impact of several potential strategies aimed at eliminating the rejection of non-unloaded trucks and alleviating the pressure on both waiting areas. The structure of the model is based on the studied inbound system of BFC and includes the four main processes: arrival, enter, unload and departure. The DES allows for the analysis of the interaction between the main processes, sub-processes and the truck logistics that move through this system in chronological order. Data for the simulation was gathered and structured into input and output data in order to finalize the construction of the simulation model. By integrating stochastic parameters, the model acknowledges uncertainties in truck arrivals and service times enhancing its realism. Verification and validation techniques ensure the model's functionality and accuracy which resulted in a proper working simulation model.

By means of an experimental plan in which the system requirements have been determined, it was able to identify and design potential strategies. This was done by identifying four key variables that are based on strategies proposed in literature, brainstorm session with bol.com and the system requirements. It is important that these strategies align with objective of this research and that they are realistic for bol.com to implement. The four key variables are based on varying the input parameters of the simulation model. The first one is the reducing of the arrival rate by increasing the number of arriving trucks with large truckloads. The second variable is the reduction of the service time per truck during arrival process. The third one, is the decrease of the basic duration during the unload process and the fourth is the even distribution of truck arrivals throughout the day. By experimenting with variations and different combinations of these key variables, a strategic selection has been made which resulted in the identification of 16 potential strategies that have a significant impact and could improve the system performance of the inbound system.

The 16 strategies have been tested against the three KPIs across the three future scenarios: SC1 (2023), SC2 (2024) and SC3 (2025). These are chosen since within these years it's expected that BFC will grow and therefore expects more arriving trucks each year. Analyzing the base cases, revealed a 49.2% increase in 2025 compared to 2023 regarding the probability of exceeding the capacity at the waiting area at the port, attributed to higher arrival rates. Additionally, the probability of exceeding the capacity at the waiting area at the dock is expected to increase by 13.9% in 2025 due to a truck throughput rate from arrival to enter exceeding 40, when arrival rates reach 35 or higher. Out of the 16 strategies, 7 strategies have been identified to successfully improve the system performance of the inbound system across all KPIs and scenarios.

An improvement of the system performance across all KPIs can first be achieved by applying certain strategies in which the arrival rate of trucks can be reduced to 30 or lower. This can be achieved by strategy 1.3, in which there is a 50% adjustment of truckloads and the even distribution of truck arrivals throughout the day. These strategies have shown to positively impact the arrival, enter and unload process. Only reducing the service time during the arrival process in strategy 2, negatively impacts the unload process and only reducing the basic duration of the unloading time in strategy 3 hasn't impact the arrival process at all. This resulted in only a partial improvement of the system performance. However, combining these with each other has resulted in another set of strategies that improve the system performance across all KPIs. First, combining the adjustments of truckloads by 40% and 50%, which reduces the arrival rate to 35 or lower, with the reduction of the service time to 1.36 min, resolves the negative impact on the unload process as it keeps the throughput rate of trucks from arrival to enter process to 40 or lower (strategy 6 and 7). Additionally, the variability in the number of trucks parked in these strategies is lower compared to strategy 1.3 and 4 due to the faster processing of trucks due to the reduction of service time. Second, as the reduction of the unloading time does not impact the arrival process, it can be combined with the reduction of the arrival rate by the 50% adjustment in strategy 10, which resulted in a 0% probability for both waiting areas. Third, combining the reduction of the service time to 1.36 min and the reduction of the basic duration to 5 min in strategy 11, which both impact different processes in the inbound process, has shown to be an effective strategy in achieving the 0% probability for both waiting areas in which the reduction of the arrival rate of trucks is not even necessary. Finally, strategy 12 which is the combination of the 50% adjustment in truckloads with the even distribution of truck arrivals, which results in the lowest and constant number of trucks parked throughout the day as these have a reinforcing impacts on each other as they both positively impact the arrival, enter and unload process. It has also been shown that the waiting time is reduced compared to the base cases in all these strategies, especially when it involves the reduction of the service time

as it ensures faster processing of trucks. To conclude, 7 strategies have been identified that all improve the system performance across all KPIs and scenarios, but a distinction can be made regarding the extent in which they improve the inbound system and therefore an evaluation is required.

The evaluation of the 7 strategies is performed to select the most appropriate strategy for bol.com to implement given their operational current circumstances. A Multi Criteria Analysis (MCA) was conducted, taking into account the technical and operational implementation efforts required for bol.com, as well as the implications for their partners and carriers. Criteria, derived from the research objective and system requirements, were weighted based on their significance to BFC. Criteria with the highest score included the number of rejecting non-unloaded trucks and risks of partners and carriers not participating. This illustrates the trade-off that is involved when selecting the most appropriate strategy for bol.com, weighing the improvements on the inbound system's performance against the associated risks and implementation efforts. This evaluation concludes that strategy 11 is the most appropriate strategy for bol.com to implement. It covers the reduction of the service time to 1.36 minutes and the reduction of basic duration of unloading time to 5 minutes. This strategy ensures a faster truck processing rate during the arrival process by the port operators, leading to reduced congestion at the waiting area at the port. When paired with the expedited unloading time due to the reduction of the basic duration, it ensures a faster unloading speed of trucks which meet the faster throughput rate of trucks during the arrival process. This combination within the strategy is focused on optimizing the internal resources which is beneficial for bol.com as they have already direct control over these resources. It also requires less implementation effort as the systems are already in place and needs limited adjustments. Moreover, this strategy is associated with low risks of no participation of partners and carriers. This results in a strategy that finds a good balance between managing risks, ease of implementation, and effectively addressing the issue of rejecting non-unloaded trucks. While there are other strategies that might present slightly enhanced outcomes for KPI 2 and KPI 3, those strategies currently pose many risks regarding the lack of participation of partners and carriers and complex technical and operational implementations efforts for bol.com. However, this offers an opportunity for bol.com to determine to what extent adjustments could be made to their current situation to mitigate the associated risks and efforts in order to make these strategies more viable to be able to implement them in the future. To conclude, bol.com can eliminate the rejection of non-unloaded trucks by improving the inbound system in which the service time in the arrival process is reduced to 1.36 minutes and reducing the basic duration of the unloading time to 5 min.

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Acronyms

Abbreviation	Definition
BFC	Bol Fulfilment Center
DES	Discrete Event Simulation
DTC	Delivery Terms & Conditions
EAN	European Article Number
FC	Fulfillment Center
KPI	Key Performance Indicators
LVB	Delivery Via Bol.com
MCS	Monte Carlo Simulation
R1	Retailer 1
SCP	Supplier Chain Portal
SDD	Sellers Dashboard
SKU	Stock Keeping unit
SSCC	Serial Shipping Container Code
TTT	Truck Turnaround Time

Definitions

Logistic facility Logistic facility is a designated location where activities take place related to the management, storage, and distribution of goods. These facilities have a critical role in the supply chain, facilitating the movement of products from retailers or manufacturers to consumers.

Peak period of bol.com The peak period of bol.com is the months in which there is an high increase in orders due to the holidays. It covers the months October, November and December.

Rejected trucks Truck rejection occurs when bol.com is mandated by the municipality to send away non-unloaded trucks that are queued on the road due to capacity issues of the waiting areas within the inbound system of BFC.

Truck logistics All the different movements trucks make within the yard at a logistic facility.

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1. Introduction

This chapter contains the introduction to this research. Section 1.1 will give the context of this research. Section 1.2 will explain the incentive behind this research in which the case study will be introduced and the objective of the research will be explained. The scientific and practical relevance of this research will be described in Section 1.3 and 1.4 respectively. Additionally, the research scope will be explained in Section 1.5, followed by the main-research question and an overview of the 8 sub-questions that will be answered in this research in Section 1.6. The structure of the research methodology will be explained in Section 1.7. Finally, an outline of the complete report will be given in Section 1.8.

1.1. Research Context

The continuing growth of the economy and increase in global trade has led to rapid growth of the e-commerce (Guan and Liu, 2009; Taher, 2021). The covid-19 health pandemic has further contributed to the growth of this sector (Bhatti et al., 2020; Sardjono et al., 2021; Kawasaki et al. 2022) as in-store shopping was restricted. The growth of the e-commerce has forced logistic companies to continuously improve their supply chain in order to stay competitive and to ensure, maintain fast and on-time delivery of products to end customers (Alvarez-Placencia et al., 2020; Ramaa et al., 2012). The rapid growth of e-commerce has also led to the increase of truck transportation, as they are one of the main drivers of the supply chain. At logistic facilities, with the focus on FCs in this research, trucks form a critical link in the inbound system as they serve as the primary mode of transportation for products between suppliers and FCs. In addition to their role of delivering products, trucks also have various other functions within FCs, which are defined as the truck logistics. The truck logistics includes all the different movements trucks make within the system of a FC: their arrival at the FC, the movements throughout the yard to the different inbound processes, and their departure. Truck logistics have a significant impact on the flow of the inbound system as they proceed through the processes of the inbound system in chronological order. Therefore, poor organized truck logistics can have many consequences to the operational logistics of the inbound system and therefore impact the system performance of the inbound system. With the increase of the e-commerce and therefore the increase in arriving trucks at the FCs, it is important to ensure a smooth flow of the truck logistics in order to have an efficient inbound system. Efficient inbound processing ensures that trucks move smoothly through the systems without any delays or high waiting times in order to unload trucks quickly to put these products on stock to fulfill the customer orders. Multiple literature studies have already highlighted the issues related to truck logistics at logistic facilities, such as many trucks arriving at the same time resulting in arrival peaks mainly in the morning, truck congestion and high waiting times which increase the Truck Turnaround Times (TTT) of trucks (Smith and Srinivas, 2019). Another issue that could happen is the issue of trucks queuing outside on the road due to overfull waiting areas within the inbound system. All of these issues related to truck logistics impacts the system performance of the inbound system negatively. This show the importance of maintaining an efficient truck logistics within the inbound system of a FC.

1.2. Research Incentive & Objective

Bol.com is the biggest e-commerce platforms of the Netherlands with a range of 36 million products and 51.000+ partners who sell their products via the bol.com online platform (bol.com, 2022). With 51.000 partners delivering products to the FCs of bol.com and the expected growth due to the continuously growth of e-commerce, it is crucial to constantly improve their logistic operations in order to stay competitive and to ensure quick delivery and excellent service to customers. For years, bol.com has focused on improving the outbound side to achieve fast en reliable delivery to end customers. However, with the growth of e-commerce and recognizing the equal importance of the inbound side, bol.com has recently shifted its focus towards improving the inbound side of BFC. The inbound system needs to ensure that products from the suppliers, brought by trucks, are quickly unloaded and booked on stock to meet the customers demand. Thereby, it is important that the truck logistics runs smoothly through the inbound system to ensure that trucks are unloaded as quick as possible. Currently, the inbound system at bol.com has occasionally experienced issues during the peak periods with the truck logistics in their inbound system. Unpredictable truck arrivals throughout the day, results in high service times, high waiting times and many trucks parked in front of the gate. Having many trucks parked in front of the porter lodge waiting to get processed by a port operator, increases the pressure on the waiting areas and could lead to a situation in which trucks need to wait outside on the road since there are more trucks arriving and than the capacity of the inbound system can handle. When this occurs, bol.com is forced by the municipality to reject these non-unloaded trucks as they traffic congestion on the public

road and surroundings. Rejecting trucks means that those trucks can't be unloaded on the desired delivery day and need to be rescheduled, leading to potential delays in stock replenishment or order processing. Additionally, continuously rejecting trucks can strain the relationships with the partners and carriers, which can affect certain collaborations. This indicates that the current regulation of the truck logistics in the inbound system of BFC during the peak period of bol.com, can't deal with the increased truck arrivals and impacts their system performance. Since bol.com is expected to grow in the next coming years, this problem will probably be escalated when the current situation remains unchanged.

Therefore, the objective of this research that will be addressed, is to eliminate rejecting non-unloaded trucks and reducing the pressure on the waiting areas within the inbound system, by improving the inbound system of the FC. Through qualitative and quantitative research methods, this research aims to provide a strategy for the logistic company bol.com on improving the inbound system for the next coming years. This can be formulated in the following main research question:

"How can fulfillment centers eliminate rejecting non-unloaded trucks, by improving their inbound process?"

1.3. Scientific Relevance & Research Gap

Conducting research into improving the inbound system of FCs with the aim of eliminating rejected trucks and reducing the pressure on the waiting areas holds significant scientific relevance. Despite the presence of research available on truck logistics at other logistics facilities, such as distribution centers, warehouses and marine/container terminals (Zhao and Goodchild, 2013; Gracia et al., 2017; Chen et al., 2011), there is a research gap in the literature regarding the improvement of truck logistics at FCs focusing on the elimination of the rejection of non-unloaded trucks and reducing the pressure on the waiting areas. By addressing this research gap, the research contributes to the advancement of knowledge in the field of supply chain management and logistics. Exploring the truck logistics at FCs, offers an opportunity to gain insights into the operational challenges and potential solutions specific to this context. By doing a case study of the truck logistics in the inbound system at a logistics company's fulfillment center, it becomes possible to conduct a research involving different measurements to identify bottlenecks and potential areas for improvement. The knowledge obtained from this research can then be shared between the domains of distribution centers, warehouses and marine/containers terminals, enabling valuable insights and methodologies for further related research.

1.4. Practical Relevance

The case study in this research is performed at bol.com in their BFC. The practical relevance of conducting the research at bol.com, is based on providing valuable insights into the current impact of the truck logistics within the inbound system and identifying bottlenecks. As it currently remains unclear for bol.com how truck logistics precisely affect their logistic operations, this research can offer findings and recommendations to improve the system performance of the inbound system. Bol.com has already experienced consequences related to truck logistics, such as truck queues forming outside the entrance of their FCs in which they are forced by the municipality to reject non-unloaded trucks. With the expected growth of e-commerce, these issues are expected to escalate further. Failure to take action puts bol.com's competitiveness against other major e-commerce companies at risk. By investigating the truck logistics within BFC, this research can identify the operational challenges and bottlenecks that arise in their inbound system. This understanding is crucial for bol.com to identify areas for improvement and recommend certain strategies to enhance their system performance of the inbound system.

1.5. Research Scope

The scope of this research is focused on the inbound system of Boll Fulfillment Center (BFC). Within the inbound system, this research is focused on the truck logistics which are part of arrival, enter, unload and departure. This leaves the processes receiving and putaway out of scope. As mentioned before, this research will only focus on one of the FCs of bol.com, BFC, which is operated by the logistic service company Ceva, and can be divided into BFC 1&2. The choice for BFC is made because, BFC processes 40%-50% of the total amount of distributed items. In Figure 1.2 a picture of BFC provides an indication of the lay-out. Furthermore, the research will focus on only pallet shipments, leaving the parcel shipments out of scope since the pallet shipments covers a wider range of truck arrivals and therefore more crucial to focus on. There will be no distinction made between the different partners of bol.com. The focus will be on the peak period of bol.com, which covers the months October, November

and December. During this period there is an increase in the truck arrivals compared to the other months and therefore prone to the elimination of rejecting non-unloaded trucks. A visual representation of the scope of this research can be seen in Figure 1.1. This figure shows the complete operational system of the BFC with the inbound and outbound systems. Within the dotted lines, the scope of this research is visible which covers a part of the inbound system: the arrival, entering and unloading process.

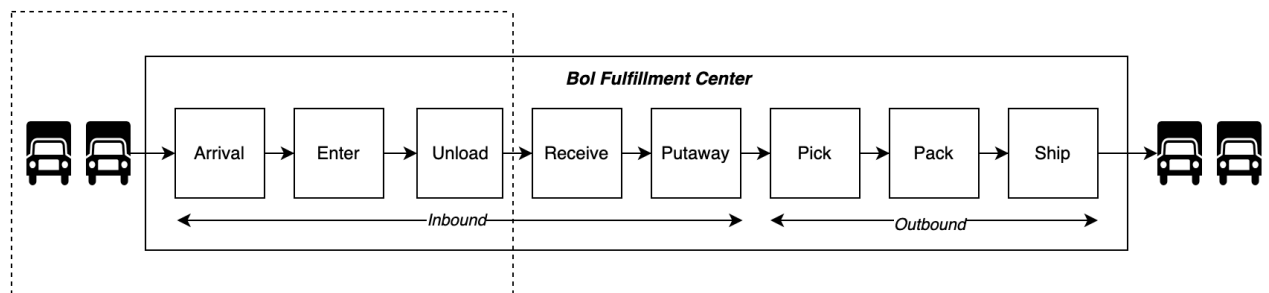


Figure 1.1: Scope of the research (source: author)



Figure 1.2: Bol Fulfillment Center 1 & 2 [22]

1.6. Research Questions

The main research question of this research is as followed:

"How can fulfillment centers eliminate rejecting non-unloaded trucks, by improving their inbound process?"

In order to answer this main research question, 8 sub-questions have been formulated that will be answered in this research. These sub-questions are listed below:

1. What literature research has already been done on improving the inbound system, in order to reduce the effects of ineffective truck logistics at fulfillment centers?
2. What are the common challenges associated with truck logistics in the inbound system and which strategies can be applied to improve according to the literature?
3. How is the current truck logistics in the inbound system described at Bol Fulfillment Center and what are the logistics bottlenecks that can be identified?
4. What Key Performance Indicators can be used to assess the system performance of the inbound system of Bol Fulfillment Center?
5. How does the model design look like that will be used to analyze the current and future inbound system of the Bol Fulfillment Center?

6. Which potential strategies can be designed to improve the system performance of the inbound system of Bol Fulfillment Center?
7. To what extent can these strategies improve the system performance of the inbound system of the Bol Fulfillment Center?
8. Which of these strategies can be put into practice to eliminate the possibility of rejecting trucks and reduce the pressure of both of the waiting areas?

1.7. Research Methodologies

The methodology approach for this research is visualized in Figure 1.3. This research is divided into different phases that address the different sub-questions. Within this figure it is also visible how these methods are connected with each other in terms of input and output. A brief explanation of each research method is presented below.

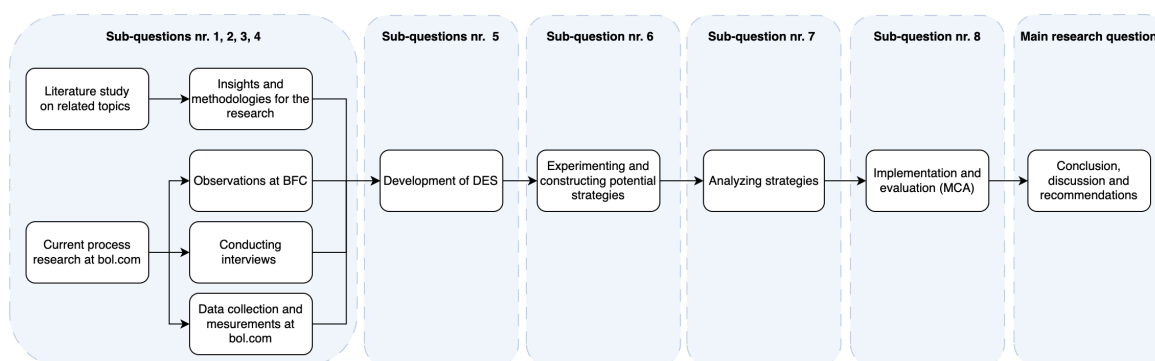


Figure 1.3: Research methodology (source: author)

1.7.1. Literature Study

The first part of this research focuses on performing a comprehensive literature review concerning the inbound system at logistic facilities, the challenges associated with truck logistics within the inbound system, and exploring potential strategies and modelling techniques proposed in existing literature studies. As mentioned earlier in the introduction, limited research is available on the inefficiencies related to truck logistics specifically at FCs. Therefore, in order to bridge this research gap, relevant literature studies from other logistics facilities, such as distribution centers, warehouses and marine/containers terminals is examined as they show similarities regarding their inbound system. Sub-questions 1 and 2 can be answered according to the performed literature study.

1.7.2. Current Process Research at bol.com

The second part of this research focuses on studying the current inbound system at bol.com, aiming to gain a better understanding of the current situation. This involves analyzing the different processes within the inbound system at BFC by conducting visits at BFC, conducting interviews with various experts, and collecting historical and empirical data by performing different measurements and data-analysis. With these methods, a better understanding of the current inbound system at bol.com will be achieved.

Observations at BFC

Multiple visits were conducted at BFC in Waalwijk to carry out observations within the inbound system. These visits involved guided tours led by various team leaders during operational hours. Specifically, the arrival, enter and unload process were observed over several hours to gain a comprehensive understanding of the current situation. These visits provided valuable insights into the existing bottlenecks and operational challenges with truck logistics in the inbound system.

Interviews

Interviews were carried out with different stakeholders that are involved in the system. During the observations at BFC, a lot of questions have been asked to different BFC employees in the inbound system which were: team leaders of the inbound process, port operators, unloading operators and receiving operators. This resulted in a deeper understanding of the challenges that occur within the current inbound system. Also, interviews with different bol.com colleagues of different teams have been held to talk about their perspective of the problem. This provided a further understanding of the

current system and also highlighted the gap that exists at bol.com in the truck arrival process.

Data collection and Measurements at bol.com

A deep dive analysis has been performed of the available data at bol.com in order to construct the current state of the simulation model. In addition, measurements were performed on-site at BFC to collect missing yet relevant data. These measurements were conducted at the port to gather relevant truck arrival data. By gathering this information, a better understanding of the truck logistics in the inbound system can be achieved.

1.7.3. Development of DES

In order to study the current situation at BFC and identify bottlenecks and eventually test potential strategies, a DES approach has been used to simulate the truck logistics within the inbound system at BFC. DES is a commonly used method in the literature for studying logistics issues and evaluating proposed changes without implementing them into the real world. The simulation aims to accurately represent the current inbound system. This current state will be verified and validated with the data retrieved from the data collection at bol.com.

1.7.4. Experimenting and Constructing potential strategies

After the model is built and verification and validation is done, an experimental plan will be set up in order to construct potential strategies. This will be done by identifying key variables that enable varying the input parameters in order to derive potential strategies. The key variables will be based on the performed literature review, system requirements and brainstorm session with bol.com. Subsequently, those variables will be experimented with in order to identify possible variations and combinations that impact the system performance. Strategic decisions will be made in order to limit the number of experiments due to limited time of this research. Eventually, a set of potential strategies will be the result which will be tested in another set of experiments based on different scenarios according to the formulated KPIs.

1.7.5. Analyzing Strategies

The strategies resulting from the experiments will be analyzed by the three formulated KPIs. This will result in different insights which contribute to the determination of which strategies are resulting in an improved system performance of the inbound system and can be used for evaluation.

1.7.6. Implementation and Evaluation

In order to select the most appropriate strategy for bol.com to implement considering the technical and operational implementation efforts and the risks involved for partners and carriers, an evaluation will be performed with a Multi-Criteria Analysis (MCA).

1.8. Report Outline

The structure of the report is as follows. In Chapter 2 the literature study will be explained which was conducted for this research. In Chapter 3 the current situation at bol.com will be analyzed and by means of qualitative and quantitative methods. Chapter 4 will discuss the construction of the DES model design which provides the conceptual model and how the data from the data collection is structured into input and output parameters. This chapter will also provide the validation and verification of the model. Chapter 5 will discuss the experimental plan in which potential strategies will be constructed. Chapter 6 will analyze the results of the strategies, using the three KPIs. Chapter 7 will evaluate the best strategies, leading to the selection of the most appropriate strategy for bol.com to implement. Finally, Chapter 8 will conclude this research in which all the sub-questions will be answered again. Additionally, a discussion and recommendations will be provided.

2. Literature Study

This chapter will provide the literature review and will answer sub-question 1 and 2. The literature review begins by providing general information about logistic facilities and specifically focus on FCs in Section 2.1. Then the complete inbound system will be explained in Section 2.2 followed by detailed explanation about the truck logistics in Section 2.3. Subsequently in Section 2.4, other literature studies that research the challenges associated with truck logistics in the inbound system at other industries will be reviewed. Moreover, potential strategies for the improvement that have been proposed and investigated in previous studies will be discussed in Section 2.4 and Section 2.5 since these offer recommendations and strategies that can be adapted to improve the truck logistics at fulfillment centers. Finally, various modeling techniques will be presented that will be considered for the implementation in this research in Section 2.6. Finally, a conclusion will be given which answers the 2 sub-questions in Section 2.7.

2.1. Logistic Facilities

Logistic facilities are facilities in which logistic operations take place such as storage, processes and distribution of goods. These facilities have a vital role in the supply chain of a product (Rimienė and Grundey, 2007). There are different type of logistic facilities such as: distribution centers, warehouses, fulfillment centers and marine/container terminals. They differ in terms of their function and purpose. Distribution centers are primarily focused on the distribution of products and act as intermediaries in the supply chain (Andrejić et al., 2016). Warehouses serve as long-term storage facilities for products until further distribution (Baker and Canessa, 2009). Marine and container terminals are specialized facilities located at ports where cargo ships unload container on trains and trucks (Imai et al., 2013). Fulfillment centers are focused on store, pick, pack and shipping products directly to end-customers (Tarn et al., 2003). These logistic facilities differ from each other in their specific function and purpose, but they all have in common that their logistic operations are based on an inbound and outbound system in which truck logistics have a vital role. Therefore, insights gained from these studies can be used as input for this research.

2.1.1. Fulfillment centers

E-commerce business heavily relies on the efficiency of the logistics of their operations (Delfmann et al., 2002) and is mainly done in a fulfillment center. The goal in e-commerce is about getting the final shipments to the customers at the right place, time and costs. High quality delivery service to the customers, results in high customer experience which boost the profits of the company. Therefore, the way how logistics is organized, has become the competitive element of a company and makes the difference for e-commerce companies. A fulfillment center, which is the focus of this research, is focused on store, pick, pack and shipping products directly to end-customers and providing value-added processes such as packaging and repairs (Heragu et al., 2005; Ramaa et al., 2012; Gu et al., 2007). The general flow of logistics operations in FCs include: arriving, unloading, receiving, putaway, temporarily storage, order picking, packaging and shipment (Smith and Srinivas, 2019). These operations can be divided into two main systems which are: inbound and outbound. The inbound system focus on arrival of products brought by trucks, unloading, receiving and putaway. The outbound system focus on order picking, order sorting and the shipment of products to end-customers. Within the inbound and outbound systems there are the truck logistics, consisting of different flows: trucks arriving with products from suppliers at FC, trucks arriving with empty trucks for outbound, trucks moving over the yard towards unloading and loading operations and trucks departing FC with shipments for customers. A generic overview of the different flows in truck logistics at a FC can be seen in Figure 2.1. Logistics at FCs form a complex system of many operations regarding three main systems: inbound, outbound and truck logistics. These operations proceed in chronological order which means that decisions made during these operations affect later operations. Therefore, an effective truck logistics is the key to success for an e-commerce company to ensure quick delivery to customers end their overall performance (Tarn et al., 2003; Cho et al., 2008).

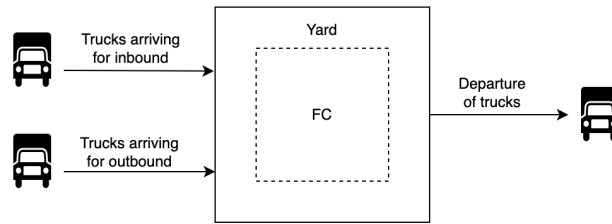


Figure 2.1: Generic overview of truck logistics at fulfillment centers (source: author)

2.2. Inbound Logistics

The inbound system is a crucial step in FCs as it includes the process of physically receiving the products into the FCs. Next to this, it includes the processes of arrival, unloading, receiving and putaway of products in chronological order (Gu et al., 2007). Efficient inbound processing ensures that trucks move smoothly through the systems without any delays or high waiting times in order to unload trucks quickly to put these products on stock to fulfill the customer orders. Any inefficiencies within the inbound system can directly affect the other processes within the inbound system which will impact the system performance. A generic overview of the operations within the inbound system, combined with the truck logistics, can be seen in Figure 3.2. An explanation of each of these processes can be found below this figure.

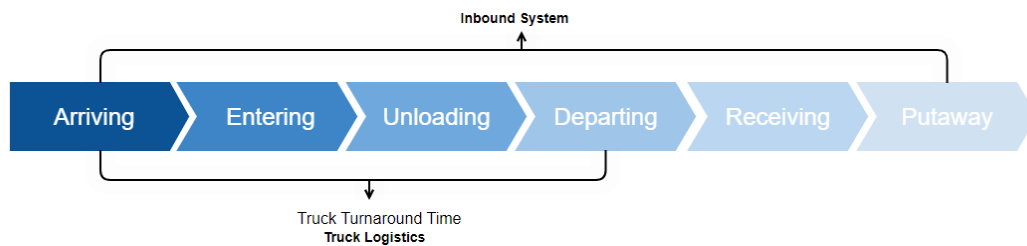


Figure 2.2: Inbound Logistics at BFC (source: author)

It can be seen that truck logistics are included in the first four processes. The arrival and unloading process can be considered as the most time-consuming processes in the inbound system, as it involves service time for trucks which varies per truck depending on the current circumstances. As a consequence, these processes are more prone to higher truck waiting times. The entering and departing process can be seen as intermediate processes within the system, where the truck does not take any specific actions apart from moving to the next process in the system. The receiving and putaway processes are also part of the inbound logistics and take place after the unloading of products. These processes don't include truck logistics, but are focused on scanning the products into the warehouse and processing the products into the determined storage location (Karásek, (2013). These two processes will not be explained more in detail since they are left out of scope.

Arrival & Enter process

The arrival and enter process is the first process in which the trucks physically arrive at the FC and continue to the check-in stage at the gate (Kumar et al., 2011; de Oliveira et al., 2022). The arrival process is defined from the moment the trucks arrive at the gate, in which the required shipment paperwork will be processed if there is a port operator available, until the moment the trucks get an available dock assigned and continue to the unload process. The paperwork is checked manually by the port operators and requires time, which is the service time during the arrival process. The amount of time required for this process, depends mainly on the correctness of the paperwork (shipment numbers, delivery day, carrier details, supplier and product information) (Smith and Srinivas, 2019; Azab and Eltawil, 2016). When the service time becomes too high, there is the possibility of trucks queuing. The registration of the paperwork needs to be done manually since it is hard to automate these processes and to prevent fraud (Wibowo and Fransoo, 2021; Dekker et al., 2013; Carboni and Deflorio, 2018). When the paperwork is correct and processed, the truck continues to the enter process in which the truck gets a dock assigned by the operator. When there is an available dock, the truck drivers get immediately a dock assigned and leaves the arrival process and continues to the unload process (Gu

et al., 2007) after which the unloading process starts. During the dock assignment, if there are no unloading docks available there is a possibility of queuing of trucks waiting for dock assignment.

The arrival process is considered as the most time-consuming process in the inbound system and often leads to queuing of trucks in front of the gate. This is caused due to the following reasons: firstly, incomplete and incorrect paperwork increases the service time per truck, staff shortage and language barriers (Wibowo and Fransoo, 2021; Dekker et al., 2013; Carboni and Deflorio, 2018). Secondly, some studies have shown that the queuing of trucks is a result of the big variation in the arrival pattern of trucks in which there is a peak in the arrivals (Dekker et al., 2013; Wibowo and Fransoo, 2021; Chen et al., 2013b). This is often caused by enforcing no rules regarding the arrivals for trucks and limited information regarding truck arrivals at the gate side. The arrival pattern is a stochastic process and usually shows two peaks, one in the morning and one in the afternoon. As shown in a study of de Oliveira et al. (2013), at the Port of Rotterdam and at a chemical site in the Netherlands (Wibowo and Fransoo, 2021) in Figure 2.3, the peaks in the arrival pattern is clearly visible on daily and weekly basis. The variation in arrival times can be explained by some external factors such as avoiding traffic jams during the day resulting in early morning travels. This uneven arrival pattern leads to non-optimal truck logistics at terminals since studies have shown that inefficiencies end queuing length could be reduced at terminals when there is more control on the truck arrival process (Phan and Kim, 2015; Wibowo and Fransoo, 2021). The congestion could result in long waiting times at the gate which contributes to delays in the entire inbound system which increases the TTT. Also, congestion at the arrival process could reduce the reliability and performance of the internal warehouse operations as they rely on inbound trucks (Maguire et al., 2010).

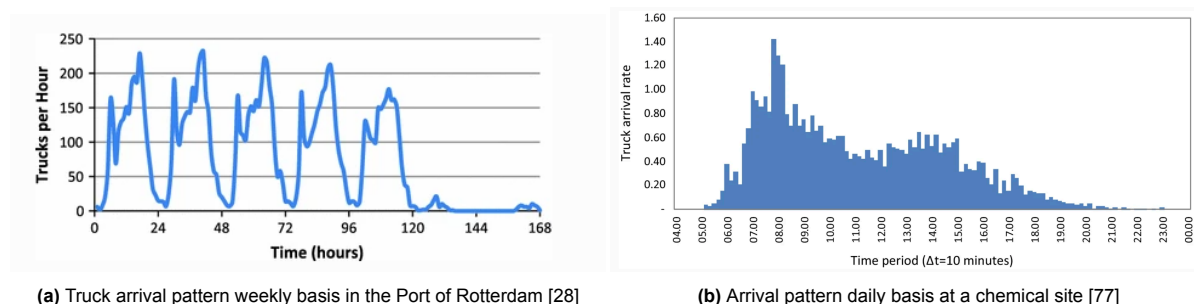


Figure 2.3: Arrival pattern trucks at terminals

Unload process

The unload process is the process in which the products get unloaded from the truck into the FC. This is the first moment in the inbound system in which the products physically arrive within the FC. The unload process ends after the truck is fully unloaded, all items have been scanned into the system, and the truck driver receives a number of empty pallets to return to the truck (van der Steenhoven, 2016). As mentioned earlier, unloading is a time-consuming process as it includes many operations, such as: unloading the truck by either the truck driver itself or the employees, checking the correctness of the required paperwork, scanning items into the systems, and checking the correctness of quantities, volumes and weights. These operations contribute to the overall unloading time of a truck. High waiting times during the unloading process is a well-known problem in container and port terminals (Tadumadze et al., 2019; Liong and Loo, 2009; Friswell and Williamson, 2019; Kang et al., 2008). These studies have identified two factors contributing to these high waiting times: the uneven arrival pattern of trucks and the limited number of available docks or cranes at terminals. When the number of trucks in the unload process is greater than the number of docks or cranes available, it forces trucks to wait. In combination with peaks in the arrival of trucks, this can lead to high waiting times during the unload process. The factors mentioned above contributing to a longer unloading time could indirectly impact the waiting time for dock assignment during the enter process as explained before. However, nothing can be found in literature about this specific subject.

Departure process

When the truck has finished unloading, the truck is ready to leave the terminal site. This process is defined as the departure process and ends when the truck exits the terminal. No complex operations takes place in this process rather than transferring the truck from the unloading docks to the exit of the terminal. The departure process marks the last process in the inbound system for truck logistics.

2.3. Truck Logistics

The problems related to truck logistics within the inbound system on the performance of a company's supply chain has been researched and acknowledged in the literature. As shown in the studies of Carlan et al. (2022); Ambrosino and Peirano (2016); Phan and Kim (2015); Phan and Kim (2015), gate congestion at port terminals is caused by inefficient planning of the truck logistics in the inbound system and is therefore proven to be a real problem for the inbound system at logistic facilities. As shown in a study of Kim et al. (2003), focused on truck logistics at container terminals, it is shown that insufficient insight in truck arrivals has led to an increase in the total time a truck spend at the terminal (TTT) (Wibowo and Fransoo, 2021). This is caused by the resulting congestion of trucks which leads to higher waiting times in the inbound system, which increases the TTT and causes delay in the entire inbound system as explained earlier. A big variation in the arrival pattern of trucks, including peak arrivals, also leads to the queuing of trucks as shown in studies of Dekker et al. (2013), Wibowo and Fransoo (2021) and Smith and Srinivas (2019), which is dedicated to a consumer goods warehouse in the US which also has shown that it eventually causes delays in deliveries. Zhao and Goodchild (2013) address the problem at a maritime terminal in which high handling times of containers are experienced in the inbound system by lacking accurate truck arrival information. All of these reviewed literature studies show evidence that an inefficient planning of the truck logistics in the inbound system leads to several consequences for the system performance of the inbound system. However, none of these study address the consequences related to the rejection of trucks due trucks queuing outside on the road.

2.4. Suggested Improvements According to the Literature

As mentioned before, there is a lack of research specifically focusing on improving truck logistics at FCs. Consequently, this literature study explores related studies that have investigated the effects of truck logistics in the inbound system related to other industries. These industries share similarities with the FC, allowing for the utilization of insights from these studies in this research. This section will address the objectives and proposed improvements discussed in those studies and how these can be used in this research.

In order to improve efficiency in the inbound system by improving the truck logistics, several studies have been conducted, each with its own unique research objective. Most studies are focused on reducing the TTT in the inbound system (van der Steenhoven, 2016; Huynh, 2009; Zehendner and Feillet, 2014; Azab and Eltawil, 2016). Others focus on maximizing the amount of unloaded trucks in the system (van den Brink, 2023). Some other researchers have looked at minimizing the total operational costs (Smith and Srinivas, 2019) and other studies have focused on lowering the waiting time of trucks at the gate (Chen et al., 2013a; Kiani et al., 2010; Kim et al., 2003). Some studies combine the lower waiting time with the sub-goal to reduce emissions caused from idling truck engines (Zehendner and Feillet, 2014). Although there are many studies that focus on improving the truck logistics, none of them specifically address the eliminating the rejection of non-unloaded trucks due to inefficient truck logistics.

Several studies have attempted to change the truck arrival behavior by implementing Truck Arrival Management systems (TAM), such as Truck Appointment System (TAS) and Drop&Swap (D&S) systems. Those systems aim at distributing the truck arrivals by requiring the truck companies to book a specific time slot before the actual arrival in order to eliminate the peaks in the truck arrivals (van den Brink, 2023; Ambrosino and Peirano, 2016; Phan and Kim, 2015; Gracia et al., 2017; Guan and Liu, 2009). While the implementation of TAM systems is popular in literature and many studies confirmed that TAM systems have the potential to reduce congestion of trucks, many studies also have found that the effectiveness of TAM systems depends on the incentives created by the logistic facilities itself (Morais and Lord, 2006; Giuliano and O'Brien, 2007; Chen et al., 2013c). Moreover, the implementation of such a TAM system needs to include the participation of many suppliers which could be challenging when having many stakeholders. Other studies have attempted to lower the TTT, by indirectly lowering the waiting time for trucks, by making efficient use of the already existing resources at the terminal for example changing the lay-out of certain processes to reduce walking time for truck drivers in certain processes at distribution centers (van der Steenhoven, 2016), or applying different check-in strategies at the port at a warehouse (de Oliveira et al., 2022) and increasing the number of gates at a marine terminal (Guan and Liu, 2009). Some of these strategies have proven to be successful such as making more efficient use of the internal resources and different check-in strategies. However, increasing the number of gates might provide only a short-term solution and might lead to the under utilization of the gate system during non-peak periods. Other studies have looked at minimizing the truck service times at terminals while respecting certain levels of congestion (Ambrosino and Caballini,

2015). Some studies have looked into the use of automated technology like implementing automated check-in procedures and computers (Smith and Srinivas, 2019; Wibowo and Fransoo, 2021; Dekker et al., 2013; Carboni and Deflorio, 2018; van der Steenhoven (2016). Improving the existing resources have proven to be successful and could reduce the waiting times experienced by trucks. A study of Muñoz-Villamizar et al. (2021), has researched the effect of increasing truckload shipments in order to analyse the environmental impact of inbound logistics caused by fast shipping. Although the objective of this study is different than this study, increasing truckload fill could be interesting to study in order to reduce the pressure on the waiting area in the inbound system.

2.5. First-Mile Pick-Up

First-mile logistics refers to the first stage of a products supply chain from its origin to its destination (Giménez-Palacios et al., 2022). This first stage is focused on the shipment from the products by the retailers to the warehouse, distribution center or FC. First-mile is operated by a single logistic provider which manage the logistics of multiple retailers, thereby decreasing the total movements of trucks delivering products. The shipments need to be send to a central consolidation center by the retailers where the shipments are brought together in trucks and then sorted to be send to the delivery location. However, first-mile pick-up service can be quite challenging due to a couple of reasons. First of all, retailers have no direct control anymore over the first part of their products supply chain making it difficult to convince them to take part. Second, centralizing multiple retailers that want to take part in the first-mile pick-up service could be difficult since retailers are often more geographically disperse. First-mile logistics have been studied from various perspectives. One of them is passenger transportation which reduces the number of people using the private modes for commuting (Kåresdotter et al., 2022). There are studies that have shown that first-mile pick-up service could form a solution to the problem of vehicles with underutilized loads and would reduce costs for the retailers (Dai and Chen, 2012; Wang and Huang, 2021; Pan et al., 2013). In a study of Chabot et al. (2018), it has been shown that collaboration among carriers also contributes to the reduction of CO2 emissions. These studies show that first-mile pick-up service could contribute to the increase of truckloads but do not focus on what the impact will be on the logistic operations of the inbound system of FCs and the problem of rejecting trucks. Therefore, it could be quite interesting to investigate what the impact is of increasing truckloads to address the problem of eliminating trucks and reducing the pressure on the waiting areas.

2.6. Modelling Techniques

In order to model the current problem in the inbound logistics at bol.com and to design potential strategies, several methodologies are available and have proven to be useful in similar studies. The most frequent used modelling methods will be discussed with their pros and cons and eventually the selected modelling method will be explained that will be used in this research. The queuing theory, mathematical optimization and simulation are different modelling methods that are useful for analyzing logistics problems and will be explained in more detail below.

2.6.1. Simulation Techniques

In order to study and experiment with the logistic system, three model categories are frequently used in logistics. Analytic, Heuristic and Simulation models (Bowersox and Closs, 1989). Analytical models are mathematical models which try to identify optimal solutions to certain problems, seeking for closed-form solutions. An example of an analytical model is the queuing theory (Chen et al., 2013c; Guan and Liu, 2009; Chen et al., 2011). These models rely on precise mathematical calculations and assumptions and therefore require precise quantitative analysis. Heuristic models are used in situations where finding the optimal solution is computationally infeasible or time-consuming (Kim et al., 2003; Chen et al., 2013b). For this reason, heuristic models are trying to identify sub optimal solutions that are still acceptable. Both analytical and heuristic models have a deterministic nature which means that all data is known and fixed with certainty and don't include any randomness (Eldabi et al., 2002). Simulation models have the capability to model a flow of events and include randomness over time, allowing to include stochastic elements of the system. Implementing data with different distributions allows the model to incorporate different uncertainties. Since logistic problems often have a stochastic characteristic, simulation models may be the best approach to capture the inbound logistics within this research.

2.6.2. Discrete Event Simulation and Agent Based Simulation

There are two common used simulation models that are used when trying to simulate truck logistics: Agent Based Modelling (ABS) and Discrete Event Simulation (DES). With ABS, different interactions in the system between individuals can be studied as they are modelled as agents in the simulation with their own behaviors and decision-making abilities. This makes it possible to study the system on an

agent/micro level. Strengths of the ABS simulation method, is the realistic representation of individual behaviour and the ability to show complex behaviours which may not be easily observed in the real world (Turrell, 2016). Despite these strengths, ABS also faces some limitations such as the limited focus since it is particularly focused on micro level (Conte and Paolucci, 2014) and the computational time, which is relatively slow compared to other simulation techniques (Bousquet and Le Page, 2004). Another limitation of ABS is that it is not widely used in literature as a method for simulating logistics systems and could therefore be a risky decision (Fleming et al., 2013).

DES focuses on a network/macro level in which different processes can be simulated as different events, which can change from one state to another state at discrete times (specific time intervals) under certain conditions (de Lara et al., 2014). The desired states of the system can be defined prior to the simulation and the outputs of a DES are the changed states (Neagoe et al., 2021). DES makes it able to model the logistic network as a whole, in which the flow of different discrete events can be analysed (Özgün and Barlas, 2009). DES is widely accepted method in literature for the simulation of logistic systems and for examining proposed improvements (van den Brink, 2023; Smith and Srinivas, 2019; van der Steenhoven, 2016; Huynh, 2009; Kiani et al., 2010; Zeegers, 2023; Gracia et al., 2017). Strength of this method is that it is a good approach for detecting bottlenecks in the network (Agalinos et al., 2020), it is an appropriate approach for including randomness in the processes (Tako and Robinson, 2012) and the computational time is relatively low. One of the limitation of DES, is that the complexity increases exponentially with the system size and that it requires detailed data in order to get accurate results

2.6.3. Monte Carlo Simulation

Simulation methods, such as DES, frequently use probability functions to incorporate uncertain parameters or inputs to replicate real-world scenarios. In order to deal with these stochastic parameters in DES, Monte Carlo Simulation (MCS) stands out as a powerful tool (Chen et al., 2011) and will therefore be used in this research. Through MCS, the impact of randomness can be mitigated, leading to more reliable results by averaging the outcomes obtained from multiple iterations. The MCS rely on the Law of Large Numbers (LLN) and the Central Limit Theorem (CLT) to approximate this average outcome. The LLN states that as the number of iterations increases, the sample mean will converge to the true population mean. In other words, performing more iterations will cause the average value of the simulated results to approach the true expected value of the system (Graham et al., 2013). The CLT states that average of random variables will be approximately normally distributed as the sample size increase, regardless of the distributions of other variables (Heyde, 2006). In conclusion, the combination of these principles ensures that the simulation results become more reliable and accurate as the number of iterations increases. The MCS will therefore be integrated within the with DES in this research.

2.7. Conclusion

This section has given an answer to the first two sub-questions which are: **1. What literature research has already been done on improving the inbound system, in order to reduce the effects of ineffective truck logistics at fulfillment centers?** and **2. What are the common challenges associated with truck logistics in the inbound system and which strategies can be applied to improve according to the literature?** Numerous literature studies have researched the impact of having a poor truck logistics within the inbound system at logistics facilities such as distribution centers, warehouses, and marine/container terminals. Logistic facilities have a critical role in the supply chain as they are designated locations in which the management, storage and distribution of goods take place. The inbound system of a logistic facility consists of the arrival, enter, unload and departure process in which truck logistics have a critical role as they deliver the products from the supplier to the facility. Those processes take place in chronological order which means that ensuring efficient truck logistics is important since the processes impact each other and could negatively impact the system performance of the facility. It is shown in those studies that ineffective truck logistics leads to congestion of trucks and an uneven arrival pattern of trucks leads to morning peaks. As a consequence, there are high waiting times for trucks in the system, long queues of trucks, and delay in operations such as service time and unloading trucks. However, none of these studies have focused on the consequence of rejecting non-unloaded trucks that are queuing outside on the road due to high congestion within the waiting areas in the inbound system. Additionally, the literature studies reviewed are not designated to FCs which highlights the research gap in science. Nonetheless, the key findings from these studies remain applicable to this research, as the logistic facilities examined in these studies share similarities with FCs. Firstly, insights from these studies validate the challenges regarding the truck logistics within inbound systems. They highlight that inefficient truck logistics contributes to operational inefficiencies in the

inbound system. Without proactive measures, these issues are likely to persist. Secondly, the objective of this research differs from the objective from the reviewed literature studies, such as minimizing waiting times, TTT, costs or maximizing number of unloaded-trucks. However, these objectives are indirectly related with the objective in this study since it impacts the elimination of rejected trucks and reducing the pressure on the waiting areas. Thirdly, the proposed strategies show valuable insights for identifying potential improvements for this research. Like optimizing internal resources, the use of TAM systems and increasing truckloads by using first-mile pick-up services. Finally, many different modelling techniques have been researched and analyzed which helps to get a better understanding of which technique is the best fit for this research. Considering the characteristics of this research, DES combined with MCS seems to be the best suitable simulation method. The inbound system can be considered as the network in the simulation in which different inbound processes takes place, which can be simulated as the different events. As this research is interested in how the different processes interact with each other under certain conditions, DES is an excellent method in capturing these discrete events and their sequencing over time under different conditions. Besides this strength, DES is computationally efficient, resulting in fast simulations and also allows for reproducibility in order to apply different replications when including stochastic behaviour. Furthermore, DES is widely been used in the literature for solving logistics problems and have been proven to be a suitable method. An overview of all the related literature that has been reviewed can be found in Table 2.1.

Table 2.1: Literature review table (source: author)

Reference	Focus	Logistic facility					Method			Solution				
		LBT	FC	DC	CT	MT	DES	OP	ABS	TAM	QS	EOR	TL	TW
Azab and Eltawil (2016)	Minimizing TTT				x				x	x				
Chen et al., (2013b)	Minimizing waiting time				x			x						x
Chen et al., (2013c)	Minimizing waiting time					x		x		x				
Chen et al., (2011)	Minimizing TTT					x		x		x				
Fleming (2013)	Minimizing waiting time					x			x		x			
Grazia et al ., (2017)	Minimizing TTT & waiting time				x		x			x				
Guan and Liun (2009)	Minimizing costs					x	x					x		
Huynh (2009)	Minimizing TTT					x	x			x				
Kim et al ., (2003)	Minimizing waiting time & costs				x		x					x		
Kiani et al., (2010)	Minimizing waiting time and TTT					x	x					x		
Muñoz-Villamizar et al., (2021)	Minimizing CO2 emissions			x			x						x	
Phan and Kim (2015)	Minimizing waiting time & costs				x			x		x				
Smith and Srinivas (2019)	Minimizing costs			x						x				
Van der Steenhoven (2016)	Minimizing TTT			x			x					x		
Van den Brink (2023)	Minimizing TTT & max. unloaded trucks	x					x			x				
Zehender and Feillet (2014)	Minimizing TTT & waiting time				x			x		x				
Zeegers (2023)	Minimizing TTT & costs			x			x	x		x				
This paper	Elimination rejecting non-unloaded trucks		x				x					x	x	

Note: LBT = Liquid Bulk Terminal; FC = Fulfillment Center; DC = Distribution Center; CT = Container Terminal; MT = Marine Terminal; DES = Discrete Event Simulation; OP = Optimization; ABS = Agent Based Modelling; TAM = Truck Appointment; QS = Queuing Strategies; EOR = Effective use of Own Resources; ITL = Increase TruckLoad; TW = Time Windows.

3. Current State Analysis

This chapter will focus on addressing sub-question 3 and sub-question 4. To gain a proper understanding of the problem, it is essential to first analyze the current situation. This research focuses only on the inbound system, so only the current situation of the inbound system is discussed. Section 3.1 until 3.4 will present general information about the inbound system, encompassing details about different product sources, the different fulfillment centers of bol.com, the stakeholders and the relevant Delivery Terms and Conditions (DTC). Moving forward, Section 3.5 will offer a comprehensive explanation of the inbound system, outlining the different processes and concluding each process description with an assessment of the logistical challenges involved. Section 3.6 will explain something about their current logistic service: Ampère. Section 3.7 will describe the extensive data collection process. Finally, this chapter ends with the selection of the KPIs to evaluate the systems performance 3.8 for this research and a conclusion in which the sub-questions are answered can be found in Section 3.9.

3.1. Product Sources

Bol.com offers over 30 million products from four different sources. These sources are also called the different partners of bol.com:

- **Retailer 1 products (R1)** = These are the products which are purchased by bol.com itself from their suppliers. The products are stored in one of the FCs and distributed to customers of bol.com.
- **Logistics via bol.com products (Lvb)** = These are the products from partners who use the bol.com online platform to sell their products. They outsource the storage of products to bol.com in one of their FCs and the distribution of products to customers. With these products the Lvb partner remains the product owner and decides how many products are sent to the FCs of bol.com, which is different from the retailer 1 products where bol.com is the owner of the products.
- **Delivery via bol.com products (Vvb)** = These are the products from partners who use the bol.com online platform to sell their products. They store the products themselves in their own storage and outsource the distribution of products to customers to bol.com. The ordered products are delivered to a collection point by the partner, and subsequently, bol.com takes care of the distribution using their contracted transport carriers.
- **Plaza products** = These are the products from partners who use the bol.com online platform to sell their products, store their own products and distribute the products to the customers.

In order to make the products available for distribution to the customers, they must first be transported to bol.com's FCs. For R1, Lvb and Vvb partners it has been contractually agreed that the transport of products is their own responsibility. This means that the partners themselves are responsible for arranging transportation with professional carriers to deliver the products to the FCs. As mentioned before, bol.com does not require partners or carriers to provide additional information about the delivery, apart from specifying the day of delivery. Besides this, no interaction flow is available between the carriers and the FCs.

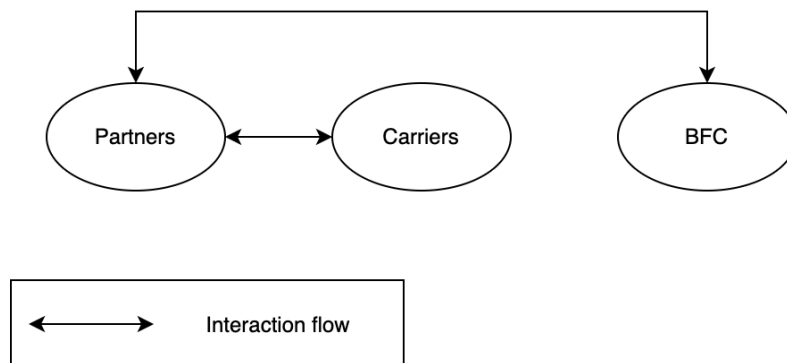


Figure 3.1: Current interaction flows at bol.com (source: author)

3.2. Different Fulfillment Centers Bol.com

Bol.com has 7 different FCs and an eighth is planned to be built. The current FCs are the following:

1. **Centraal Boekhuis:** When bol.com started as a company they first only sold books. These were stored in the already existing 'Centraal Boekhuis' location which is located in Culemborg.
2. **Veerweg:** This location is the first FC that bol.com opened when they expanded their assortment with other products than books and is located in Waalwijk.
3. **Bol Return Center:** This location is designated for all items returned by customers and is located in Waalwijk.
4. **Bol Fulfillment Center 1&2 (BFC):** BFC is the newest and biggest FC of bol.com and is based on automated and innovated systems and is located in Waalwijk. It distributed 40%-50% of the total amount of distributed items. During the peak period in the months October, November and December this amount can be 2.5 times as large. BFC1 and BFC2 are located next to each other and are internally connected.
5. **BFC XL:** This location is meant for XL products such as dishwashers and fridges. This location is located in Nieuwegein.
6. **Amsterdam Hub:** This is a small distribution center, which is used for same-day deliveries located in Amsterdam.

As already mentioned, this research focus on BFC1&2 since this is the largest and their own FC of bol.com which needs to process a huge amount of items. Therefore, the information in the remainder of this report is only based on BFC and does not necessarily hold for the other fulfillment centers.

3.3. Stakeholders

In the inbound logistics of bol.com multiple stakeholders are involved, each with their own interests and objectives. The relevant stakeholders for this research will be discussed below:

- **Bol.com:** Bol.com, the company itself, is the main stakeholder within this research. Their overarching objective is to keep all their employees, end-customers, partners, carriers and warehouse operators satisfied. By meeting the needs and expectations, bol.com aims to maintain their relationships, trust and provide an excellent experience to all stakeholders involved. Their objective is to receive as much orders as possible and deliver the shipments as soon as possible. This entails efficient and smooth fulfillment operations.
- **Partners:** The partners of bol.com play a crucial role in selling and providing the products that will be delivered to BFC and eventually send out to the end customers. Their goal is to ensure on time and accurate delivery of the products to meet the customer demand in order to gain as much profit as possible.
- **Carriers:** The carriers are responsible for transporting the products from the partners to the FCs of bol.com. Their objective is to ensure efficient, fast and on time delivery while optimizing their own transportation operations.
- **BFC employees:** The employees of BFC need to perform the logistic operations like the port process, unloading, receiving and putaway. Their goal is to handle these operations as efficient as possible and facilitating a smooth flow of operations within BFC. Next to this, their objective is to work in an friendly and nice environment in order to earn money.
- **End-customers:** End-customers of bol.com are the people who place the orders for products on the online platform. Their objective is to receive the ordered products as soon as possible. For end-customers, reliability and quick order fulfilment are important factors in their satisfaction with bol.com.

3.4. Delivery Terms and Conditions

In order to properly process products into the FCs of bol.com, partners are required to deliver their products to BFC according to specific requirements which are stated in the Delivery Terms and Conditions (DTC) of bol.com. In case partners don't comply with these delivery terms, bol.com may refuse deliveries, return deliveries or perform actions necessary to process the delivery at the partners' expense. It has been observed that bol.com does not consistently enforce all of its delivery terms, creating a gray area

in terms of adherence to these terms. As a result, there is a potential risk that logistics operations may be carried out inefficiently since operators lack a standardized approach. Next to this, there is a possibility that compliance with delivery term may no longer be the top priority of partners as not all port operators not adhere to it. This can potentially result in challenges during the processing of products.

3.5. Inbound System

The inbound system at BFC consists of one information process and six physical processes which are: announcement, arrival, enter, unload, departure, receiving and putaway. A complete overview can be seen in Figure 3.2. To give a better understanding how these processes look like, a visual presentation is presented of the lay-out of BFC together with the processes in Figure 3.3. Within this figure the arrival, enter, unload and departure process are visible and indicated with the arrows. The red coloured areas indicate the waiting areas of the port and dock. It can also be seen what the location is of the part and the unloading docks. As explained in Chapter 2, to ensure a smooth inbound flow, it is crucial that each process in the inbound system is executed efficiently. The primary objective of this research is to investigate potential bottlenecks of the truck logistics in the inbound system, which involves investigating and comprehending the truck logistics. As explained in Section 1.5, the scope of this research involves the arrival, enter, unload and departure of the inbound system since these include truck logistics. The above mentioned processes will be explained more in detail later on since it is crucial to gain a comprehensive understanding of the current situation in order to identify potential inefficiencies as these steps interrelate with each other. However, it is important to note that the excluded processes, namely announcement, receiving and putaway, may not directly involve truck logistics but still have a significant impact on or are influenced by the aforementioned processes.

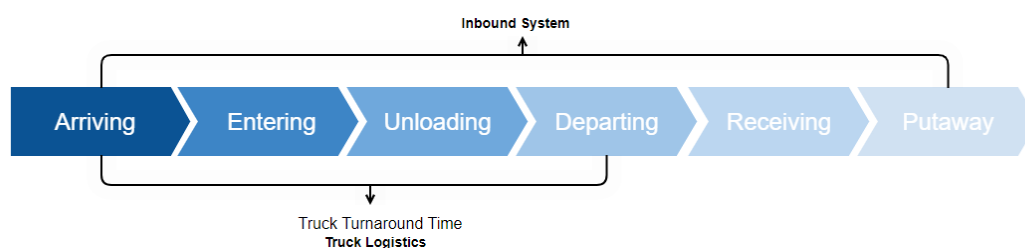


Figure 3.2: Inbound processes within the inbound system at BFC (source: author)

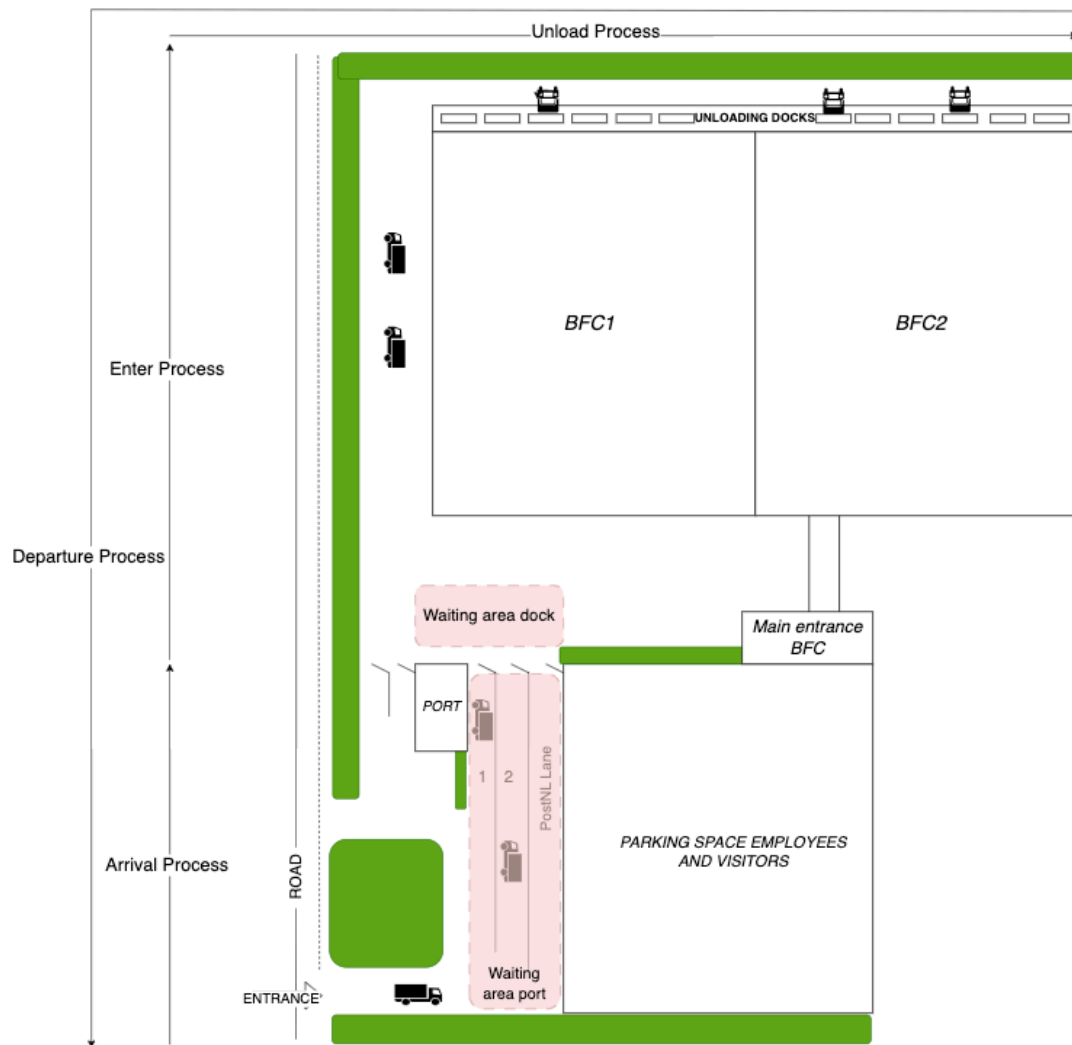


Figure 3.3: Lay-out BFC (source: author)

In the following sections each process of the inbound system will be explained and what operations it requires to accomplish each step. In order to explain all the processes, a flowchart will be used in which the steps of a process are visualised in sequential order. The aim of using a flowchart is to explain how a process is carried out (ASQ, 2017). Different symbols are used in a flowchart to illustrate different functions which are explained in figure 3.4.

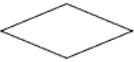
Symbol	Function
	Represents a start or end point
	Represents a relationship between shapes
	Represent an input or output
	Represent a process
	Represents a decision point

Figure 3.4: Flowchart symbols [80]

3.5.1. Arrival process

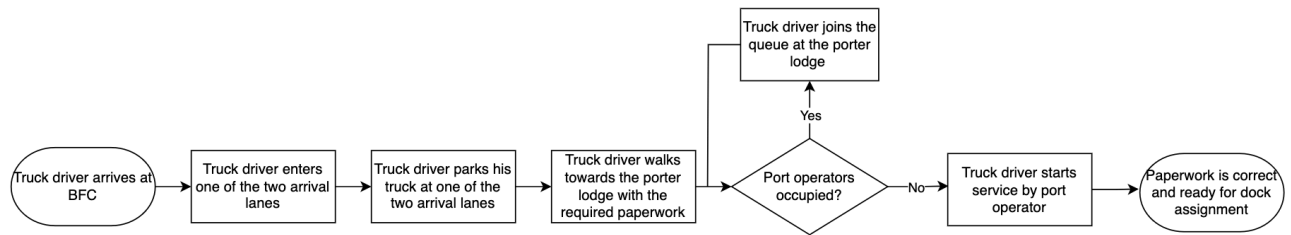


Figure 3.5: Arrival process flow (source: Author)

The arrival process is the process where the carrier trucks physically arrive at the port at BFC in order to deliver the shipment(s) from the partner and where the required paperwork of the shipment is checked by the port operators at the porter lodge. A simplified overview of the arrival process is given in Figure 3.5. It starts by trucks physically arriving at BFC and entering one of the two arrival lanes as seen in Figure 3.3. The first two lanes are meant for inbound trucks for BFC and the third lane is meant for PostNL trucks which is located at the other side of BFC. These arrival lanes are also meant as the imaginary waiting area for trucks in the arrival process and where truck drivers park their truck to walk inside the porter lodge. However, this waiting area has no capacity set by bol.com which results in a never-ending queue. This could form a possible risk for the logistics operations and the logistics facilities in the surroundings of BFC, as explained before. The driver parks the truck and transfers to the porter lodge with the required paperwork which the truck driver needs to receive from the partner. This paperwork needs to be checked and verified manually by one of the two port operators inside the porter lodge, which is done with the help of their data system: Supplier Chain Portal (SCP). The paperwork is checked on the following: supplier name, delivery number, delivery date and pack list ID. If everything is correct, the port operator needs to assign an available unloading dock to the truck which is part of the next process, the enter process. As explained above, inside the porter lodge the required paperwork is being checked by the port operators. At BFC a maximum of two port operators are operational, meaning that two trucks can be served at once. When both port operators are occupied, the truck drivers will queue up in the waiting room of the porter lodge. The arrived trucks at the porter lodge are handled on a First Come First Serve (FCFS) basis.

Logistic challenges arrival process

The observations and interviews conducted during the arrival process at BFC have given insights on several crucial logistic challenges. The observed logistic challenges in the arrival process are leading to longer waiting times for trucks and high congestion at the port. Below these challenges will be addressed and explained:

1. **No enforcement regarding the truck arrival times and underutilized trucks:** Perhaps the most critical issue is the freedom given to carriers to choose their own arrival times at BFC. Bol.com does not impose specific arrival schedules on carrier trucks, leading to a preference for morning arrivals which results in a morning peak. This leads to congestion of parked and waiting trucks at the port. Additionally, trucks are arriving with an underutilized truckload which leads to many more trucks arriving.
2. **No capacity set on the waiting area for trucks at the port:** Bol.com has not set a capacity limit for the waiting area at the port, resulting in an endless queue of trucks and might escalate when unexpected events occur. This could lead to the situation in which trucks may queue up on the roads, causing traffic congestion and potentially leading to legal issues and fines imposed by the municipality of Waalwijk. This results in a risk of rejecting non-unloaded trucks, causing problems with the stock of those products.
3. **No standardized working procedure for the port operators:** The lack of a standardized working procedure for port operators has led to variations in the service times for each truck and therefore leads to higher and mainly an inconsistent overall service time. An example observed is that port operators do not all adhere to the DTCs which results in different treatment of the partners. This leaves truck drivers feeling frustrated when they were once allowed to continue and at another time are not allowed anymore. Also, it was observed that port operators are checking the paperwork differently which could lead to longer service times.

4. **No standardized and often lack of proper paperwork:** An observation revealed significant variations in the paperwork submitted by truck drivers, and frequently, crucial information was found to be missing. This inconsistency in paperwork requires additional time and effort from port operators to sort out the discrepancies, leading to longer service times. Moreover, the absence of strict enforcement of the DTC and crucial shipment information creates a situation where the port operators are unable to follow a standardized procedure when processing the paperwork, since truck drivers are trying to get exceptions which results in discussions.
5. **Language barriers:** Language barriers between the port operators and the truck drivers is a common problem at the porter lodge. It can lead to miscommunication between port operators and truck drivers, which may result in misunderstandings, incorrect instructions or misinterpretation. Furthermore, it can lead to frustration and stress for both parties involved. This could affect their focus and efficiency. So, language barriers could lead to longer service times.

3.5.2. Enter process

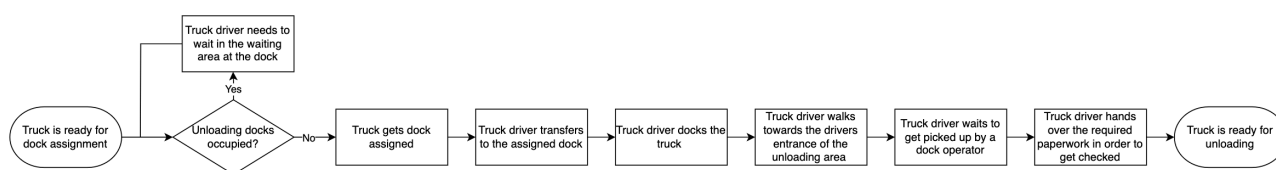


Figure 3.6: Enter process flow (source: author)

The enter process starts when the paperwork is correctly checked by the port operators and the truck needs to get an unload dock assigned to proceed to unloading. When all the 30 unloading docks are occupied, the truck driver needs to join the queue and wait until there is a dock available. Trucks are waiting in the non-official waiting area at the dock as indicated in Figure 3.3. Since BFC has relatively many unloading docks available, it rarely happens that trucks need to wait for dock assignment. Therefore, BFC has not a designated waiting area at the dock and also no capacity set to this waiting area. But, with the expected growth of trucks in the next few years, this could form a problem for bol.com. After the truck gets a dock assigned, the truck driver transfers to the assigned dock in the unloading area. The truck driver docks the truck and walks towards the drivers entrance of BFC to continue to the unloading area within BFC. Here, the truck driver needs to wait until he or she get picked up by a dock operator. A small queue can exist here, but this is left out of scope in this research. After the truck driver is picked up by a dock operator, the paperwork will be checked again. If everything is correct, the pallets are ready to get scanned by the dock operator. A simplified process of the enter process can be seen in the flowchart in Figure 3.6.

Logistic challenges enter process

- **No designated waiting area for queuing of trucks and no capacity set:** The enter process is a relatively small process compared to the other processes within the inbound system. However, there is 1 important logistic challenge which is already mentioned. There is no designated waiting area for trucks to wait before a dock is available. Currently, trucks are forced to wait just outside the premises of the porter lodge as can be seen in Figure 3.3, however limited space is available. Another option is to wait at the parking area at the unloading area, but this complicates the communication between the truck drivers and the port operators for letting know them that the dock is available. Additionally, there is no capacity set to this waiting area which leads to the possibility of an endless queue.

3.5.3. Unload process

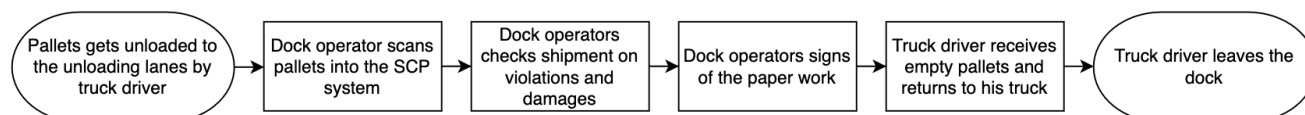


Figure 3.7: Unload process flow (source: author)

The unload process is defined as the process of unloading the items into BFC. A simplified flowchart is given in Figure 3.7. It starts from the moment the truck driver has handed over the paperwork to a dock operator. Then the truck driver can start with unloading the pallets from the truck into BFC. At bol.com truck drivers need to unload their trucks themselves on the unloading lanes available in front of the dock of which a picture is visible in Figure 3.8a. Simultaneously, the dock operator starts scanning the pallets and links it to the SCP system. At the same time, the dock operator checks the pallets on possible damages and violations and counts if the number of items corresponds as pre-announced in the shipment. When violations, damages or quantity errors are found, this is registered in SCP. When all pallets are scanned, the dock operator will sign off the paperwork and provide the truck driver with empty pallets to return to the supplier. The truck driver will return to the drivers lodge and leaves the dock, this completes the unloading process. The unloading time depends on the unloading speed which is based on the following factors and determines the speed of the availability of docks during the dock assignment.

- **Number of dock operators & number of available docks:** The first factor is the number of dock operators which is equal to the number of available docks. In total, BFC has 30 docks available, 10 at BFC1 and 20 at BFC2. For unloading one truck, one dock operator is required. The inbound characteristics are visible in Table 3.1.
- **Unloading time:** A second factor is the unloading time which depends on the number of pallets and the average preparation time. The number of pallets differs per truck and can vary for example from 3 pallets to a maximum of 33 pallets. At BFC, 1 minute per pallet is taken for scanning. The more pallets a truck contains, the longer it takes to unload a truck. Efficient handling of pallets are thus essential to expedite the unloading process and minimize delays. The average preparation time includes the time taken for the transfer of the truck driver from the truck to the dock until the first item is scanned by a dock operator.
- **Availability of space at the unloading lanes:** The last factor is the availability of space at the unloading lanes. If all lanes are filled up with pallets and no additional space is available, it becomes impossible to unload more trucks. The space available depends on the speed of the receiving process, as it impacts the clearance of pallets from the unloading lanes.

Table 3.1: Unload characteristics (source: author)

Characteristics	Value
Number of docks BFC 1	10
Number of docks BFC 2	20
Dock operators required per unloading truck	1

Logistic challenges unload process

Below a list of the logistic challenges observed during the unload process is visible, resulting in extended unloading times and a higher number of occupied docks simultaneously. This, in turn, increases the likelihood of truck queuing due to the lack of available unloading docks.

1. **Double-checking the paperwork:** When the truck driver is picked up by the dock operator and hands over the paperwork, the dock operator checks the paperwork again even though it has already been verified at the port. This repetitive task consumes valuable time that could be allocated to other essential tasks, leading to delays in the unloading process.
2. **Self-unloading by truck drivers:** The requirement for truck drivers to unload their trucks themselves can potentially lead to an overall higher waiting time. Some drivers may not be as experienced or skilled as others, which potentially causes delays in the unloading operations. Another problem is the high preparation time involved for truck drivers as they need to prepare the unloading of items.
3. **No standardized paperwork:** As already explained earlier, the lack of standardization of the paperwork forms also a risk for delay in the unload process as the paperwork needs to be checked again which could possibly leads to higher overall unloading times.

4. **No designated waiting area for queuing of trucks:** As mentioned before, there is no designated area for trucks that need to wait before a dock is available. Currently, trucks are forced to wait just outside the premises of the porter lodge as explained before, however limited space is available over there. Another option is to wait at the parking area at the unloading area, but this complicates the communication between the truck and the port operator for letting know the available dock.



(a) An unloading dock with unloaded pallets



(b) Lay-out of unloading area inside BFC

Figure 3.8: Unloading process (source: author)

3.5.4. Departure process

The departure process is defined from the moment the truck driver has finished unloading and is ready to leave the dock until the moment the truck actually leaves the BFC site via the exit gates. This departure process is relatively the smallest process of the inbound system and is not as important as the other processes since it requires no operational processes in which delays can occur. The departure process is also the last process of which truck logistics are a part of. A simplified flowchart diagram can be seen in figure 3.9

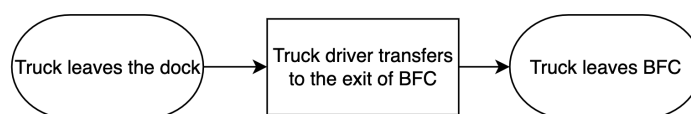


Figure 3.9: Departure process flow (source: author)

3.6. Ampère

At bol.com, a first-mile pick-up service, known as 'Ampère' has been implemented for parcel deliveries. Ampère is a startup that originates from bol.com with the goal of aligning logistics services in the Netherlands more closely with market demands (Surname et al., 2022). This logistics service is primarily designed for Vvb partners, with bol.com taking responsibility for the pick-up and delivery of products, subject to certain costs. The service involves the collection and consolidation of parcels into trucks which optimize truckloads and reduces the overall number of trucks used for transportation. However, it is currently only applied to parcel deliveries which only covers a smaller part of the total shipments compared to pallet shipments. Additionally, not all Vvb-partners take part of it yet since it is a relatively new concept. Though, this potentially could be a solution for the problem of too many trucks arriving at BFC.

3.7. Data Collection

As part of the current state analysis, the process of data collection has been conducted in order to collect several necessary data for the construction of the simulation model in Chapter 4. This data collection process involves analyzing the databases at bol.com and conducting additional measurements to obtain any missing essential data. This was achieved through a series of interviews and on-site visits at BFC. As mentioned before, there is a lack of available data regarding the truck arrivals at bol.com, specifically precise arrival times, service times per truck during the arrival process, truck turnaround times, and departure times. Consequently, measurements were essential to gather this missing data, as it was required for developing a truck arrival pattern. These measurements were performed on a random selected day in May, from 7 a.m. until 5 p.m. involving data of 66 arriving trucks. Using a stopwatch, the desired data for each truck was recorded and documented in Excel sheets, resulting in empirical data. A detailed explanation of the performed measurements and results can be found in Appendix B. Additionally, existing historical data related to the inbound system at bol.com was obtained through their data systems. Since this research is focused on the peak period of bol.com and a truck arrival pattern of the peak period needs to be constructed, historical data from the most recent peak period in 2022 was collected through bol.com's data systems. Combining this historical data with the empirical data yielded in a complete truck arrival pattern during peak periods, which will be elaborated upon in Section 3.7.2. Furthermore, characteristics regarding the enter and unload process were gathered, along with a forecast data set regarding expected inbound items used for the scenarios which will be later explained in Chapter 5. The next following sections, will provide detailed explanations of all the collected data, which will serve as inputs for the simulation model.

3.7.1. Trucks Transfers

Transfers between different locations within BFC contribute to the overall duration that a trucks spends in the inbound system. Therefore, it is crucial to have precise information about these transfer durations. However, bol.com does not have specific data on these transfer durations and were therefore measured in order to obtain this specific data. The durations of these transfers have been documented and are presented in Table 3.2. During the measurement process, the durations of each transfer were recorded for each truck. To incorporate these durations into the simulation model, average values were chosen, as indicated in the table. The complete overview of the obtained data is visible in Appendix B in Figure B.3. This resulted in three different transfers. Firstly, the '*Transfer.BFC.PorterLodge*', which is defined as the time it takes for a truck drivers to arrive at BFC, park the truck, and then proceed to the porter lodge, which approximately takes 2 minutes. Secondly, the '*Transfer.PorterLodge.Gate*', which represents the duration from when the truck driver completes the server process until the moment they exit the arrival process through the gates of the porter lodge, which is approximately 1.45 minutes. Lastly, the '*Transfer.Gate.Dock*', which corresponds to the time it takes for a truck driver to drive to the unloading docks, enter BFC and deliver the required paperwork, which takes approximately 15 minutes and was already determined.

Table 3.2: Transfers within the inbound system (source: author)

Parameter	Description	Process	Mean value
<i>Transfer.BFC.PorterLodge</i>	Duration transfer truck driver arrived at BFC until arrived at the porter lodge	Arrival Process	2 min
<i>Transfer.PorterLodge.Gate</i>	Duration transfer truck driver arrived at porter lodge until exit gate porter lodge	Arrival Process	1.45 min
<i>Transfer.Gate.Dock</i>	Duration transfer of truck driver from arrival process until start unloading process	Enter Process	15 min

3.7.2. Truck Arrival Pattern

To simulate the arrivals of trucks during a peak period as input for the DES, it is necessary to establish the truck arrival pattern during a peak period. The exact arrival times of trucks at BFC are not directly captured in their data systems. Instead, the system records only the time when a port operator completes the server process at the porter lodge. As explained before, this research is focused on the peak season of bol.com since this is when the problem mainly occurs. However, due to the time frame of this research it was not possible to perform measurements during a peak season. Therefore, the reference case will be focused on the most recent peak season, which is the year 2022 of which historical data is

available. Combining the historical data set of the year 2022 with the empirical data set, it is possible to derive at the precise arrival times of trucks during the peak season of 2022 and to determine the complete truck arrival pattern on a regular day. This information is essential for the simulation model as it represents the current situation at BFC and can be used as input for the simulation. The data-analysis of the historical data existed out of extracting a subset of 30 days from the historical data of the months October, November and December 2022. Due to the complexity of calculations, it is chosen to select 10 operational days from each month. The data sets are then subjected to Formula 3.1, which results in the exact arrival times of trucks for each day.

$$ExactArrivalTimeTruck = FinishTimeTruck(SCP) - (Server.Time.Port + Transfer.BFC.PorterLodge) \quad (3.1)$$

Next, the number of truck arrivals per hour is calculated for each operational day between 7 a.m. and 5 p.m., resulting in the number of truck arrivals throughout the whole operational day of 10 hours. This calculation is performed for each data set, and the results are summed up per hour to obtain the total truck arrivals per hour. As a result of this analysis, the following truck arrival pattern during the peak period is obtained and is visible in Figure 3.10, represented as the percentage of truck arrivals per hour during one operational day. The exact Excel calculations can be found in Appendix C.1

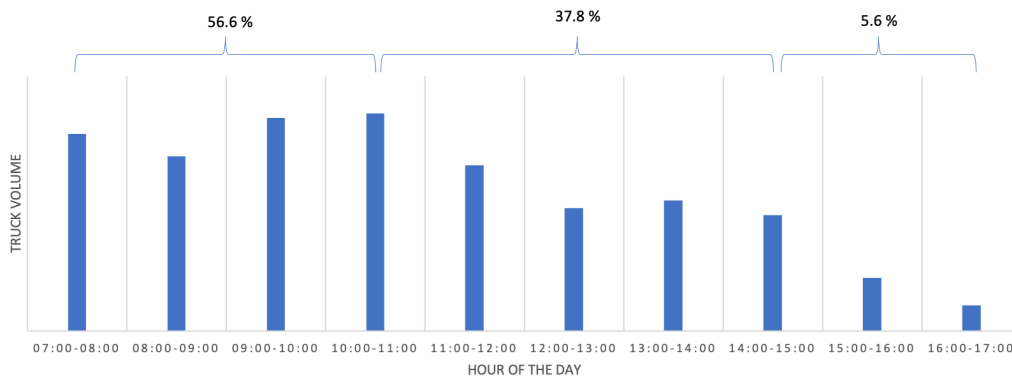


Figure 3.10: Truck arrival pattern during peak season (source: author)

Based on Figure 3.10, three time intervals can be described: peak, sub-peak and non-peak. As a result, the total number of trucks arriving within these time intervals is converted into percentages, which can be seen in Table 3.3. These percentages can then be applied to every data set in which the total number of truck arrivals is known on an operational day, resulting in the arrival pattern of trucks divided into three time intervals.

Table 3.3: Specific time intervals of truck arrivals (source: author)

Time interval	Time	Duration [h]	Percentage [%]
Peak	07:00-11:00	4	56.6%
Sub-Peak	11:00-15:00	4	37.8%
Non-Peak	15:00-17:00	2	5.6%

3.7.3. Service Time Porter Lodge

The service time per truck at the porter lodge during the arrival process is defined as the duration required for a port operator to serve a truck while checking the necessary paperwork. Since bol.com do not record any data regarding the service time of trucks in the arrival process, measurements were required to obtain this information. The measurements were done at the porter lodge in the arrival process, recording the service time of 66 trucks. As previously explained in Section 3.5.1, the service time varies throughout the day due to multiple factors, which was also evident from the measurements due to the varying service times as visible in Appendix B in Figure B.4. To take this variation into account, probability functions will be used which will be explained later in Section 4.5.3. The service time of each truck was determined based on the obtained empirical data, in which the starting time and the ending time of each truck was recorded, resulting in the service time by the Formula 3.2.

The different service times were categorized into different service time intervals and the corresponding frequencies were determined. These frequency intervals and their visualization can be observed in Figure 3.11. A more detailed overview of the different calculations on the service time can be found in Appendix C.3. As mentioned before, bol.com has no historical data available regarding the service times of trucks and therefore it was not able to gain the data regarding the service times of trucks during a peak period. However, different employees working at the porter lodge, have confirmed that the obtained service times does not differ materially from those during a peak period. Therefore, it is assumed that these service times also represents the service times during a peak period.

$$Service.Time.Port = End.Time(Port) - Start.Time(Port) \quad (3.2)$$

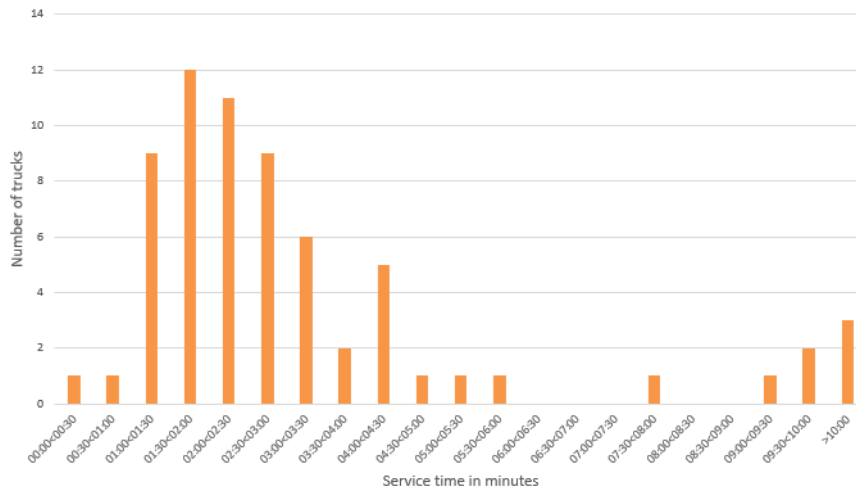


Figure 3.11: Frequency service time at the port (source: author)

3.7.4. Unloading time trucks

The unloading time at the docks is determined by the number of pallets that need to be unloaded out of the trucks, as well as the preparation time at the docks and the number of pallets that can be processed within 1 hour. This is combined in a formula which is visible in 3.3 and gives the unloading time in minutes. The values of these parameters are described in Table 3.4.

$$Unloading.Time = Basic.Duration + 60 * \frac{Number.Of.Pallets}{Pallets.Per.Hour} \quad (3.3)$$

Table 3.4: Parameters unloading time trucks (source: author)

Parameter	Unit	Value
BasicDuration	[min]	15
NumberOfPallets: small truckload	[#]	3
NumberOfPallets: medium truckload	[#]	13
NumberOfPallets: large truckload	[#]	33
Pallets.Per.Hour	[#/h]	60
Unloading.Time: small truckload	[min]	18
Unloading.Time: medium truckload	[min]	28
Unloading.Time: large truckload	[min]	48

While some data regarding the unload process is available at bol.com, still some assumptions have been made about those parameters. Furthermore, since this research primarily focuses on the truck arrivals, no measurements were conducted specifically for the unload process due to the limited time of this research. The '*BasicDuration*' has a value of 15 minutes and includes the preparation of a

truck driver at the docks as explained in Section 3.5.3. This value is based on knowledge from the dock operators and is chosen to remain constant in the simulation. The '*NumberOfPallets*' determines the truckload of a truck. Historical data provides insights into the variety of truckloads brought by trucks, in terms of the number of pallets. To incorporate this variation into the simulation, three distinct truckloads categories have been defined based on historical data: small truckload, medium truckload, and large truckload trucks. These categories correspond respectively to 3, 13, and 33 pallets, as shown in Table 3.4. Obtaining the exact distribution of truckloads on a regular day from the historical data at bol.com proved to be challenging and time-consuming. Therefore, an alternative approach was adopted. The distribution of truckloads was determined based on the truckload information obtained during the measurement of the 66 trucks. From this empirical data different percentages of the three truckloads were determined which is visible in Table 3.5. These percentages also impact the number of trucks arriving at BFC. The '*PalletsPerHour*' is set to 60 which is determined by the operators of unloading and represents the pallets per hour that can be processed within one hour.

Table 3.5: Distribution truckloads (source: author)

Measurement	Distribution
Small truckload trucks	40%
Medium truckload trucks	40%
Large truckload trucks	20%

3.7.5. Capacity waiting areas

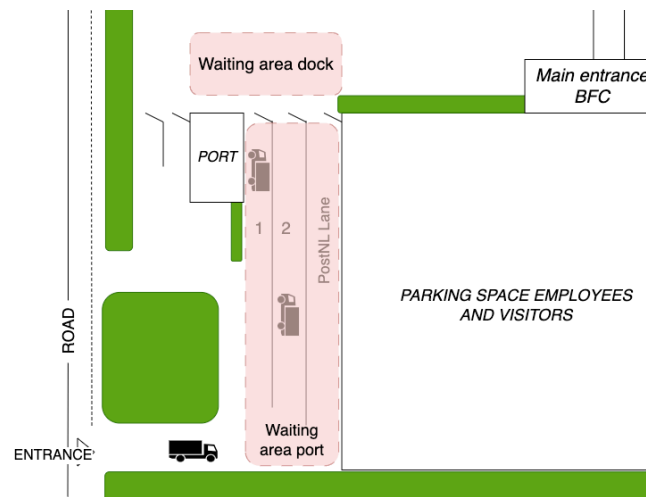


Figure 3.12: Lay-out of waiting areas (source: author)

The capacity of the waiting area at BFC at the port and dock is not specified at bol.com as already mentioned before. Since this determines KPI 1 of this research, which will be explained in the next section, it is important to determine the values for this capacity. Figure 3.12 shows a zoomed in version of the floor plan of BFC in which the waiting areas are indicated for the port and the dock. As explained before, the arrival lanes during the arrival process is meant as the imaginary waiting area at the port. The first two lanes are meant for the inbound trucks for BFC and the other lane for PostNL and therefore only the first two determine the capacity of the waiting area at the port. The determination of the capacity of the waiting area of the port was done through a rough calculation based on the length of one truck. Subsequently, the length of the truck was marked on the lanes using Google Maps, and it was determined how many trucks could fit on these lanes. This results in a capacity of 15 and has been validated by the BFC operators. For determining the capacity of the waiting area of the dock, the same method cannot be applied because there is no designated waiting area. As explained earlier, this is due to the fact that it is rare for a truck to wait for the assignment of a dock since BFC has a relatively large number of docks. Together with the BFC operators, it has been decided to set the capacity at 5 trucks. Figure 3.13 gives a geographical representation of the capacities of both waiting areas.

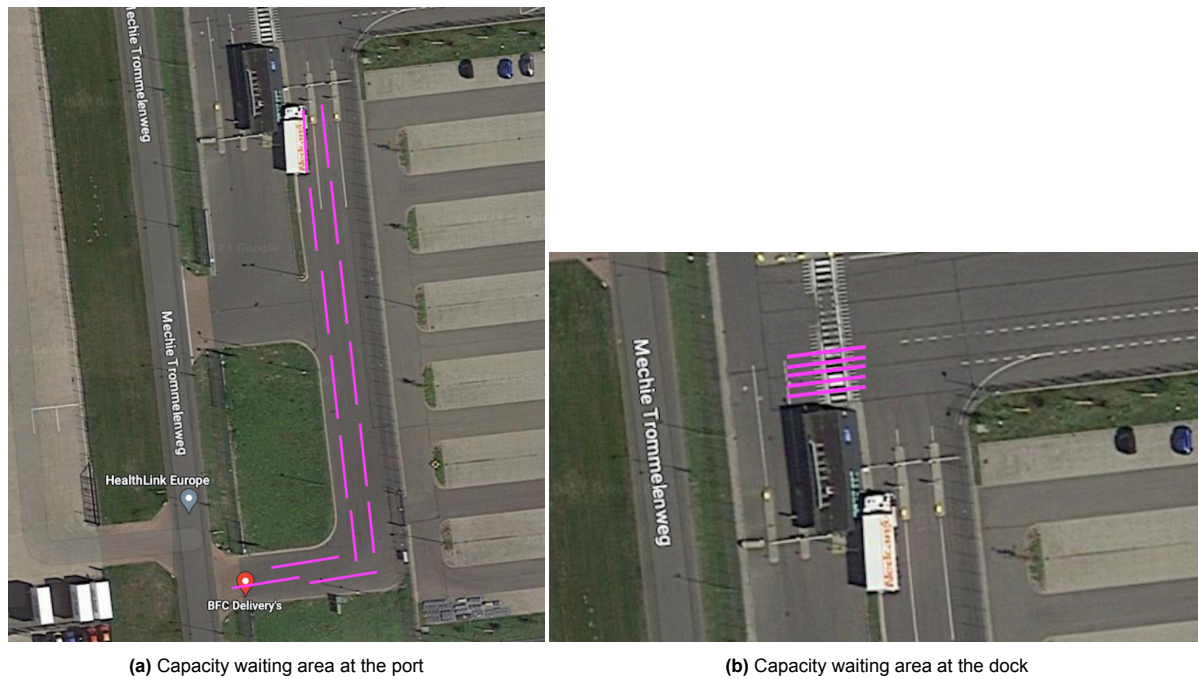


Figure 3.13: Capacity of the waiting areas [57]

3.8. Key Performance Indicators

The assessment of the operational system's performance relies on Key Performance Indicators (KPIs) which are measurable indicators achieving specific outcomes (KPI.org, 2000; Cluster, 2022). For this research, the KPIs are focused on the waiting areas within the inbound process, which will be defined as the *"waiting area at the port"* and the *"waiting area at the dock"* as visualized in Figure 3.12. This means that the result of each KPI will be given two times. Based on the current state analysis performed, objective of this research, literature review and expert consultation the following KPIs have been defined:

1. Probability of exceeding the capacity of the waiting area at the port and dock
2. Number of trucks parked at the waiting area at the port and dock
3. Waiting time per truck in queue during arrival and enter process

KPI 1: Probability of exceeding the capacity at both waiting areas

The logistic situation at a FC is very unpredictable. One day the operation runs smoothly, and the other day the operation face logistics problems. Since this research focused on the elimination of rejecting non-unloaded trucks in the entire peak period, it is chosen to represent this KPI in a probability, expressed in a percentage, of exceeding the capacity at the waiting area throughout the entire peak period. This will be determined for the two waiting areas, the waiting area at the port and the waiting area at the dock. The capacity of the waiting area is determined by the number of trucks parked and the number of trucks waiting in queue in the arrival and enter process. As mentioned before in Section 3.7.5, the capacity of the waiting area at the port is set to 15 and the waiting area at the dock is set to 5.

KPI 2: Number of trucks parked per hour at both waiting areas during a full operational day

KPI 1 indicated how big the probability is that the capacity will be exceeded during a peak period. However, it does not give any other information about the number of trucks parked at those waiting areas and therefore KPI 2 is defined. This KPI will give insights in the total number of trucks arrived every hour on an operational day. Additionally, it will gives an indication about the pressure on the waiting areas and also the buffer for unexpected events. This is important to know since the logistics system remains unpredictable due to external factors as mentioned in Chapter 2.

KPI 3: Waiting time per truck in the queues in arrival and enter process

The waiting time of trucks in the queue in the arrival and enter process is important since it affects the number of trucks waiting and contributes to the occupancy rate of the waiting areas. Therefore, KPI 3 has an indirect impact on KPI 1 and KPI 2 and therefore on the overall system performance.

Measuring the waiting times for both queues will provide additional insights in the system performance of the inbound system. Additionally, it gives some information in the truck drivers experience since the total waiting time impact the TTT.

3.9. Conclusion

This chapter focused on answering sub-questions 3: *"How is the current truck logistics in the inbound system described at Bol Fulfillment Center and what are the logistics bottlenecks that can be identified?"* and sub-question 4: *"What Key Performance Indicators can be used to assess the system performance of the inbound system of Bol Fulfillment Center?"* A current state analysis has been performed in which the inbound system at BFC is thoroughly examined and an extensive data collection have been performed. By several visits at BFC, in which guided tours were provided by experts of BFC and interviews with bol.com experts and BFC employees, a comprehensive understanding of the current situation was obtained. Additionally, insights from the literature review in Chapter 2 have been incorporated to the current state analysis to answer sub-question 4. The inbound system at BFC exist out of the arrival, enter, unload en departure process with each their own operational operations and the truck logistics. Trucks follow these processes in chronological order. By means of flowcharts, the sub-operations included in each process have been explained given more detailed insight into the current inbound system. It has been observed that there are two imaginary waiting areas within the arrival and enter process filled with parked and waiting trucks. Trucks need to wait during the arrival process when both of the port operators are busy serving trucks checking the required paperwork. It has been observed that having no standardized and often missing paperwork, having no standardized working procedure for port operators, no enforcement regarding the truck arrival times and underutilized trucks leads to higher service times and therefore long queues of trucks. Additionally, by conducting measurements at BFC to determine the truck arrival pattern of trucks in the arrival process it has been observed that there are three time intervals in which truck arrive: peak interval: 7 a.m. - 11 a.m. arriving 56.6% of the trucks, sub-peak interval: 11 a.m. - 3 p.m. arriving 37.8% of the trucks and non-peak interval: 3 a.m. - 5 p.m. arriving 5.6% of the trucks. This results in the situation in which many trucks are arriving at the same time in the morning which contributes to the occupancy rate of the waiting area at the port. The other waiting area is within the enter process where trucks need to wait when there are no docks available for the dock assignment which forces trucks to wait as they are not allowed to continue to the unload process without dock assignment. Currently, it rarely happens that trucks need to wait for dock assignment as they are 30 docks available. However, when the number of arriving trucks will increase, it will exceed the capacity of the available docks and therefore will higher the risk of queuing trucks as the port operators can't handle all the arriving trucks as the same time. Additionally, the waiting areas within the inbound system are not officially assigned as the waiting areas and therefore no capacity limit has been set to these areas. Resulting in the possibility of endless queue forming. Logistic challenges during the unload process, such as the high preparation time for truck drivers as they are required to unload their trucks themselves. Also, the paperwork is getting checked again even though it has already been verified at the port. These two factors are contributing the higher unloading times which could contribute to more trucks waiting at the waiting area at the dock for dock assignment. To summarize the logistic challenges in the current inbound system at bol.com, a cause and effect tree have been made and can be seen in Figure 3.14. Additionally, data collection on the current state has been performed in order to gather the necessary data for the construction of the simulation model in the next chapter. The data collection existed out of several interviews and measurements at BFC in order to collect required missing data, and analyzing the data-systems at bol.com in order to collect necessary historical data. This resulted in some interesting insights such as the full truck arrival pattern of a peak period as described before which was unknown for bol.com, the distribution for service times during the arrival process which varies a lot and enter and unload characteristics. As for sub-question 4, several brainstorm sessions were conducted and insights from the literature were used in order to identify suitable KPIs for this research. The chosen KPIs reflect the system's performance of the inbound system of BFC and are crucial to define prior to the research. For this study, the selected KPIs are the probability of exceeding the capacity of the waiting area at the port and dock, the number of trucks parked at the waiting area at the port and dock and the waiting time per truck in queue during arrival and enter process.

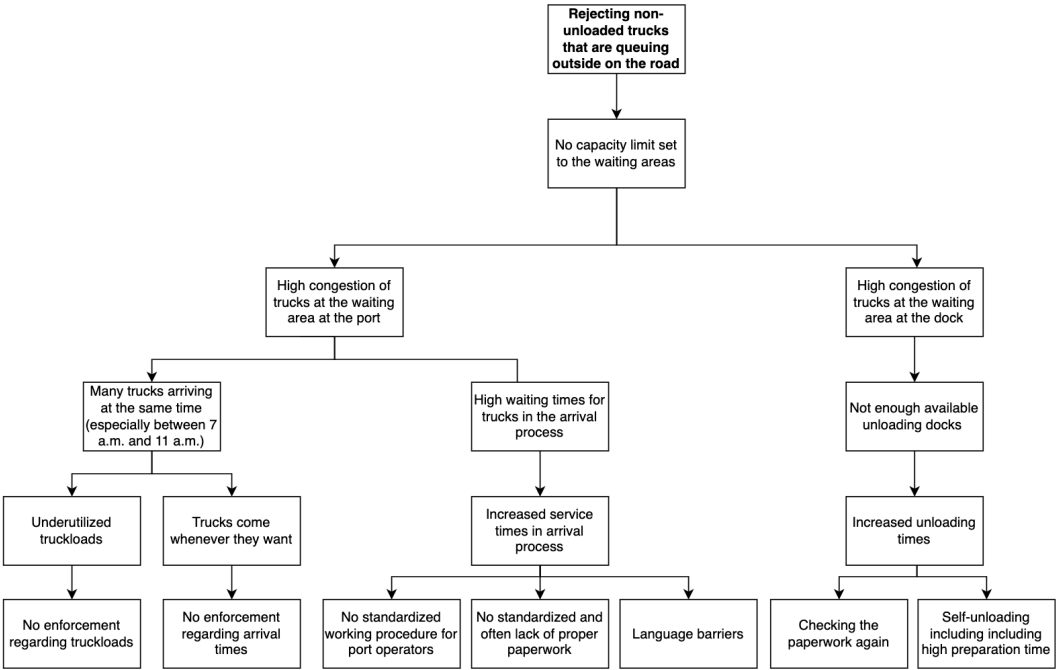


Figure 3.14: Cause and Effect tree of the inbound system (source: author)

4. Model Design

This chapter focus on addressing the sub-question 5. The information on the current situation in Chapter 3 about the inbound system and the data collection can be used as the input for the model design. In Section 4.1 the conceptual model of DES model will be explained. Section 4.2 until 4.4 describes the model's objective, requirements and assumptions, which are important to formulate before the model is constructed. Section 4.5 will explain different the model components followed by a complete overview of all the input and output parameters in Section 4.6. After the construction of the model, Section 4.7 gives more information about the software used for the simulation model. The verification and validation is explained in Section 4.8 followed by a conclusion of the chapter in which sub-question 5 is answered in Section 4.9.

4.1. Conceptual model DES

Before a simulation model can be build, a conceptual model should be constructed that visualizes the model design. A flowchart is used to visualize the conceptual model for the simulation model and is visible in Figure 4.1. It starts with a truck arriving at BFC at one of the arrival lanes. After parking the truck at one of the arrival lanes (in other words, the imaginary waiting area at the port), the truck driver walks towards the porter lodge and enters the porter lodge. At the porter lodge there is the possibility of a queue of truck drivers when both of the port operators are occupied with serving another truck driver. If there is a queue, the truck driver join this queue at the porter lodge and waits until a port operator becomes available again. When a port operator is available again, the truck driver gets serviced by a port operator in which the paperwork will be checked. When the paperwork is checked and everything is correct, a dock needs to be assigned to the truck. If there isn't a dock available for the truck, the truck driver needs to wait in queue of the enter process and joins the waiting area at the dock. When a dock becomes available again, the truck driver transfers back to the truck and drives to the assigned dock in the unload process. The truck driver parks the truck at the assigned dock and walks inside the BFC to get picked up by a dock operator. The truck driver hands over the paperwork to the dock operator and the pallets will get scanned. When the unloading of the shipment is done, the truck driver finish unloading and exits BFC. This marks the end of the conceptual model.

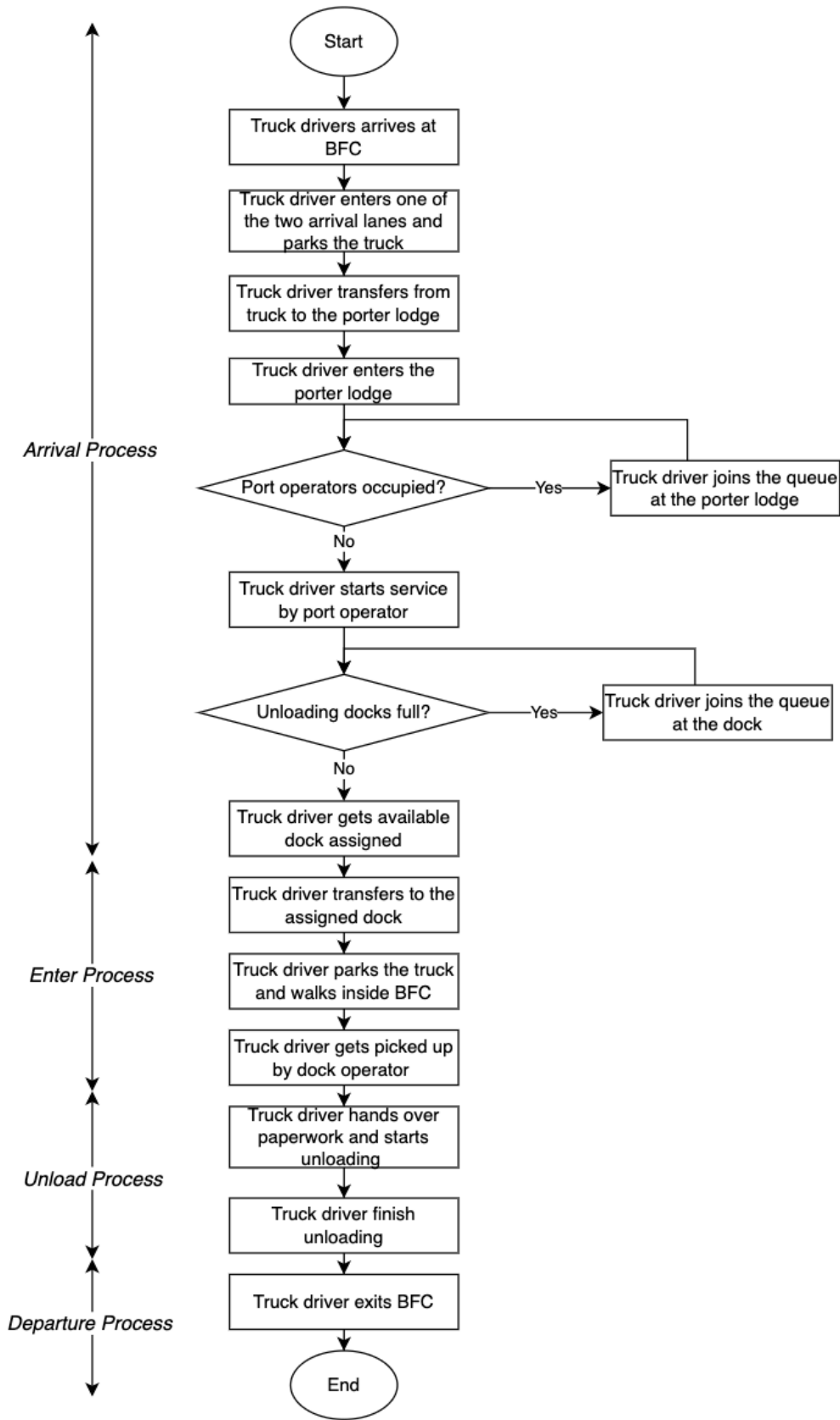


Figure 4.1: Conceptual model of the DES model (source: author)

4.2. Model Objective

The objective of the simulation model is to simulate a part of the inbound system of bol.com in which trucks move through this system within a certain time frame of an operational day at BFC. The aim is to understand how the trucks move through the system and how these impact certain processes within the inbound system. By analyzing this interaction of trucks, bottlenecks can be identified that leads to the rejection of trucks. Eventually, the simulation model will be used to test several improvements and examine what the impact is on the system performance according to the three KPIs.

4.3. Model Requirements

When building the model it is important that it meets certain requirements. Therefore, it is important to define clear model requirements to ensure the alignment with the model objective. The most important model requirements are listed below.

- *The model should represent the real world:* It is important that the model need to accurately reflects the real-world processes and dynamics in order to make plausible conclusions.
- *The model should generate the results for the KPIs:* In order to analyze the system performance, it is important that the model should reproduces the results that align with the defined KPIs.
- *The model needs to have a reasonable computational time:* This addresses the practical aspect of the model development. It is important that the model runs within an acceptable duration in order to compute different results for the research.
- *The model should be scalable:* When the volume of data increases its important that the model can handle the growth without decreasing the the performance of the model.
- *The model should handle uncertainty:* The model should be able to handle uncertainty in terms of handling stochastic parameters which contributes to the realism of the simulation model.
- *The model should be adaptable:* The model should be adaptable to changing conditions or processes in the real world.

4.4. Model Assumptions

When constructing the model, specific model assumptions will be incorporated. These assumptions are an important part of modelling, as it is often too complex to consider every detail of the real world. By formulating these assumptions, the model will focus on the most essential parts of the research. Nevertheless, it is crucial that these assumptions align with the actual realities of the situation.

- The simulation generates a random full operational day during the peak period.
- Each of the trucks can have a small, medium and large truckload which are assigned to the trucks by defined percentages.
- All items arrive at pallets.
- All arriving trucks are carrier shipments containing pallets shipments.
- There is no distinction made between shipments for BFC1 and BFC2 during unloading, so all trucks are assigned to one of the 30 docks available together at BFC.
- No queue can arise of truck drivers during the unload process. Therefore, some extra time is incorporated in the preparation time.
- All trucks are assigned to one dock only.
- Trucks in the queue at the porter lodge are waiting in queue which is presents the two arrival lanes as explained before.
- No human factors are captured in the simulation which could lead to lower waiting times experienced by trucks.
- None of the trucks receives a red card in which its meant that the truck is rejected because it does not comply to the delivery terms.
- Trucks that need to wait too long and decide to leave BFC are taken into account in the simulation model.
- All 30 unloading docks are open for unloading.

4.5. Model Components

The simulation model exists out of multiple model components which ensures that the model works as intended. Section 4.1 already showed insights into the conceptual model of the simulation and how it is structured. In the next following sections, detailed explanations of the key model components will be explained that are essential for understanding the simulation model.

4.5.1. Simulation Time and the Number of Replications

The simulation time gives a specific time frame for the simulation in which the code needs to be generated. The length of the simulation time is based on the objective of the model. Since this research aims at analyzing an entire operational day during the peak period, each simulation run spans 600 minutes. This represents a full operational day at BFC of 10 hours from 7 a.m. until 5 p.m. As explained before in Section 2.6.3, the MCS is used in order to deal with the stochastic parameters and decrease the effect of outliers. Using a specific amount of replications will result in plausible results of each of the KPIs. The number of replications used is equal to 700. This quantity was determined using a graphical method outlined in Appendix D.

Table 4.1: Simulation time and number of replications (source: author)

Parameter	Unit	Value
Length of the simulation	[min]	600
Number of replications	[runs]	700

4.5.2. Processes in DES

Within the simulation, the different main processes of the inbound system are simulated by means of their different sub-processes and are modelled as the 'events' which are part of the DES method. From each of these sub-processes the durations are determined in the simulation which adds up to the total durations of the arrival, enter, unload and departure process. In Figure 4.2 it is visible how the processes and sub-processes are connected with each other in the simulation. Table 4.2 provides a short explanation of these different sub-processes.

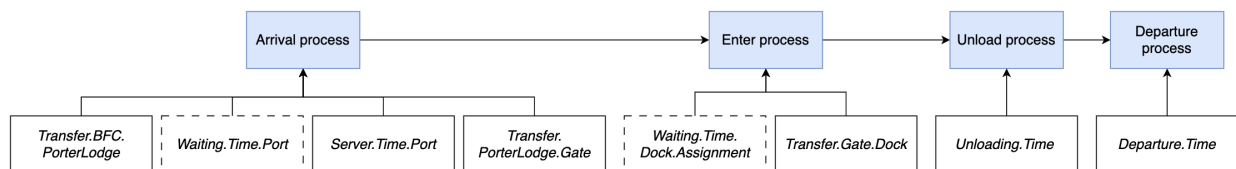


Figure 4.2: Overview of the processes and sub-processes (source: author)

Table 4.2: The different processes of the inbound system that are simulated in DES (source: author)

Process	Sub-process	Description
Arrival process	<i>Transfer.BFC.PorterLodge</i>	Duration transfer truck driver arrived at BFC until arrived at the porter lodge
	<i>Waiting.Time.Port</i>	Duration of the waiting time in the queue at the port waiting for an available server
	<i>Service.Time.Port</i>	Time at which the trucks is done with the serving process and enters the gate to the BFC site
	<i>Transfer.PorterLodge.Gate</i>	Duration transfer truck driver arrived at porter lodge until exit gate porter lodge
Enter process	<i>Waiting.Time.DockAssignment</i>	Duration of the waiting in the queue waiting for an available dock
	<i>Transfer.Gate.Dock</i>	Duration transfer truck from arrival process until start unloading process
Unload Process	<i>Unloading.Time</i>	Time it takes to unload a truck at the dock
Departure Process	<i>Departure.Time</i>	Time it takes to exit the dock and leave the site of BFC

The total durations of each of these main processes within the inbound system are calculated by different formulas which can be seen below. Those exist out of the different sub-processes which are also visible in the table above (4.2).

$$\text{Arrival.Process} = \text{Transfer.BFC.PorterLodge} + \text{Transfer.BFC.PorterLodge} + \text{Server.Time.Port} + \text{Waiting.Time.Port} + \text{Transfer.PorterLodge.Gate} \quad (4.1)$$

$$\text{Enter.Process} = \text{Waiting.Time.Dock.Assignment} + \text{Transfer.Gate.Dock} \quad (4.2)$$

$$\text{Unload.Process} = \text{Unloading.Time} \quad (4.3)$$

$$\text{Departure.Process} = \text{Departure.Time} \quad (4.4)$$

4.5.3. Distributions Truck arrivals and Service times

The inbound system deals with some randomness and variability, such as the truck arrivals and the service time at the porter lodge. In order to take this randomness and variability into account in the simulation and to avoid deterministic events and processes, probability functions can be introduced to the simulation. By incorporating the probability functions, DES can simulate the trucks arrivals and service times more realistically. The probability functions allow for the generation of random values that follow a specific probability function. Based on statistical analysis and assumptions, distributions for the trucks arrivals and service time have been determined.

Truck Arrivals

The simulation starts with generating trucks by a truck generator within the arrival process. As mentioned before, truck arrivals follow a stochastic process which means the random arrivals of trucks and independent from each other. In order to include this stochastic behaviour in the DES model, a probability function is used. In this research it is chosen to simulate the truck arrivals based on a Poisson distribution. The Poisson distribution is chosen since it appears to be the most suitable distribution. The inter arrival times between truck arrivals are relatively constant over time and the arrival of one of the trucks does not affect the arrival of another truck. From the measurements of the 66 trucks, it can be observed that the inter arrival time of trucks is more or less constant between different time intervals. As explained in Section 3.7.2, an operational day at BFC is divided into three different time intervals in which the number of trucks arrivals varies. By applying separate Poisson distributions to the different time intervals, it is possible to capture this variability in truck arrivals which results in a more accurate arrival process. This approach has also been done in another study which proven to be a successful representation (Smith and Srinivas, 2019). The Poisson distribution is described by the parameter lambda λ , which represent the arrival rate of trucks per hour. When the number of total trucks arriving at BFC during one day during peak season is known, the percentages of Table 3.3 can be applied. This will result in three

different Poisson distributions and can be used as the input for the truck arrivals in the DES model.

Table 4.3: Poisson distributions for the truck arrivals in different time intervals (source: author)

Measurement	Distribution
Truck arrivals: Peak	$Poisson(\lambda)$
Truck arrivals: Sub-peak	$Poisson(\lambda)$
Truck arrivals: Non-Peak	$Poisson(\lambda)$

Service Time Trucks During Arrival Process

The service times at the port varies throughout the day per truck due to certain circumstances as explained in Section 3.7.3. In order to account for the variation in service times, a probability function is implemented in the simulation. To model the service times, a lognormal distribution is chosen based on certain characteristics of the observed service time. First of all, the service time is always greater than zero which is represented by the lognormal distribution. Secondly, the lognormal distribution is right-skewed, which allows for small service times but there is also a possibility of long service times occurring less frequently. Finally, based on the obtained empirical data distribution in Figure 3.11 in Section 3.7.3, it can be observed that this aligns well with a lognormal distribution. The parameters of the lognormal distribution are the mean (μ) and the standard deviation (σ) resulting in: $Logn(\mu, \sigma)$. These values are calculated from the service time frequencies which is visible in Appendix C.3. Table 4.4 displays the resulting values of these parameters of the lognormal distribution.

Table 4.4: Lognormal distribution for the service time with its characteristics (source: author)

Measurement	Distribution	Range of service time
Service time port	$Logn(0.945, 0.646)$	[1 min - 12.5 min]

4.6. Overview input and output parameters

After explaining all the collected data in Chapter 3 and explaining how this will be used in the simulation model, this chapter provides an overview of all the input and output parameters have been created. A complete overview of all the input parameters is provided in Table 4.5. Complete overview of the output parameters is provided in Table 4.6.

Table 4.5: Input parameters DES (source: author)

Parameter	Unit	Value	Process
<i>Truck.Arrival.Rate</i>	[min]	$Poisson(\lambda)$, $Poisson(\lambda)$, $Poisson(\lambda)$	Arrival
<i>Transfer.BFC.PorterLodge</i>	[min]	2	Arrival
<i>Port.Operators</i>	[#]	2	Arrival
<i>Server.Time.Port</i>	[min]	$Logn(0.945, 0.646)$	Arrival
<i>Transfer.PorterLodge.Gate</i>	[min]	1.45	Arrival
<i>Transfer.Gate.Dock</i>	[min]	15	Enter
<i>Unloading.Docks</i>	[#]	30	Unload
<i>Number.Of.Pallets</i>	[#]	3 (S), 13 (M), 33 (L)	Unload
<i>Truckload.Distribution</i>	[#]	40% (S), 40% (M), 20% (L)	Unload
<i>Basic.Duration</i>	[min]	15	Unload
<i>Pallets.Per.Minute</i>	[#/min]	1	Unload
<i>Departure.Duration</i>	[min]	5	Departure

Table 4.6: Output parameters DES (source: author)

Parameter	Unit	Process
<i>Arrived.At.BFC</i>	[hh:mm:ss]	<i>Arrival</i>
<i>Arrived.At.Port</i>	[hh:mm:ss]	<i>Arrival</i>
<i>Truck.Started.PortProcess</i>	[hh:mm:ss]	<i>Arrival</i>
<i>Truck.Finished.PortProcess</i>	[hh:mm:ss]	<i>Arrival</i>
<i>Server.Time.Port</i>	[min]	<i>Arrival</i>
KPI 3: <i>Waiting.Time.Port</i>	[min]	<i>Arrival</i>
<i>Finished.Gate</i>	[hh:mm:ss]	<i>Arrival</i>
KPI 1: Probability waiting area port	[%]	<i>Arrival</i>
KPI 2: Trucks parked waiting area port	[#]	<i>Arrival</i>
<i>Waiting.time.DockAssignment</i>	[min]	<i>Enter</i>
KPI 3: <i>Time.DockAssignment</i>	[hh:mm:ss]	<i>Enter</i>
KPI 1: Probability waiting area dock	[%]	<i>Enter</i>
KPI 2: Trucks parked waiting area port	[#]	<i>Enter</i>
<i>Started.Unloading</i>	[hh:mm:ss]	<i>Unload</i>
<i>Finished.Unloading</i>	[hh:mm:ss]	<i>Unload</i>
<i>Unloading.Time</i>	[min]	<i>Unload</i>
<i>Truck.Left.BFC</i>	[hh:mm:ss]	<i>Departure</i>

4.7. Model Implementation

The simulation model has been developed using Python version 3.9.12. Execution of the model is carried out within the Spyder environment through the Anaconda platform. For implementing "Discrete Event Simulation", the "SimPy" library version 4.0.1 has been downloaded into Spyder. This library offers several tools and functionalities essential for DES, including environments, timeouts, events, resources, and processes. In addition, various other libraries and packages have been imported that were required for the simulation. These include numpy, random, matplotlib, pyplot, tabulate, pandas, scipy and datetime.

4.8. Verification and Validation

After formulating the simulation model and implementing the code in Python, the next step is to perform verification and validation. Verification and validation are crucial processes that assess the accuracy, reliability, and usefulness of the simulation model. These processes ensure that the simulation model is reliable and can be used to test and evaluate improvements for the real world. The verification and validation of the simulation model can be done by several approaches and needs to be compared between empirical data and simulation data. In this research, the measurements performed during an off peak period is used for comparison, offering real-time data as a benchmark. This data set contains 66 arriving trucks, serving as the basis for comparison. Furthermore, experts from BFC and bol.com will review and assess other components of the simulation model. Given the limited empirical data availability, these experts have a vital role in ensuring that the simulation represents the real-world.

4.8.1. Model Verification

The purpose of verification during the simulation construction, is to ensure that the model has been implemented correctly according to its specifications and requirements. It involves reviewing the code, inputs and equations to ensure that the simulation accurately represents the intended system. Verification is done while designing the simulation and consist of the following techniques: thoroughly code review, debugging and model consistency. By applying these techniques while implementing the simulation step-by-step, it helps to detect any unusual results or errors. This approach helps to identify and resolve issues early on, resulting in a more reliable and error-free simulation. During this process, several errors were detected and removed again. Resulting in a time-intensive process in which a

better understanding of the simulation model was gained and resulting in a fully functional simulation that aligns precisely with its intended purpose. Results of the model were printed to verify the correct execution of each event. The printed outputs served as evidence to ensure that the events were correctly simulated according to the intended logic. Additionally, various plots and histograms were generated to visualize any unusual behavior within the simulation. These visual representations provided a means to quickly detect any strange results in the simulation outputs. The most important verification results that have been checked can be found below with a brief explanation.

Generated trucks

The number of trucks generated must be an integer since no partial trucks exist. This is checked by checking the number of trucks in the printed results. Additionally, the number of trucks should be more or less equal to the implemented input for the amount of trucks. This is checked by running the simulation several times to assess if the total number of generated trucks aligns to the intended input.

Chronological order or the inbound processes

The simulation model represents the inbound system including 4 chronological processes: arrival, entering, unloading and departure. A verification test has been done in order to check if the trucks follow these processes in chronological order. This entailed tracking the progression of trucks through each process by printing the time stamps at which a truck initiates and concludes each process.

Truck Turn Around Time

Besides the chronological order of processes in the inbound system, it is also important that the total duration of each process aligns with the total Truck Turn Around Time. In order to verify if the simulation generates the duration of each process correctly, the duration of each process has been printed. These have been summed up in order to check if these align with the TTT of each truck.

Trucks waiting in queue at the port and docks

Trucks are joining the queue at the port or docks when the server is occupied. Since the amount of trucks in the queue is one of the KPIs, it is important to make sure the simulation model monitors the amount of trucks that needs to wait. In order to do this two approaches has been used. First, a complex qualitative analysis have been performed to verify whether the model accurately tracks the number of trucks in the queue. Multiple runs has been executed of which all the necessary simulation results have been documented and cross-verified to ensure the accurate calculations of waiting times and the number of trucks in the queue. Second, the result of the number of trucks in queue have been visualized in a histogram in order to double check if the results of the calculations align with the results of the simulation. Initially, some incorrect results were obtained during the initial runs, indicating inaccuracies in the model. Following debugging and subsequent adjustments, the accurate outcome was ultimately achieved.

Extreme values test

The input parameters have been replaced with extreme values in order to check if the model generates the expected results. During these tests, a couple of errors have been detected when the model didn't generate the expected results. Adjustments have been made to the model logic, which resulted in a model which aligns with the expected results.

4.8.2. Model Validation

Model validation is the process of comparing the outputs of the simulation with real-world observations (Jager, 2016). A validated model can be used to decide which decisions needs to be made in the real-world (Manuj et al., 2009). Ideally, validation is done with input of the real-world data and the outputs of the simulation model are then compared to the existing data. Unfortunately, bol.com has limited data regarding the arrival process and enter process. To be able to validate the model, the resulting data-set of the measurements will be used as a input for the simulation. The outputs of the simulation will then be checked with the data set of the measurements. Since the empirical data set is only a small data set, the validation cannot be very extensive. This implies that only the relevant parameters that have been measured can be checked in the simulation. Since this is only a part of the model, experts are also consulted to validate the remaining parts of the model using their expertise. The results of the validation is visible in Table 4.7. The second column "*Real data value*" provides the values of the real data (empirical data) which are compared to the simulated values which is visible in the third column. The difference between the values are presented in percentages in column four.

Table 4.7: Validation results (source: author)

Parameter	Real data value	Simulated value	Difference
Number of trucks arriving [#]	66	67	1.49%
Average service time [min]	03:12	03:08	-2.13%
Probability of exceeding the waiting area at the port (KPI 1) [%]	0%	0%	100%
Probability of exceeding the waiting area at the dock (KPI 1) [%]	0%	0%	100%
Minimum and maximum trucks parked in waiting area port (KPI 2) [#]	[1,3]	[1,4]	[100%, 25%]
Minimum and maximum trucks parked in waiting area dock (KPI 2) [#]	[1,1]	[1,1]	[100%, 100%]
Minimum and maximum waiting time during arrival process (KPI 3) [min]	[00:00,02:45]	[00:00,02:18]	[100%, -19.57%]
Minimum and maximum waiting time during enter (KPI 3) [min]	[00:00,00:00]	[00:00,00:00]	[100%, 100%]

Comparing the simulation results with the empirical data, it can be seen that the difference is relatively small for each of the tested parameter. For the number of trucks, over 700 replications an average of 67.1 trucks were generated, where the input was to create 66 trucks over 10 hours. In a second run of 700 replications, an average of 66.46 trucks were generated. From these tests, it can therefore be assumed that the generation of trucks correctly represents the input variables. For the average service time, over 700 replications an average of 03:08 has been calculated. This only differs with 2.13% from the input parameter and can be assumed as validated. Then the three KPIs are tested. First KPI 1: the probability of exceeding the waiting area at the port and dock. This is in both cases 0% which results in a 100% validation result. Then KPI 2 is tested, which is the number of trucks parked at the waiting area at the port and dock. For the waiting area at the port this results in a 100% validation result for the minimum value and 25% validation result for the maximum value. Finally, KPI 3 is tested which is the minimum and maximum waiting time per truck during arrival process and enter process. The maximum waiting time per truck at during the arrival process is 02:18 minutes in the simulation, which differs with 20 seconds from the empirical data. This results in a relatively larger percentage difference. This could be explained by human factors which have not been Incorporated in the model as explained before during the model assumptions. The maximum and minimum waiting time per truck during the enter process results in a 100% validated result since this is zero in both situations. Overall, it can be assumed that these simulation results of the parameters are valid.

Data Validation

Data validation is necessary for the distributions used in the simulation. For this simulation model, the data validation is executed on the arrival of trucks and the service times. The data that has been analysed is retrieved from the measurements. The validation for the distributions is done by means of the Chi-Squared test. The Chi-Squared is a statistical test to determine if there is a significant difference between the simulation results and the empirical data and checks if the sample data matches the chosen distribution. It is based on formulating the null hypothesis (H_0), which states there is no difference between the simulated data and the historical data and the alternative hypothesis (H_1), which states there is a difference between the simulated data and the empirical data (Center, 2023). An example of the formulated hypothesis can be seen in Formula 4.5. Then, the chi-square (χ^2) will be calculated using the Formula 4.6. This formula uses the data of the Observed data (O_i) which represents the simulated results and the Expected data (E_i), which results the empirical data. After this, the critical value needs to be determined which is based on the degrees of freedom (df) which is the number of the total data set minus one. Using the chi-square distribution table visible in Appendix C.5 in Figure C.6, the critical value can be found based on the chosen significance level which is 0.05. If the resulting chi-square value is less then the critical value, the alternative hypothesis can be rejected indicating that there is no difference between the simulation data and the historical data.

$$\begin{aligned}
 H_0 : SimulationData &= EmpiricalData \\
 H_1 : SimulationData &\neq EmpiricalData
 \end{aligned}
 \tag{4.5}$$

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}
 \tag{4.6}$$

Truck Arrivals Distribution

The validation of the Poisson distribution of truck arrivals is done with the Chi-Squared test. The comparison is made between the measured data and the results of the simulation with the data set of the measured data. Figure 4.3a, shows the truck arrival pattern derived from the measurements and contains real-time data regarding truck arrivals. Based on this truck arrival pattern a Poisson distribution was converted that was implemented in the simulation to derive at the same truck arrival pattern. As mentioned before, the Poisson distribution was chosen since it correspond to the requirements of a Poisson distribution and since most of the studies also use the Poisson distribution. Again, three separated Poisson distributions were used for the same periods: Poisson(12), Poisson(6) and Poisson(1). Figure 4.4b shows the arrival of trucks distribution resulting from the simulation. As can be seen, the arrival pattern shows roughly the same pattern in the simulation as of the empirical data. The Chi-Squared test was performed which resulted in the defined hypothesis as defined in Formula 4.6. The degrees of freedom were equal to 9 and with a significance level of 0.05 this resulted in a critical value of 16.92. After applying the Formula 4.6, the result of the chi-square is equal to 2.51. It can be concluded that the chi-square value is less than the critical value in which the H1 hypothesis can be rejected. This shows that there is no significant difference between the simulated data and the empirical data and therefore the Poisson distribution can be used for simulating the truck arrivals in the simulation. The Excel calculations on the Chi-Square test for the arrival of trucks is visible in Appendix C.3

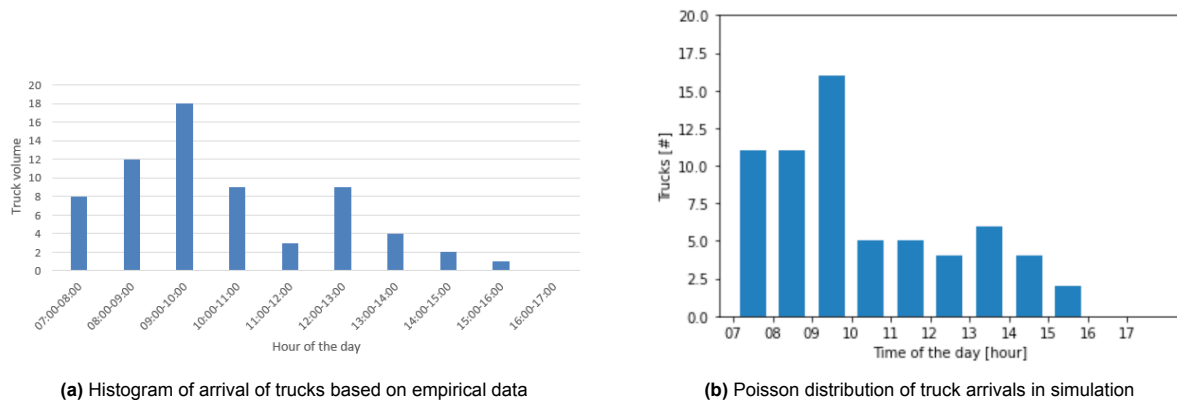


Figure 4.3: Data validation truck arrivals (source: author)

Service Time Distribution

The validation of the lognormal distribution of the service time of trucks at the porter lodge is also done with the Chi-Square test. This detailed Excel calculations on the Chi-Square test for the service time can be found in Appendix C.4. Figure 4.4a, shows the service time distribution derived from the measurements and contain real-time data. Based on this distribution, the lognormal distribution with the derived parameters was implemented in the simulation model to check if it results in the same distribution of the service time. Figure 4.4b shows the service time distribution resulted from the simulated with as input real-time data. After performing the Chi-Squared test it resulted in the defined hypothesis as defined in Formula 4.6. The degrees of freedom were equal to 20 and with a significance level of 0.05 this resulted in a critical value of 31.41. After applying the Formula 4.6, the result of the chi-square is equal to 21.25. It can be concluded that the chi-square value is less than the critical value in which the H1 hypothesis can be rejected. This shows that there is no significant difference between the simulated data and the empirical data and therefore the Lognormal distribution can be used for simulating the service times in the simulation. The result of this validation test shows that the lognormal distribution is a good fit.

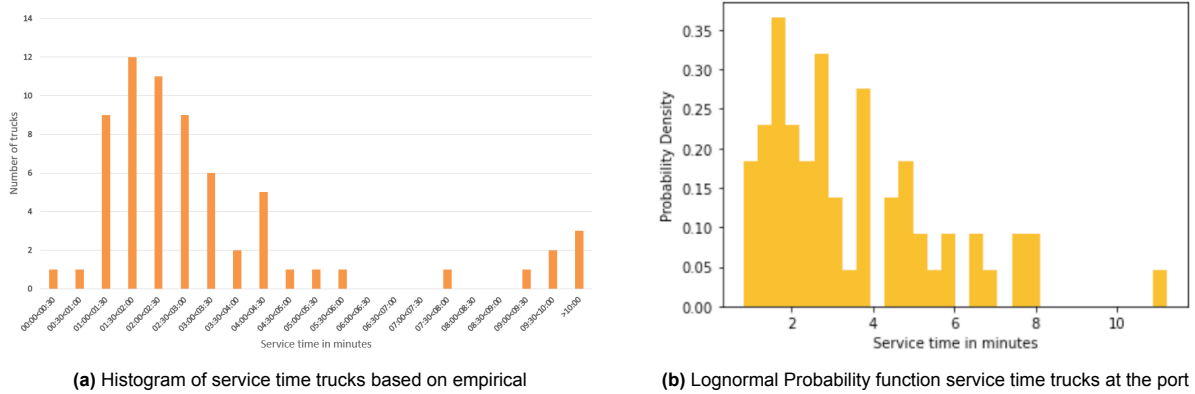


Figure 4.4: Data validation service time trucks at the port (source: author)

Consulting Experts

Since limited data is available regarding the truck arrival process, complete data validation is difficult. Therefore it is necessary to consult experts to discuss the simulation model. The experts are from BFC and bol.com headquarters from the inbound team. Those experts assess the model's consistency and logic to ensure it represents the real-world. Firstly, two experts from BFC are asked to verify the model. These two experts are experienced employees at BFC who have a lot of knowledge about the inbound system at BFC. Throughout an interview, several questions were asked regarding the simulation model and if it could represent real world situations at BFC. Both employees at BFC confirmed that the results of the simulation model could represent the real world. Secondly, two experts from bol.com head office were asked to verify the model. Those two experts have much expertise in the back-end of the inbound system. The same approach was used, asking questions throughout an interview about the simulation model. Both experts confirm that the simulation represents the real world.

4.9. Conclusion

In this chapter the sub-question 5 has been addressed which is: ***"How does the model design look like that will be used to analyze the current and future inbound system of Bol Fulfillment Center?"*** The model design that is constructed for this research is a Discrete Event Simulation model as it suits best for simulating different logistics processes and to analyze how they interact with each other. The objective of the model is to examine the impact of several potential strategies in order to eliminate the rejection of non-unloaded trucks. Several model requirements and assumptions have been made that are included in the model. The model design is based on the 4 main processes of the inbound system: the arrival, enter, unload and departure process with each their own sub-processes and the trucks as moving entities through the system. The sub-processes cover the different truck transfers, possible waiting times, unloading time and departure times. In order to simulate all these processes, data resulting from the data collection was categorized into input and output data and explained how they will be used in the simulation model. After the model implementation, the model is verified and validated. Verification is done while building the model in order to detect any errors and resolving them right away. Several checks have been done by means of visualisation of the results and hand-written calculations with the results of the simulation. Validation is done by comparing the simulated, empirical data. Second, data validation is done with a Chi-squared test in order to validate the distribution functions used. Finally, experts have been consulted since there is less empirical data available. From the different verification and validation tests, it can be concluded that the simulation represents a realistic inbound system of BFC which can be used to analyze the current and future system. No significant differences have been found between the simulation results and the historical and empirical results.

5. Experimental Plan

This chapter shows the experimental plan, in which the sub-question 6 will be addressed. The objective of the experimental plan is to use the constructed simulation model to experiment with possible variables and combinations to identify potential strategies that could improve the system performance of the inbound system of BFC. First, the system requirements will be defined in Section 5.1. Then, the different scenarios and their inputs will be presented in Section 5.2. Section 5.3 will explain the key variables that will be used in the experiments to identify potential strategies. Section 5.4 will describe the method of testing these key variables and Section 5.5 will discuss the resulting potential strategies and their input parameters. Finally, Section 5.6 will conclude this chapter by answering the sub-question 6.

5.1. System Requirements

In order to construct strategies for the inbound system of BFC, requirements need to be defined first. These are essential for the design and development of a system and to ensure that it meets the intended objective. It also prevents constructing strategies that are out of the scope of the research. There are two types of system requirements: functional requirements and non-functional requirements. Functional requirements describe the functionalities of characteristics that a system must need to have for meeting the intended research objective. It basically answers the question: *"What does the system needs to do?"* Non-functional requirements are the qualities or characteristics that define how the system should perform and answers the question: *"How should the system perform?"*

Functional requirements:

- The system should eliminate non-unloaded rejected trucks that need to wait outside on the road
- The system should reduce the amount of trucks waiting and parked in the waiting area at the port
- The system should reduce the amount of trucks waiting and parked in the waiting area at the dock
- The system should reduce the waiting time experienced by trucks in the queues
- The system should have a certain buffer to handle unexpected events
- The system should make it possible to unload all arriving trucks on the same day

Non-functional requirements:

- The system should be able to handle increased truck arrivals during peak seasons without rejecting trucks.
- The system should maintain and improve the overall performance of the inbound system
- The system should be able to reduce nuisance for the neighbourhood
- The system should be able to improve the throughput flow of trucks in the inbound system
- The system should be realistic to implement for bol.com in the next 3 years
- The system should be reasonable for partners and carriers

5.2. Scenarios

Scenarios are defined as different sets of conditions that represent specific real-world situations that may arise. These scenarios are used to test and evaluate the behavior of the system under different circumstances. This will help to better understand the behavior of the system under different situations and will provide valuable insights. In this research the different scenarios are based on the expected growth of the logistic company bol.com. This growth leads to an increase in the total number of arriving trucks at BFC and will therefore help to identify issues that can occur. Each scenario will represent only the months during the peak period. The forecast data available for this research was based on the years 2023, 2024 and 2025. Within this forecast data it can be seen how much items BFC will expect in the next coming years per month. By knowing the number of pallets that fit in a truck for BFC 1 and BFC 2, the number of trucks required can be calculated for the peak period in these years.

5.2.1. Input Scenarios

Each scenario covers a different year and differs in the amount of total trucks that is arriving at BFC. The amount of required trucks for each year is based on the available forecast data which covers the total expected items at BFC1 and BFC2. Based on several calculations, the amount of items can be converted into the amount of trucks that are required based on the small, medium and large truckload distribution that have been determined earlier. Since BFC1 is mainly meant for large items, and BFC2 for smaller items, there is a difference in the total amount of items expected at BFC1 and BFC2. Therefore, for these calculations only, a distinction is made between BFC1 and BFC2, after which the total number of trucks required for BFC1 and BFC2 is combined again. In order to calculate the amount of trucks required in the next coming years for the three scenarios, some essential data is required regarding the characteristics of trucks, which is visible in Table 5.1. Together with bol.com experts, the amount of items per pallet is determined for BFC1 and BFC2 and can be seen in the table. The *amount of items per pallet* is based on an estimation of available data at bol.com which results in 150 items per pallets for BFC1 and 250 pallets per item for BFC2. These values differ for BFC1 and BFC, since BFC1 receives larger items then BFC2. The *amount of items per truck size* is the sum of the amount of pallets per truck based on truckloads, multiplied by the items per pallet.

Table 5.1: Characteristics trucks (source: author)

BFC nr.	Amount of items per pallet	Amount of items per truck size		
		S (3 pallets)	M (13 pallets)	L (33 pallets)
BFC1	150	450	1950	4950
BFC2	250	750	3250	8250

Based on the truck data in Table 5.1, the forecast data of the expected inbound items, and the truckload distribution percentages, the number of arriving trucks per day in the peak season can be calculated for each of the three scenarios. The results for each scenario are shown in Table 5.2. Detailed calculations on these results can be found in Appendix E.

Table 5.2: Overview of the different scenarios and their arrival rate (source: author)

Scenario	Total arriving trucks per day	Peak arrival rate	Sub-peak arrival rate	Non-peak arrival rate
1: 2023	240	<i>Poisson(34)</i>	<i>Poisson(23)</i>	<i>Poisson(7)</i>
2: 2024	255	<i>Poisson(36)</i>	<i>Poisson(24)</i>	<i>Poisson(7)</i>
3: 2025	277	<i>Poisson(39)</i>	<i>Poisson(26)</i>	<i>Poisson(8)</i>

5.3. Four Key Variables

To construct several potential strategies in order to enhance the system performance of the inbound system of BFC, it has been determined which input parameters can be adjusted to potentially improve the system. Based on proposed solutions in the literature, brainstorm sessions with bol.com experts and the system requirements, this resulted in the identification of four key variables. These four variables are based on the input parameters of the simulation model. This results in the situation in which several variations can be made by adjusting these input parameters to explore the potential changes to the current system. Below an overview of these variables will given. Additionally, the input parameter table is provided in which it is visible which parameters will be adjusted.

5.3.1. Variable 1: Reduce the arrival rate by increasing number of arriving trucks with large truckloads

Variable 1 is focused on increasing the truckloads which will result in reducing the amount of arriving trucks per hour. This would impact the number of trucks parked in the waiting area at the port. This is done by adjusting the current truckloads percentages of truckloads. An increase in large truckload trucks, would make the biggest difference since it contains 33 pallets. Therefore, its chosen to increase the percentages for large trucks arriving at BFC by 10% and decrease the medium and small trucks arriving at BFC by 5%. By increasing the trucks arriving with large truckload fill and decreasing the number of trucks arriving with a medium and small truckload fill, the arrival rate of trucks will change

per time interval. This is because, based on the number of pallets per truck, the number of arrivals are determined in the three scenarios. When the number of pallets per truck change, the number of arriving trucks will also change.

Table 5.3: Input parameters DES - Variable 1 (source: author)

Parameter	Unit	Value	Process	Changed value?
<i>Truck.Arrival.Rate</i>	[min]	<i>Poisson</i> (λ), <i>Poisson</i> (λ), <i>Poisson</i> (λ)	<i>Arrival</i>	Yes
<i>Transfer.BFC.PorterLodge</i>	[min]	2	<i>Arrival</i>	No
<i>Port.Operators</i>	[#]	2	<i>Arrival</i>	No
<i>Server.Time.Port</i>	[min]	<i>Logn</i> (0.945, 0.646)	<i>Arrival</i>	No
<i>Transfer.PorterLodge.Gate</i>	[min]	1.45	<i>Arrival</i>	No
<i>Transfer.Gate.Dock</i>	[min]	15	<i>Enter</i>	No
<i>Unloading.Docks</i>	[#]	30	<i>Unload</i>	No
<i>Number.Of.Pallets</i>	[#]	3 (S), 13 (M), 33 (L)	<i>Unload</i>	No
<i>Truckload.Distribution</i>	[#]	40% (S), 40% (M), 20% (L)	<i>Unload</i>	Yes
<i>Basic.Duration</i>	[min]	15	<i>Unload</i>	No
<i>Pallets.Per.Minute</i>	[#/min]	1	<i>Unload</i>	No
<i>Departure.Duration</i>	[min]	5	<i>Departure</i>	No

5.3.2. Variable 2: Decrease service time per truck during arrival process

Variable 2 is focused on the process that takes place within the arrival process, the server time. By decreasing the server time, it is expected that the throughput of trucks during the arrival process would improve. Therefore, it is tested what the impact is of lowering the service time and making the service time more consistent. It is chosen to test with lowering the service time by 25%.

Table 5.4: Input parameters DES - Variable 2 (source: author)

Parameter	Unit	Value	Process	Changed value?
<i>Truck.Arrival.Rate</i>	[min]	<i>Poisson</i> (λ), <i>Poisson</i> (λ), <i>Poisson</i> (λ)	<i>Arrival</i>	No
<i>Transfer.BFC.PorterLodge</i>	[min]	2	<i>Arrival</i>	No
<i>Port.Operators</i>	[#]	2	<i>Arrival</i>	No
<i>Server.Time.Port</i>	[min]	<i>Logn</i> (0.945, 0.646)	<i>Arrival</i>	Yes
<i>Transfer.PorterLodge.Gate</i>	[min]	1.45	<i>Arrival</i>	No
<i>Transfer.Gate.Dock</i>	[min]	15	<i>Enter</i>	No
<i>Unloading.Docks</i>	[#]	30	<i>Unload</i>	No
<i>Number.Of.Pallets</i>	[#]	3 (S), 13 (M), 33 (L)	<i>Unload</i>	No
<i>Truckload.Distribution</i>	[#]	40% (S), 40% (M), 20% (L)	<i>Unload</i>	No
<i>Basic.Duration</i>	[min]	15	<i>Unload</i>	No
<i>Pallets.Per.Minute</i>	[#/min]	1	<i>Unload</i>	No
<i>Departure.Duration</i>	[min]	5	<i>Departure</i>	No

5.3.3. Variable 3: Decrease unloading time by decreasing the basic duration

Variable 3, covers the reduction of the basic duration during the unload process. Since there is a possibility of a queue at the waiting area at the dock when all docks are occupied, it is tested whether decreasing the unloading time has impact on the system performance. This is done by decreasing the basic duration time of trucks, which covers the preparation time for truck drivers. It will be tested what the impact is of lowering the basic duration by 5 minutes.

Table 5.5: Input parameters DES - Variable 3 (source: author)

Parameter	Unit	Value	Process	Changed value?
<i>Truck.Arrival.Rate</i>	[min]	<i>Poisson</i> (λ), <i>Poisson</i> (λ), <i>Poisson</i> (λ)	<i>Arrival</i>	No
<i>Transfer.BFC.PorterLodge</i>	[min]	2	<i>Arrival</i>	No
<i>Port.Operators</i>	[#]	2	<i>Arrival</i>	No
<i>Server.Time.Port</i>	[min]	<i>Logn</i> (0.945, 0.646)	<i>Arrival</i>	No
<i>Transfer.PorterLodge.Gate</i>	[min]	1.45	<i>Arrival</i>	No
<i>Transfer.Gate.Dock</i>	[min]	15	<i>Enter</i>	No
<i>Unloading.Docks</i>	[#]	30	<i>Unload</i>	No
<i>Number.Of.Pallets</i>	[#]	3 (S), 13 (M), 33 (L)	<i>Unload</i>	No
<i>Truckload.Distribution</i>	[#]	40% (S), 40% (M), 20% (L)	<i>Unload</i>	No
<i>Basic.Duration</i>	[min]	15	<i>Unload</i>	Yes
<i>Pallets.Per.Minute</i>	[#/min]	1	<i>Unload</i>	No
<i>Departure.Duration</i>	[min]	5	<i>Departure</i>	No

5.3.4. Variable 4: Even distribution of truck arrivals per hour throughout the day

Strategy 4 is focused on the even distribution of truck arrivals instead of the unexpected arrivals of the trucks in the different time intervals. This has impact on the arrival rate of trucks in which there won't be three separate Poisson distributions anymore. It is tested what the 100% even distribution of truck arrivals is throughout the day which means that all truck arrivals is divided throughout the day.

Table 5.6: Input parameters DES - Variable 4 (source: author)

Parameter	Unit	Value	Process	Changed value?
<i>Truck.Arrival.Rate</i>	[min]	<i>Poisson</i> (λ), <i>Poisson</i> (λ), <i>Poisson</i> (λ)	<i>Arrival</i>	Yes
<i>Transfer.BFC.PorterLodge</i>	[min]	2	<i>Arrival</i>	No
<i>Port.Operators</i>	[#]	2	<i>Arrival</i>	No
<i>Server.Time.Port</i>	[min]	<i>Logn</i> (0.945, 0.646)	<i>Arrival</i>	No
<i>Transfer.PorterLodge.Gate</i>	[min]	1.45	<i>Arrival</i>	No
<i>Transfer.Gate.Dock</i>	[min]	15	<i>Enter</i>	No
<i>Unloading.Docks</i>	[#]	30	<i>Unload</i>	No
<i>Number.Of.Pallets</i>	[#]	3 (S), 13 (M), 33 (L)	<i>Unload</i>	No
<i>Truckload.Distribution</i>	[#]	40% (S), 40% (M), 20% (L)	<i>Unload</i>	No
<i>Basic.Duration</i>	[min]	15	<i>Unload</i>	No
<i>Pallets.Per.Minute</i>	[#/min]	1	<i>Unload</i>	No
<i>Departure.Duration</i>	[min]	5	<i>Departure</i>	No

5.4. Experiments - Selection of Strategies

In order to assess what the impact is of changing the key variables on the system performance and identify potential strategies, experiments were conducted across the three scenarios, incorporating the variations of the variables and their combinations. Given that there are four variables, the possible combinations are numerous, leading to a vast number of potential experiments. Given the constraints of time and computational resources, conducting every possible experiment wasn't feasible. In order to avoid results without necessarily providing additional insights, the following procedure in the experiments was chosen. First, all the variables will be tested individually in order to examine the impact on the system performance. Then, combinations of the variables were tested to find those combinations

that yield significant better system performance, which were subsequently selected for further strategy development.

This has resulted in a total selection of 16 viable strategies that significantly influence system performance and are practical for bol.com's consideration. These selected strategies had a notable impact on performance, making them particularly worthy for analysis. Combinations and variations that were excluded either didn't enhance system performance, made only a marginal difference, or were less realistic for bol.com, especially those involving three or four variables only delivered marginally better outcomes. Hence, only certain combinations of two variables have been integrated into the proposed strategies. Examples of some combinations that were not selected are listed in Appendix F.

5.5. Experiments - Potential Strategies

The resulting 16 potential strategies resulting from the experiments in which the variations of the four variables and certain combinations have been tested, will be further tested in a new set of experiments. The results of these experiments will be given and described in Chapter 6, combined with a thorough analysis interpreted by the three KPIs. Within this section, all the 16 strategies will be provided together with the input parameters in order to get a better understanding of what will change.

5.5.1. Strategy 1.1 until 1.3

Strategy 1.1 until 1.3 are based on the increase of trucks arriving with a large truckload. The truckload distribution of trucks will be changed as described earlier when explaining variable 1. This results in three strategies in which there is a 30%, 40% and 50% increase in trucks arriving with a large truckload which can be seen in Table 5.7. Second, by changing the truckloads, the number of arriving trucks per time interval also changes. The number of trucks arriving per time interval in the three scenarios, can be seen in Appendix E.5 in Figure E.8 and E.9. These are not visualized in this section since the data set is too big.

Table 5.7: Strategy 1: Increase truckload fill (source: author)

Strategy nr.	Truckload Distribution
	S/M/L
Base	40% / 40% / 20%
1.1	35% / 35% / 30%
1.2	30% / 30% / 40%
1.3	25% / 25% / 50%

5.5.2. Strategy 2.1 and 2.2

In strategy 2.1 and 2.2 the service time during the arrival process will be reduced by 25% in each strategy compared to the base case and the variance will be reduced. This has resulted in two strategies in which in strategy 2.1, the service time is reduced to 2.24 min and in strategy 2.2 reduced to 1.36 min. An overview is visible in Table 5.8.

Table 5.8: Strategy 2: Decrease service time (source: author)

Strategy nr.	Server time port	Variance	Average service time
Base	$Logn(0.945, 0.646)$	[0.5 min - 12.5 min]	3.12 min
2.1	$Logn(0.745, 0.146)$	[0.5 min - 4 min]	2.24 min
2.2	$Logn(0.345, 0.146)$	[0.5 min - 4 min]	1.36 min

5.5.3. Strategy 3.1 and 3.2

Strategy 3.1 and 3.2 covers the reduction of the unloading time by reducing the basic duration. The basic duration is the preparation time for a truck driver to get ready for unloading. By reducing the basic duration with 5 min in each strategy, a lower total unloading times is achieved for the different truck sizes. An overview of these parameters can be seen in Table 5.9.

Table 5.9: Strategy 3: Decrease unloading time (source: author)

Strategy nr.	Unloading time per truckload	Basic duration
	<i>S/M/L</i>	
Base	18 / 28 / 48	15 min
3.1	13 / 23 / 43	10 min
3.2	8 / 18 / 38	5 min

5.5.4. Strategy 4

Strategy 4 covers the even distribution of trucks arrivals per hour throughout the day. Its chosen to implement just one variation of the even distribution of trucks and that is the 100% distribution. This results in just one Poisson distribution for the arrival rate, instead of the three Poisson distributions in the base case due trucks arriving in different time-intervals. The inputs for this strategy are presented for each of the three scenarios, since it differs per scenario due to the different total number of arriving trucks. This can be seen in Table 5.10.

Table 5.10: Strategy 4 (source: author)

Strategy nr.	Scenario nr.	Total arriving trucks per day	Truck arrivals per hour
4	1: 2023	240	<i>Poisson</i> (24)
4	2: 2024	255	<i>Poisson</i> (26)
4	3: 2025	277	<i>Poisson</i> (28)

5.5.5. Strategy 5 until 7

In strategy 5, 6 and 7, the combinations have been applied of increasing the number of trucks arriving with a large truckload and the reduction of the service time during the arrival process. The 30%, 40% and 50% adjustment is tested in combination with the 1.36 minutes service time. During the experiments, it has been observed that reducing the service time to 1.36 min instead of 2.24 min is more effective on the system performance. Since the reduction to 1.36 min is also realistic in the context of this research, it is chosen to implement this in the strategies. An overview can be seen in Table 5.11.

Table 5.11: Strategy 5 until 7 (source: author)

Strategy nr.	Truckload Distribution	Server time port
	<i>S/M/L</i>	
Base	40% / 40% / 20%	<i>Logn</i> (0.945, 0.646)
5	35% / 35% / 30%	<i>Logn</i> (0.345, 0.146)
6	30% / 30% / 40%	<i>Logn</i> (0.345, 0.146)
7	25% / 25% / 50%	<i>Logn</i> (0.345, 0.146)

5.5.6. Strategy 8 until 10

Strategy 8, 9 and 10 covers the combination of the increase of trucks arriving with a larger truckload and the reduction of the basic duration in the unload process by 10 minutes. Combining two things that has impact on the arrival and unload process could provide some valuable insights into the impact of such a strategy.

Table 5.12: Strategy 8 until 10 (source: author)

Strategy nr.	Truckload Distribution	Basic duration
	<i>S/M/L</i>	
Base	40% / 40% / 20%	15 min
8	35% / 35% / 30%	10 min
9	30% / 30% / 40%	10 min
10	25% / 25% / 50%	10 min

5.5.7. Strategy 11

Strategy 11 covers the combination of the reduction of the service time during the arrival process to 1.36 minutes and the reduction of the basic duration to 5 minutes in the unload process. Overview of the input parameters can be seen in Table 5.13.

Table 5.13: Strategy 11 (source: author)

Strategy nr.	Service time port	Basic duration
Base	$\text{Logn}(0.345, 0.146)$	15 min
11	$\text{Logn}(0.945, 0.646)$	5 min

5.5.8. Strategy 12

Strategy 12 covers the combination of the 50% increase of trucks arriving with a large truckload, and the even distribution of trucks per hour throughout the day. An overview is given in Table 5.14

Table 5.14: Strategy 12 (source: author)

Strategy nr.	Scenario nr.	Truckload Distribution	Truck arrivals per hour
		<i>S/M/L</i>	
12	1: 2023	25% / 25% / 50%	$\text{Poisson}(17)$
12	2: 2024	25% / 25% / 50%	$\text{Poisson}(18)$
12	3: 2025	25% / 25% / 50%	$\text{Poisson}(19)$

5.6. Conclusion

In this chapter the sub-question 6: **Which potential strategies can be designed to improve the system performance of the Bol Fulfillment Center?** have been addressed. In order to answer this sub-question, an experimental plan has been constructed. To begin, the system requirements were defined in order to make sure that the strategies will meet the intended objective. Next, three scenarios were developed, each reflecting a significant increase in arriving trucks, mirroring BFCs projected growth over the next three years. These scenarios are used to make clear that there is a potential escalation of issues if the current situation remains unchanged. Subsequently, by using these three scenarios, potential challenges will be provided to bol.com over the upcoming years. Based on literature reviews, brainstorm sessions with bol.com, and the system requirements, four key variables were identified: 1. Reduce the arrival rate by increasing the number of arriving trucks with large truckloads, 2. Decrease the service time per truck during the arrival process, 3. Decrease unloading time by decreasing the basic duration and 4. Even distribution of truck arrivals per hour throughout the day. By experimenting with variations and combinations of these variables, a selection of 16 potential strategies have been identified based on the system requirements. In conclusion, 16 potential strategies have been identified to be further analyzed against the three formulated KPIs in order to get valuable insights into their impact on the system performance of the inbound system of bol.com. A complete overview of the 16 strategies is given in Table 5.17.

Table 5.15: Overview strategies (source: author)

Strategy	Description
1.1 until 1.3	10% increase of trucks arriving with a large truckload, 5% decrease of trucks arriving with a medium and small truckload
2.1. and 2.2	Reduction of the service time during the arrival process within the port by 2.24 min and 1.36 min
3.1 and 3.2	Reduction of the basic duration during the unload process with 10 and 5 minutes
4	Even distribution of truck arrivals
5	30% Increase in trucks with large truckloads and reduction of service time to 1.36 min
6	40% Increase in trucks with large truckloads and reduction of service time to 1.36 min
7	50% Increase in trucks with large truckloads and reduction of service time to 1.36 min
8	30% Increase in trucks with large truckloads and reduction basic duration during unloading to 10 min
9	40% Increase in trucks with large truckloads and reduction basic duration during unloading to 10 min
10	50% Increase in trucks with large truckloads and reduction basic duration during unloading to 10 min
11	Reduction of service time to 1.36 min and unloading time to 5 min
12	50% Increase in trucks with large truckloads and even distribution truck arrivals

Table 5.16: Overview strategies (source: author)

Strategy	Trucks with large truckload	Service time arrival process	Preparation time unload process	Truck arrival pattern
Base	20%	3.12 min	15 min	Uneven
5	30%	1.36 min	15 min	Uneven
6	40%	1.36 min	15 min	Uneven
7	50%	1.36 min	15 min	Uneven
8	30%	3.12 min	10 min	Uneven
9	40%	3.12 min	10 min	Uneven
10	50%	3.12 min	10 min	Uneven
11	20%	1.36 min	5min	Uneven
12	50%	3.12 min	15 min	Even

Table 5.17: Overview strategies (source: author)

Strategy	Trucks with large truckload	Service time arrival process	Preparation time unload process	Truck arrival pattern
Base	20%	3.12 min	15 min	Uneven
1.3	<u>50%</u>	3.12 min	15 min	Uneven
4	20%	3.12 min	15 min	<u>Even</u>
6	<u>40%</u>	<u>1.36 min</u>	15 min	Uneven
7	<u>50%</u>	<u>1.36 min</u>	15 min	Uneven
10	<u>50%</u>	3.12 min	<u>10 min</u>	Uneven
11	20%	<u>1.36 min</u>	<u>5min</u>	Uneven
12	<u>50%</u>	3.12 min	15 min	<u>Even</u>

6. Results Experiments

This chapter focus on answering sub-question 7. The results of the 16 potential strategies from the experiments as described in Chapter5, will be analyzed in this chapter to determine to what extent these strategies could improve the system performance of the inbound system of BFC. This chapter will first explain the interpretation of the results in Section 6.1, which will be done by the three formulated KPIs. In Section 6.2, the results for the base cases of each scenario will be presented to provide insights into the current problem and how it will escalate in the next coming years. Section 6.3 will represent the results of the individually strategies and Section 6.4 will represent the results of the interactive strategies. Finally, this chapter will be concluded in Section 6.5 in which the sub-question 7 will be answered.

6.1. Interpretation of the Results

The outcomes of the experiments will be analyzed using the three formulated KPIs defined in 3. Every KPI will be tested for both waiting areas within the inbound system, located at the port and the dock. Its important to mention that the results in this chapter will only be given for scenario 3, the worst case scenario. This was done because for each scenario, the same trend was evident when testing the strategy. By only showing scenario 3, the focus is placed on the worst-case scenario, ensuring that the strategy also works for scenarios 1 and 2. Only those strategies that improve the system performance for all scenarios will be selected. The results of the other scenarios can be seen in Appendix G and H.

6.1.1. KPI 1: Probability of exceeding the capacity of the waiting area at the port and dock

KPI 1 will be presented in a table that includes the probabilities of exceeding the capacity for both the waiting areas at the port and dock, expressed as a percentage. This percentage can be understood as the probability that the waiting area at port and/or dock will be exceeded on an operational day during a peak period of bol.com. The waiting area at the port has a capacity of 15, while the dock's capacity is set at 5. Additionally, the table will provide the number of trucks when exceeding the capacities, offering an estimate of the scale of the problem. The objective of this research is to eliminate the possibility of rejected trucks, which corresponds to a 0% probability for KPI 1. However, in theory, it is difficult to say that there is 0% probability because there may always be an extremely small change practically. When the results of the simulation model gives a 0% probability, it can be considered as a probability so small that it can effectively be considered as zero. So, although in theory a 0% probability will never be zero, a 0% probability for KPI 1 in this research corresponds to an extremely unlikely occurrence that the capacity is being exceeded. It is important to emphasize this in order to enhance the research's validity.

6.1.2. KPI 2: Number of trucks parked at the waiting area at the port and dock

As the number of trucks parked at the waiting area at both the port and dock can vary from day to day and from hour to hour, KPI 2 will be visually represented using a boxplot. A boxplot is chosen since it provides clear visualization of the data distribution, which emphasize the variability in the number of trucks parked. By presenting the data through a boxplot, which gives insights into key statistics including the minimum, median, first and third quartile, and maximum values, more insights can be obtained regarding the system performance of the inbound system. The boxplots are presented for each operational hour, resulting in 10 boxplots for each experiment. This approach is chosen since KPI 2 deals with variability during the operational day and thus gives a better understanding of when the issue occurs during an operational day. The range of the number of trucks parked, which is visible by the boxplots minimum and maximum values, provides insights into the pressure on the waiting areas and, consequently, impacts the operational activities during the processes of the inbound system. A small range of trucks parked implies low pressure on the waiting area which allows a buffer of unexpected events and contributes to a smoother flow of the inbound system.

6.1.3. KPI 3: Waiting time per truck in queue during arrival and enter process

The waiting time per truck in the queue during the arrival process and in queue during the enter process can fluctuate on an operational day. Therefore, KPI 3 will also be presented as hourly boxplots. The waiting time is given on truck level and are cumulative averages. Lowering the waiting time per truck is not the main objective of this research. However, the waiting time indirectly impacts the results of KPI 1 and KPI 2 since a lower waiting time contributes to the reduction of rejecting trucks and the reduction

in the number of trucks parked. Therefore, it is interesting to analyze this. Additionally, it gives an indication of the TTT of trucks since the total waiting time is part of the TTT. A lower TTT improves also the truck drivers experience.

6.2. Base Cases

The base case is defined as the situation in which nothing is done to the current situation. Therefore, it is interesting to compare the results of the experiments against the base cases of each scenario since it gives a good indication of how well the strategy performs. In this section the base cases of each scenario will be presented. As seen in Table 6.1 the probability of exceeding the capacity in the waiting areas at the port and the dock (KPI 1), increases in the next coming years. In other words, the situation is expected to worsen in the upcoming years. The increase in truck arrivals can be attributed to the fact that bol.com expects an increase in customer orders and therefore an increase in deliveries of products from the partners which results in more truck arrivals. For KPI 1, focusing at the port situation, there is a 16% increase between SC1 and SC2, and an even more significant 32% increase between SC2 and SC3. The expected increase can be attributed to the increase in truck arrivals at BFC in the coming years, which causes a higher arrival rate per hour.

The same pattern is observed when focusing at the dock waiting area. It can be seen that in scenario 1 (2023), there is a 0% probability that the capacity will be exceeded. However, when looking at scenario 2 (2024) and 3 (2025), it can be seen that this probability increases. In order to determine what causes this, the number of trucks ready for dock assignment have been analyzed in scenario 2 and 3. It appears that when the arrival rate is more 35 or higher, which is the case in scenario 2 and 3, there is a probability that the trucks ready for dock assignment could increase to 40 or higher per hour. When this happens, it appears that the unload process can't keep up with the speed of the arrival process and therefore all available docks are occupied which causes more trucks to wait for dock assignment. Although, the increase is less compared to the port situation and the probability remains relatively low, it still provides valuable insights into this rising trend and the problem BFC is facing in the next coming years.

Examining KPI 2 for both port and dock scenarios, it can be observed in Figures 6.1 and 6.2, that the boxplot becomes bigger in each scenario, indicating that the variability in the number of trucks parked increases. The problem mainly occurs between 7 a.m. and 12 p.m., which can be defined as the critical period of the day and is also known as the morning peak as shown in Chapter 3. However, after 12 p.m., across all scenarios, it can be noticed that the number of trucks parked in the waiting area at both the port and dock gradually decreases to zero. This can be explained by the fact that the number of arriving trucks reduces after 12 p.m. (sub-peak and non-peak time interval) as explained in Section 3.7.2 and therefore the number of trucks parked at those waiting areas will decrease.

The same trend is observed when analyzing the results for KPI 3, the waiting time per truck in both queues which are visible in Figure 6.3. In SC3, the year 2025, the maximum waiting time for trucks can reach 53 minutes in the arrival process and 16 minutes in the enter process which is a significant increase.

So, it can be concluded that in the upcoming years, the pressure on both waiting areas at port and dock, will increase due to the expected growth of BFC. This is evident from the substantial increase in the probability of exceeding the capacities of these waiting areas, the increased variability in the number of parked trucks and the increased waiting times for trucks in both queues. These results highlight the importance of conducting this research and construct strategies to improve the inbound system.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table 6.1: Results for the base cases, KPI 1 (source: author)

Scenario nr.		Prob. of exceeding capacity		Amount of trucks exceeding	
		Port	Dock	Port >15	Dock >5
SC1	Base: 2023	16.3 %	0%	[1-8]	[0]
SC2	Base: 2024	33.4%	6.7%	[1-15]	[1]
SC3	Base: 2025	65.4%	13.9%	[1-30]	[1-3]

KPI 2: Number of trucks parked at the waiting area at the port and dock

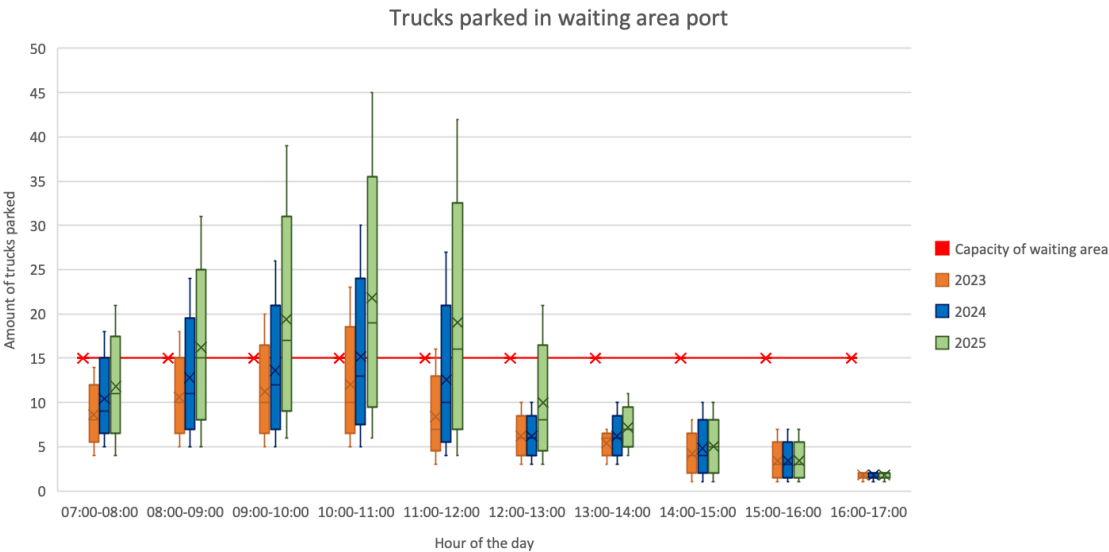


Figure 6.1: Result for the base cases: Number of trucks parked in waiting area port, KPI 2 (source: author)

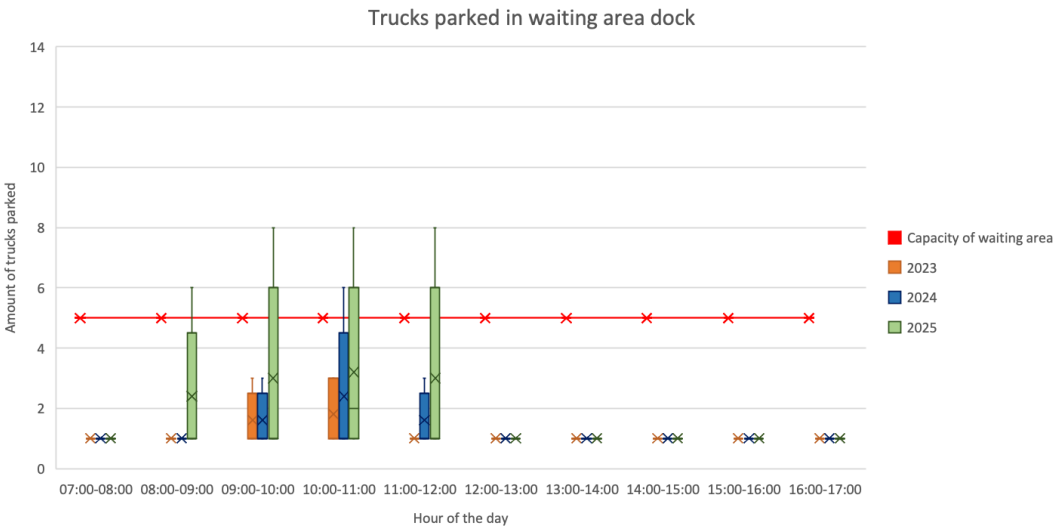


Figure 6.2: Results for the base cases: Number of trucks parked in waiting area dock, KPI 2 (source: author)

KPI 3: Waiting time per truck in queue during arrival and enter process

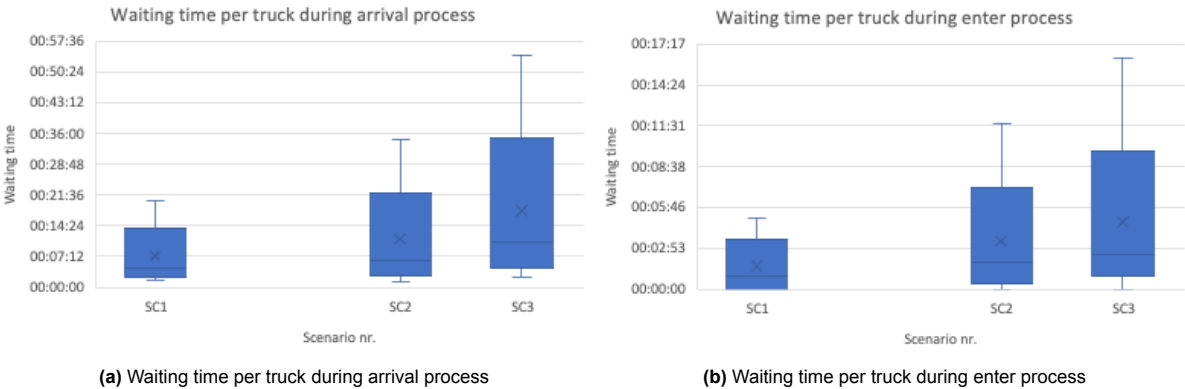


Figure 6.3: Results for the base cases: Waiting time per truck, KPI 3 (source: author)

6.3. Individually Strategies Experiments

In this section the results of the experiments will be explained in which the strategies have been applied individually in order to examine their individual impact on the system performance. As explained before, the experiments will be explained focused on scenario 3.

Examining KPI 1, which assesses the probability of exceeding the capacity at both the port and dock waiting area, reveals some interesting distinctions when considering the individually strategies as indicated in Table 6.2. Firstly, when experimenting with different truckload implementations, the 30% adjustment in strategy 1.1, the 40% adjustment in strategy 1.2, and the 50% adjustment in strategy 1.3, a consistent decreasing trend can be observed in the probability of exceeding the capacities at both the port and dock waiting areas. Notably, the 50% adjustment (strategy 1.3), yields the lowest probability of 0% at both waiting areas. The decreased probabilities for both the waiting areas at the port and the dock when adjusting the truckloads, can be attributed to the fact that the total number of arriving trucks decreases through the implementation of strategy 1.1, strategy 1.2 and strategy 1.3, reducing from 277 in the base case to 191 in strategy 1.3. With fewer trucks arriving at the port, the arrival rate per hour is lower, which results in a smoother workflow in the arrival process. Additionally, it has been observed that when the arrival rate becomes equal or lower then 30, the probability of exceeding the capacity of the waiting areas is effectively eliminated. For example, in strategy 1.2, where the arrival rate between 7 a.m. and 11 a.m. is equal 31 trucks as can be seen in Appendix E.5 in Figure E.8, there is still a modest 6.1% probability of exceeding the capacity at the port waiting area. However, when the number of arriving trucks falls below this threshold, as can be seen in strategy 1.3, where the arrival rate between 7 a.m. and 11 a.m. is equal to 27 trucks, this risk decreases to a 0% probability. This also leads to the reduction of the probability for the waiting area at the dock as the number of trucks ready for unloading will not exceed the number of 40 as explained in Section 6.2. So, it can be concluded, that the adjustment of truckloads impacts the arrival, enter and unload process positively.

Secondly, when experimenting with reduced and more consistent service time per trucks during the arrival process, it can be seen that this has a significant impact on the probability for the waiting area at the port. Namely, compared to the base case and implementing strategy 1.1, a decrease of 53.2% in the probability is achieved by reducing the arrival rate. By implementing strategy 2.1, a 38.9% decrease is achieved compared to the base case when only lowering the service time in the arrival process. This shows that this strategy is a very effective method by only reducing the service time. This decreased probability for the waiting area at the port, can be attributed to the fact that each truck spends less time at the port, which creates a smoother flow of operations in the arrival process. The congestion of trucks will be reduced and there will be more available space for trucks in the waiting area at the port, lowering the probability of trucks being rejected due to insufficient capacity. However, this reduction in service time does not yield the same outcome for the waiting area at the dock in strategy 2.1 and 2.2, where the probability is significantly higher compared to the base case. This increase can be explained by the fact that the throughput rate of trucks, from arrival to enter process, increases due to faster processing of trucks in the arrival process while the arrival rate of trucks per hour within the morning peak is still equal to 39 in scenario 3. As explained in Section 6.2, when the arrival rate of trucks is more than 35, the number of trucks ready for dock assignment can increase to 40 per hour which leads to the situation in which the unload process can't keep up with the speed of the arrival process. This leads to more trucks parked in the waiting area at the dock which, increases the probability of exceeding this capacity. It can be concluded that, although the reduction of the service time is an effective strategy for lowering the probability at the waiting area at the port and resolve the arrival rate of trucks more than 30, it negatively impacts the enter and unload process.

Thirdly, another notable observation is that reducing the basic duration in strategy 3.1 and 3.2 during the unload process has, no impact on the probability for the waiting area at the port as the probability remains unchanged compared to the base case. This shows that this strategy has no impact on the arrival process. However, it does result in a reduction in the probability for the waiting area at the dock. This improvement can be attributed to the fact that trucks are unloaded at a faster rate. Consequently, the time each truck spends at the unloading docks is reduced, thereby lowering the risk of all unloading docks become occupied. These findings suggest that, only implementing a reduction in the basic duration during the unload process won't necessarily lead to an improved system performance for both waiting areas. Instead, it primarily benefits the waiting area at the dock by facilitating faster unloading, while the impact on the port waiting area appears to be negligible.

Lastly, the implementation of an evenly distributed truck arrival pattern (strategy 4), leads to a significant reduction in the probability of exceeding the capacities at both the port and dock waiting

areas. This outcome can be attributed to the fact that the number of trucks arriving every hour is equal to 28 with implementing strategy 4 due to the even distribution of trucks throughout the day. As previously explained, it appears that when the number of trucks arriving per hour is less or equal to a number of 30, the probability of exceeding the capacity at the waiting area at the port and dock is eliminated. So, it can be concluded that this strategy positively impacts the arrival, enter and unload process.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table 6.2: Results of individually strategies, KPI 1 (source: author)

Scenario nr.	Strategy nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		Port	Dock	Port >15	Dock >5
Base	-	65.4%	13.9%	[1-30]	[1-3]
SC3	1.1	26.5%	11.1%	[1-11]	[1]
SC3	1.2	6.1%	0%	[1]	[0]
SC3	1.3	0%	0%	[0]	[0]
SC3	2.1	12.2%	38.1%	[1-5]	[1-11]
SC3	2.2	0%	41.4%	[0]	[1-13]
SC3	3.1	65.4%	0%	[1-18]	[0]
SC3	3.2	65.4%	0%	[1-18]	[0]
SC3	4	0%	0%	[0]	[0]

When examining KPI 2, which concerns the number of trucks parked in the waiting area at both port and dock, similar trends can be seen but more variations in the results of the strategies are visible. The outcomes can be seen in in Figure 6.4 for the waiting area at the port and in Figure 6.5 for the waiting area at the dock. In these figures the trends described earlier regarding KPI 1, are visible through the reduced sizes of the boxplots, indicating decreased variability in the number of trucks parked within the waiting areas.

Looking at Figure 6.4, which concerns the waiting area at the port, it can be observed that implementing strategy 1.3, increased truckloads, strategy 2.2, reduced and more constant service times, and strategy 4, the even distribution of trucks arrivals during the day, results in the number of trucks parked below 15 as also indicated for KPI 1. As explained in Section 6.2, in the base cases of all the three scenarios, the most critical hours are between 7 a.m. and 12 p.m., which covers the peak time-interval. Within these hours, it can be seen that implementing strategy 1.3, results in the relatively smallest range of trucks parked compared to strategy 2.2 and 4. It results in a range between a minimum of 4 trucks and a maximum of 11 trucks. From 11 a.m. towards the end of the day it can be seen that the range decreases even more which can be attributed to the different time intervals of peak arrivals as explained in Chapter 3. Another interesting result can be observed when looking at the implementation of strategy 4. A range between a minimum of 4 and a maximum of 11 trucks parked is visible for each hour of the day. Especially between 3 p.m. and 5 p.m. this results in more trucks parked in the waiting area at the port compared to the other strategies. This result can be explained by the fact that the arrivals of trucks is evenly distributed throughout the day, resulting in an equal variability in the number of trucks parked each hour. This constant range of trucks parked throughout the day improves the productivity of the employees in the inbound process as there is a constant flow of trucks.

Focusing at the waiting area at the dock in Figure 6.5, the same trends are visible as explained for KPI 1. Strategy 2.1 and 2.2, leads to a huge increase in number of trucks parked within the waiting area at the dock, especially between the critical hours of the morning peak. The other strategies, which has resulted in a 0% probability for the waiting area at the dock, a significant decrease can be observed in which strategy 1.3, 3.1, 3.2 and 4 results in just 1 truck parked within the waiting area. Within these strategies, the arrival rate was reduced to 30 or lower, which appears to result in just 1 truck parked since strategy 1.2, in which the arrival rate is equal to 31 in the morning doesn't result in 1 truck parked. So, examining KPI 2, it can conclude that differences are observed within the strategies that accomplish a 0% probability for KPI 1. Those difference are mainly related to having a constant

range of trucks parked or a varying range of trucks parked which decreases towards the end of the day.

KPI 2: Number of trucks parked at the waiting area at the port and dock

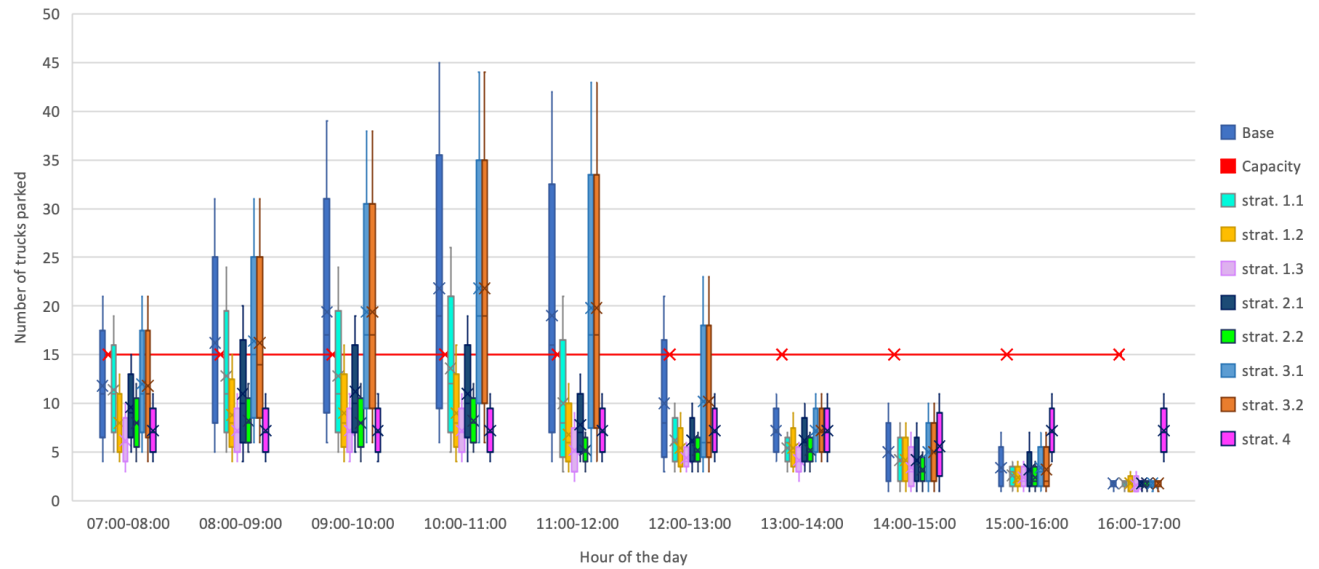


Figure 6.4: Results of individually strategies: Trucks parked in waiting area port, KPI 2 (source: author)

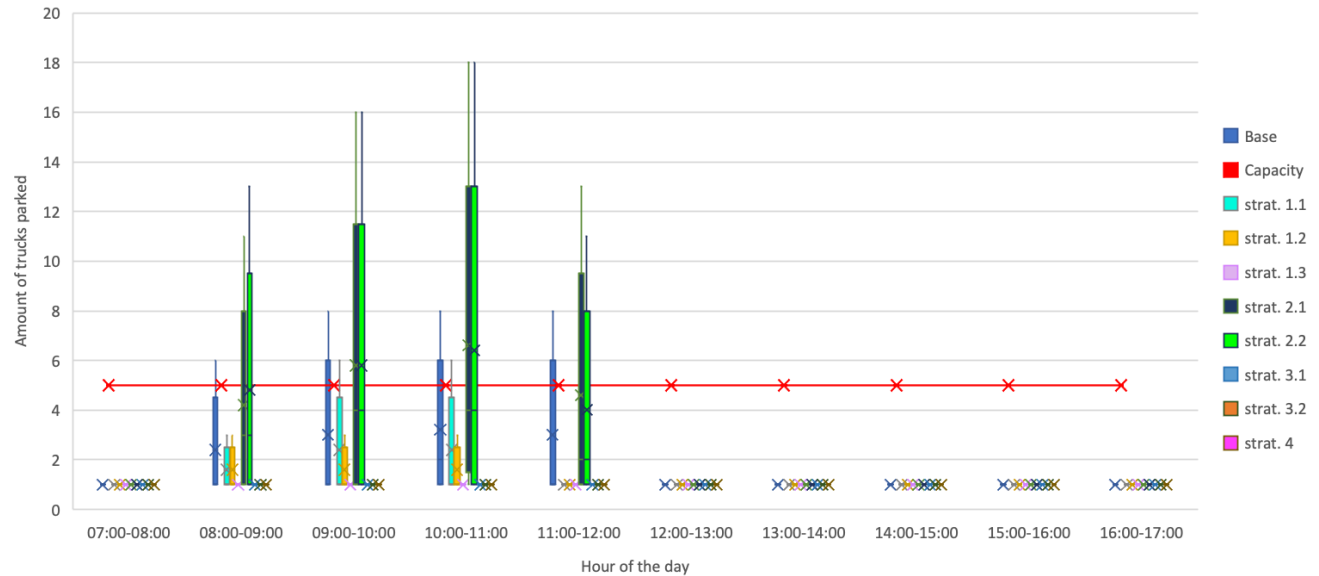


Figure 6.5: Results of individually strategies: Trucks parked in waiting area dock, KPI 2 (source: author)

Finally, KPI 3 can be examined which covers the waiting time experienced by trucks in the queue of the arrival process and enter process. The results are visible in Figure 6.6, which corresponds to the waiting time in queue during the arrival process and Figure 6.7, which corresponds to the waiting time in queue during the enter process. Focusing at the waiting time in the queue of the arrival process, a decreasing pattern can be observed again when increasing the trucks arriving with a large truckload (strategy 1.1, 1.2 and 1.3), reducing the service time per truck during the arrival process (strategy 2.1 and 2.2) and, implementing an even distribution of truck arrivals (strategy 4). The reason for the reduction of the waiting time, is the same as already explained for these strategies regarding KPI 1 and KPI 2. An interesting result is that although the implementation of strategy 1.3 and strategy 4 leads to the best results for KPI 1 and KPI 2 regarding the system performance of the inbound system, this doesn't hold when considering the waiting time per truck in the queue of the arrival process. The best results for KPI 3 are obtained when reducing the service time per truck during the arrival process. When looking at the waiting time in the queue of the enter process, the same patterns can be seen again as already described for KPI 1 and KPI 2. Even a zero minute waiting time for trucks can be achieved with the implementation of the maximum reduction of the basic duration during the unload process and the

even distribution of truck arrivals which indicates that no trucks are waiting.

KPI 3: Waiting time per truck in queue during arrival and enter process

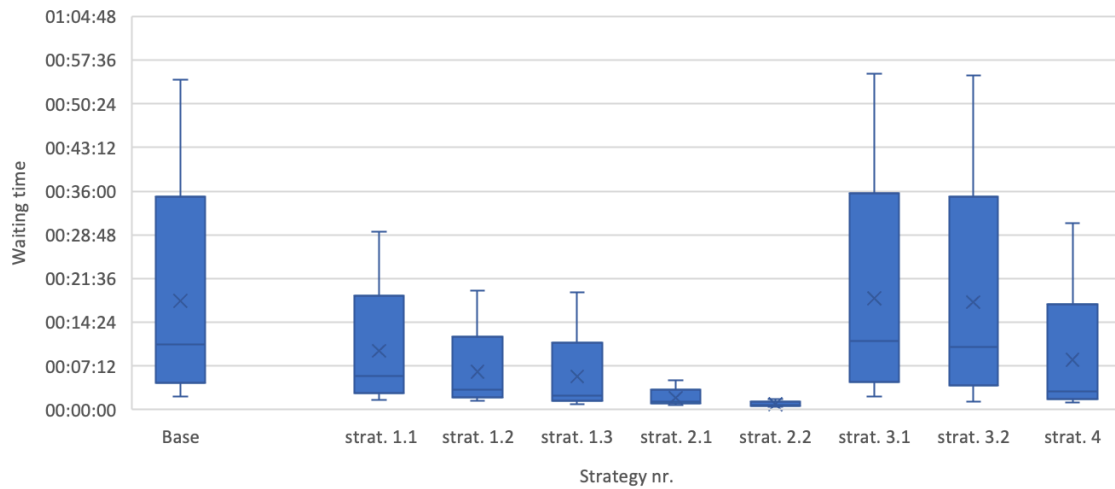


Figure 6.6: Results of individually strategies: Waiting time per truck in queue during the arrival process, KPI 3 (source: author)

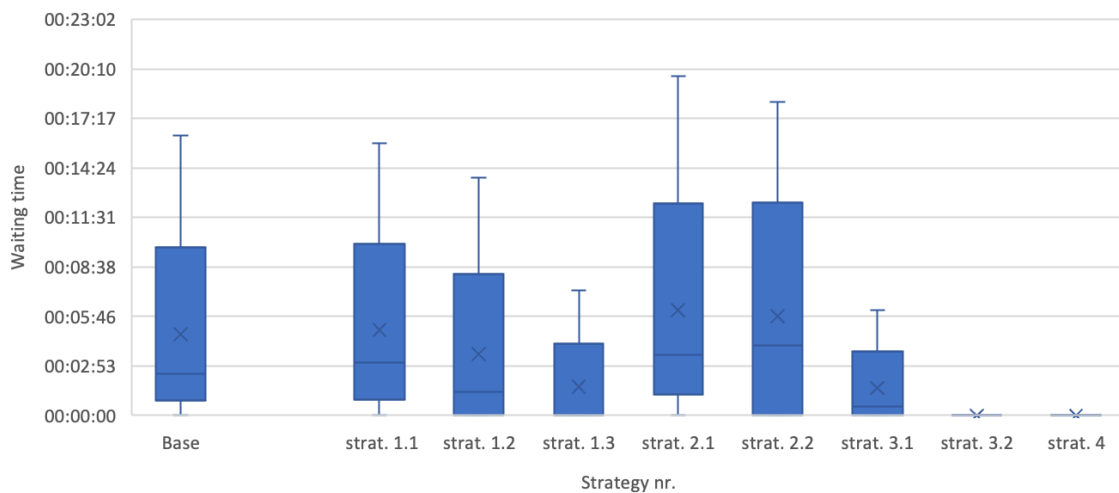


Figure 6.7: Results of individually strategies: Waiting time per truck in queue during the enter process, KPI 3 (source: author)

After a thorough analysis of the results of experimenting with the individually strategies, several patterns and insights have emerged which leads to the following conclusions. First, adjusting the truckloads and therefore reducing the arrival rate of trucks, have proven to positively impact the arrival, enter and unload process as it decreases the probability for both waiting areas (strategy 1.1, 1.2 and 1.3). Additionally, it has been observed that reducing the arrival rate to 30 or lower has effectively eliminated the probability of the capacity being exceeded, resulting in a 0% probability. Second, reducing the service time during the arrival process and making it more consistent, has a positive impact on the arrival process as it decreases to a 0% probability, but negatively impacts the enter and unload process. Reducing the service time has proven to be a very effective strategy to reduce the probability for the waiting area at the port without changing the arrival rate of trucks, but not for the waiting area at the dock when the throughput rate of trucks from arrival to enter increases to 40 or more which increases the probability at the waiting area at the dock (strategy 1.2 and 2.2). Third, reducing the basic duration in the unload process only impact the enter and unload process but doesn't impact the arrival process and therefore doesn't reduce the probability for the waiting area at the port. Fourth, the even distribution of trucks arrivals throughout the day also positively impacts the arrival, enter and unload process. This is also attributed to the reduction of arrival rate to 30 or lower. Across all individually strategies, it can be stated that **implementing strategy 1.3 and strategy 4 results in an improved system performance across all KPIs and all scenarios**. The 50% adjustment of truckloads (strategy 1.3) and the implementation of an evenly distributed truck arrival pattern (strategy 4) leads to a significant reduction in all KPIs, thereby improving the overall system performance of the inbound system. As the

other strategies only improve a part of the system performance, it suggests that there may be potential to achieve improved system performance of the inbound system by strategically combining the strategies with each other. This possibility has been explored and will be further explained in the following section.

6.4. Interactive Strategies Experiments

In this section the results of the experiments will be explained in which the key variables have been combined in order to examine their impact on the system performance. As explained before, the experiments will be explained focused on scenario 3.

Examining KPI 1, which assesses the probability of exceeding the capacity of the waiting area at the port and dock, some interesting distinctions can be observed when analyzing the implementation of the different combinations. These results are visible in Table 6.3. Compared to implementing the individually strategies, it can directly be observed that when implementing certain combinations, more reduced probabilities of exceeding the capacity of both waiting areas is achieved. Firstly, focusing on strategy 5, 6 and 7, which covers the combination of increasing the number of trucks arriving with an increased truckload (30%, 40% and 50%), together with the reduction of service time to 1.36 minutes. It can be observed that the individually implementation of the reduction of the service time, which negatively impacts the enter and unload process, is resolved when combining it with the truckload adjustments which has a positive impact on the enter and unload process. This can be seen by the results of strategy 5, 6, and 7. When implementing a 30% increase of trucks arriving with a larger truckload the arrival rate is still 35, but combining this with the faster processing of trucks in strategy 5, it ensures a 0% probability for the waiting area at the port which resolves the arrival rate being higher than 30. However, although there is a reduced reduction in the probability for the waiting area at the dock, the throughput rate of trucks from arrival to the enter process is still equal to 35 which causes a even higher probability that the capacity could be exceeded at the waiting area at the dock compared to the base case (as explained earlier in Section 6.2). This probability is increased due to the faster processing rate of trucks in the arrival process, which increases the throughput rate from arrival to enter process. However, further increasing the trucks arriving with a large truckload to 40% (strategy 6) with a decreased arrival rate to 31 and the 50% in strategy 7, with a decreased arrival rate to 27, resolves this issue as the throughput rate is lower than 35 and results in a 0% probability for the waiting area at the dock. So, it can be concluded that the negative impact on the unload process due to the reduction of the service time, can be resolved when combined with the reduction of the arrival rate to 35 or lower.

The second set of strategies covers the combination of again increasing the number of arriving trucks with a large truckload, and now with the reduction of the basic duration during the unload process to 10 minutes in strategy 8, 9 and 10. Interesting to see when analyzing the results, is that combining these two strategies leads to a decreased pattern in the probability of exceeding the waiting area at the port, which couldn't be achieved when only applying the reduction of the unloading time. This decreasing pattern can be attributed to the fact, that within these strategies there is a decreased arrival rate of trucks which reduces the probability for the waiting area at the port. However, even though the probability is lower then compared to the base case in strategy 8 and 9, it still doesn't result in the 0% probability for the waiting area at the port since the arrival rate is still more than 30 in those strategies. However, in strategy 10 in which there is the 50% adjustment of truckloads and an arrival rate lower than 30, a 0% probability is achieved for both waiting areas and therefore this particular combination is an effective strategy. So, it can be concluded that the reduction of unloading can be applied, but only in the strategy in which the arrival rate is lower then 30 in order to also improve the waiting area at the port.

The third combination of strategies, covers the reduction of the service time during the arrival process and the reduction of the basic duration during the unload process, which results in strategy 11. Combining these two, it can be seen that a 0% probability is achieved for both waiting areas which couldn't be achieved implementing these individually. This can be attributed to the fact that the reduction of service time positively impacts the arrival process, but negatively impacts the enter and unload process. The reduction of the unloading time does not impact the arrival process but only the unload process. Combining these two would result in the improvement for both waiting areas. This can be attributed to the fact that strategy 2.2 ensures a faster truck processing at the port, which increases the throughput rate of trucks ready from the arrival to enter process and keeps the probability of rejecting trucks at the port low. Adding the strategy of the reduction of the basic duration to 10 min in strategy 3.2, will also speed up the process during unloading and therefore the throughput rate of trucks ready for dock assignment will not be a problem anymore. This shows that this strategy is an effective combination of two strategies that have a positive impact on each other and result in a system improvement, which couldn't be achieved when implementing separately. Also, it validates the result

of Section 6.3 again, in which it was stated that the reduction of the service time is an effective strategy of not needing to reduce the arrival rate to 30 or lower.

Lastly, the combination of the evenly distribution of truck arrivals together with the increase of truckloads in strategy 12. It can be seen in the table that this results in a 0% probability for both waiting areas which can be attributed to the fact that both positively impact the arrival, enter and unload processes and therefore has a reinforcing impact on each other.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

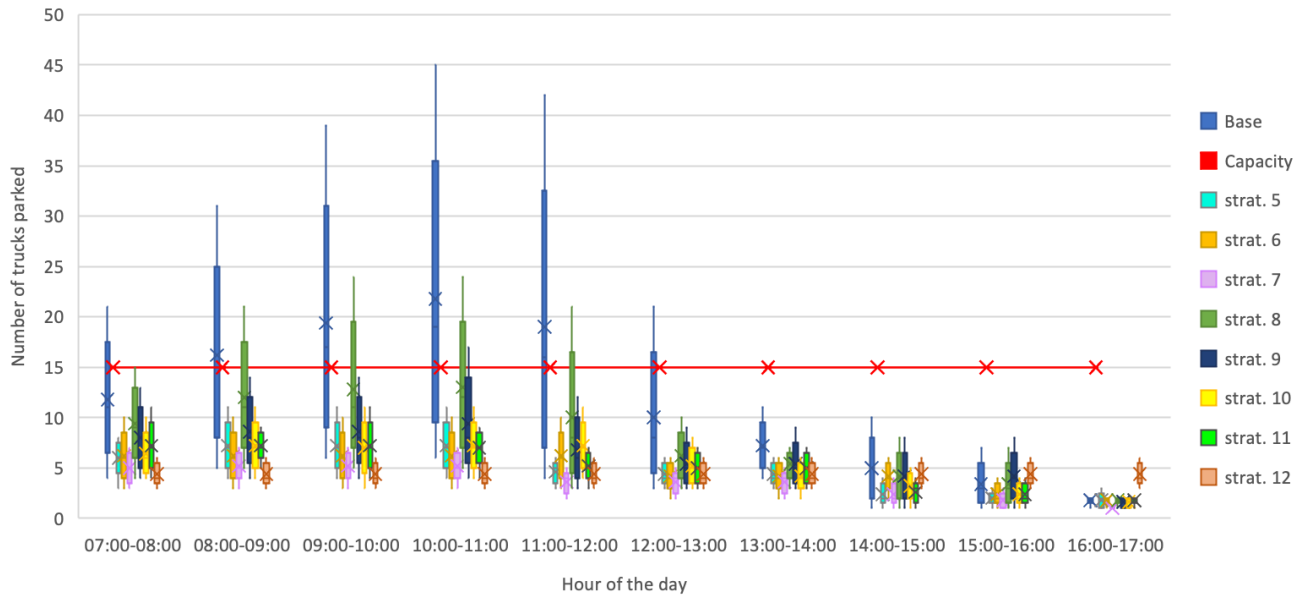
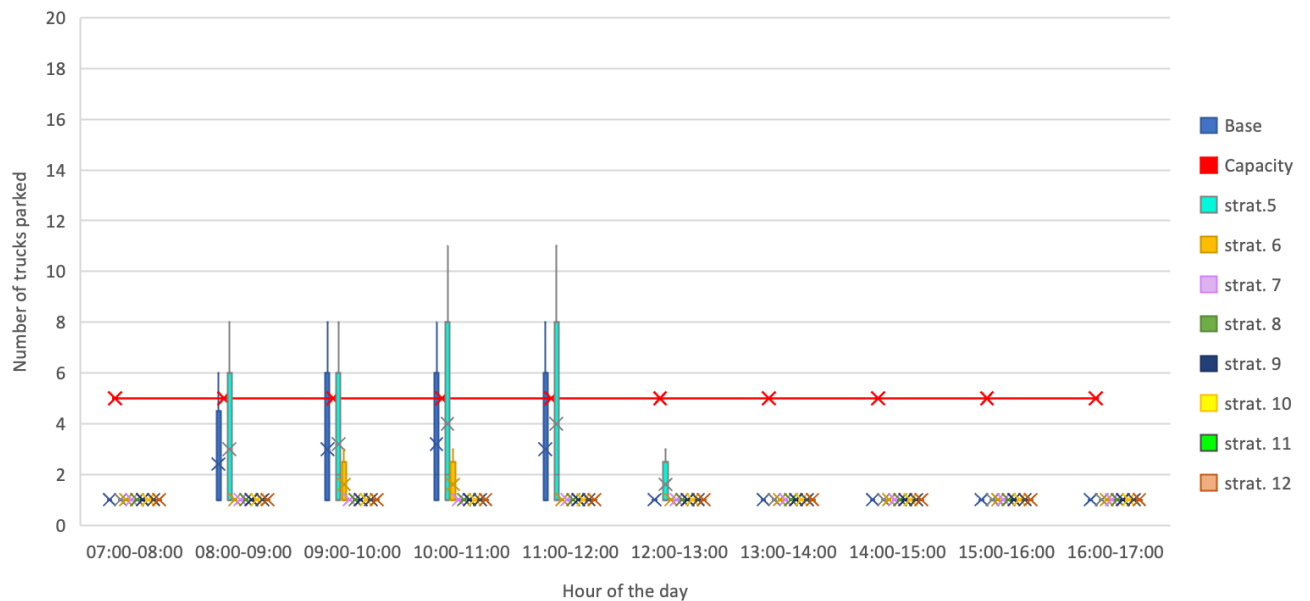
Table 6.3: Results of interactive strategies, KPI 1 (source: author)

Scenario nr.	Strategy nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		<i>Port</i>	<i>Dock</i>	<i>Port >15</i>	<i>Dock >5</i>
Base	-	65.4%	13.9%	[1-30]	[1-3]
SC3	5	0%	16.9%	[0]	[1-3]
SC3	6	0%	0%	[0]	[0]
SC3	7	0%	0%	[0]	[0]
SC3	8	23.4%	0%	[1-9]	[0]
SC3	9	11.3%	0%	[1-2]	[0]
SC3	10	0%	0%	[0]	[0]
SC3	11	0%	0%	[0]	[0]
SC3	12	0%	0%	[0]	[0]

The results for KPI 2, concerning the number of trucks parked at the waiting area at the port, is visible in Figure 6.8 and the results for the waiting area at the dock is visible in Figure 6.9. Looking at the variability in the number of trucks parked at the waiting area at the port, differences can be observed between the different strategies that couldn't be observed when analyzing the results of the experiments for KPI 1. As mentioned before, a smaller variability in the number of trucks parked at the waiting areas, indicates a reduced pressure on the waiting area which contributes to a smoother flow of the processes in the inbound system. The results for KPI 1 are also reflected for KPI 2, however differences can be observed to what extent KPI 2 can be improved regarding the strategies that achieves the 0% probability at both waiting areas.

It can be observed that looking at the strategies that involves the reduction of the service time in strategy 6, 7 and 11, a lower range of trucks parked is observed than the strategy which involves the reduction of unloading time in strategy 10. This is attributed to the fact that the service time ensures faster processing and thus results in a faster processing flow of trucks in the arrival process which keeps the congestion low at the waiting area at the port. It can also be observed that the 50% adjustment of truckloads (strategy 7 and 10) results in a lower range of trucks parked than the 40% adjustment since there are less trucks arriving (strategy 6). The range of parked trucks in strategy 11, is almost equal to the range in strategy 6 and 10 in which there is a reduction of the arrival rate. This indicates, that this combination is a highly effective strategy to lower the number of trucks parked throughout the day without even decreasing the arrival rate. Strategy 12, in which the even distribution of trucks throughout the day is combined with the 50% adjustment in truckloads, results in the lowest and constant number of trucks parked throughout the day. This can be attributed to the fact that the arrival rate of trucks is equal to 19 every hour which causes the low range but also the constant range. This also improves the productivity of the employees at BFC. So, although all of these strategies results in a significant reduced pressure in the number of trucks parked which is lower than the capacity of 15, differences can be seen regarding the variability of the number of trucks parked.

Looking at the variability in the number of trucks parked at the waiting area at the dock, it can be seen except for the adjustments of 30% and 40% in truckloads, all the other strategies results in just 1 truck parked every hour. This can be attributed to the fact that the throughput rate of trucks from arrival to enter stays below the 35 in all the other strategies. Therefore, the issue of the waiting area at the dock will be no issue as explained before.

KPI 2: Number of trucks parked at the waiting area at the port and dock**Figure 6.8:** Results interactive strategies: Trucks parked in waiting area port, KPI 2 (source: author)**Figure 6.9:** Results interactive strategies: Trucks parked in waiting area dock, KPI 2 (source: author)

Focusing at KPI 3, the waiting time per truck in queue during the arrival and enter process can be analyzed. The results for the arrival process can be seen in Figure 6.10, while the results for the enter process are depicted in Figure 6.11. Focusing at the queue in the arrival process, it can be seen that every strategy results in a lower waiting time compared to the base case. The lowest waiting time for trucks can be seen in strategy 5, 6, 7 and 11. This can be attributed to the fact that these strategies involve the reduction of the service time which decreases the waiting time in the arrival process significantly due to faster processing of trucks. The lower waiting times in strategy 8, 9 and 10 are attributed to the reduction of the arriving trucks, but are not impacted by the reduction in unloading time. As for strategy 12, the waiting time is relatively higher compared to strategy 7 in which there is also a 50% adjustment of truckloads and therefore less trucks. However, strategy 12 does not involve the reduction of service time but is combined with the even distribution of truck arrivals. This lowers the number of trucks arriving per hour but remains constant throughout the day which could contribute to the overall relatively higher waiting time.

Shifting the focus to the waiting time per truck in queue during the enter process, it can be seen that all strategies except for strategies 5 and 6, results in a zero waiting time. This indicates the situation in which no trucks are waiting for dock assignment. Strategy 5 results in a higher waiting time compared to the base case which is logical results since there will be more trucks waiting in the dock area.

KPI 3: Waiting time per truck in queue during arrival and enter process

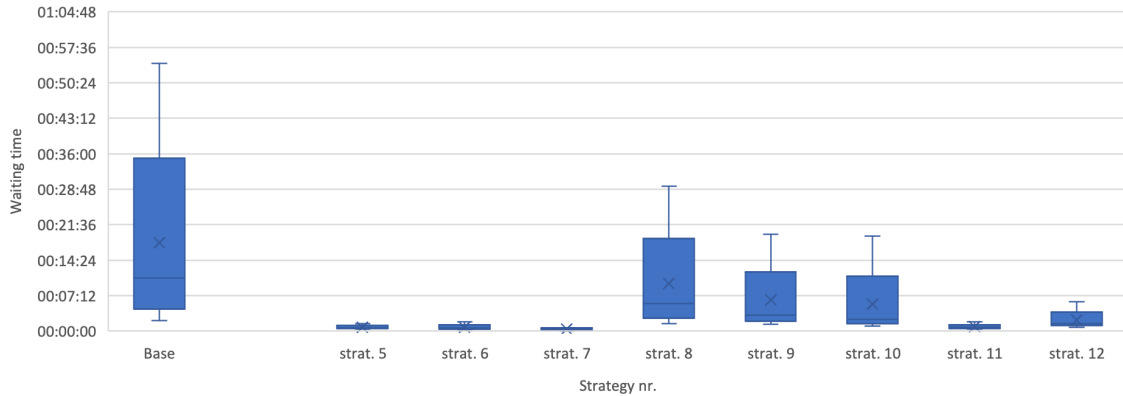


Figure 6.10: Results of individually strategies: Waiting time per truck in queue during the enter process, KPI 3 (source: author)

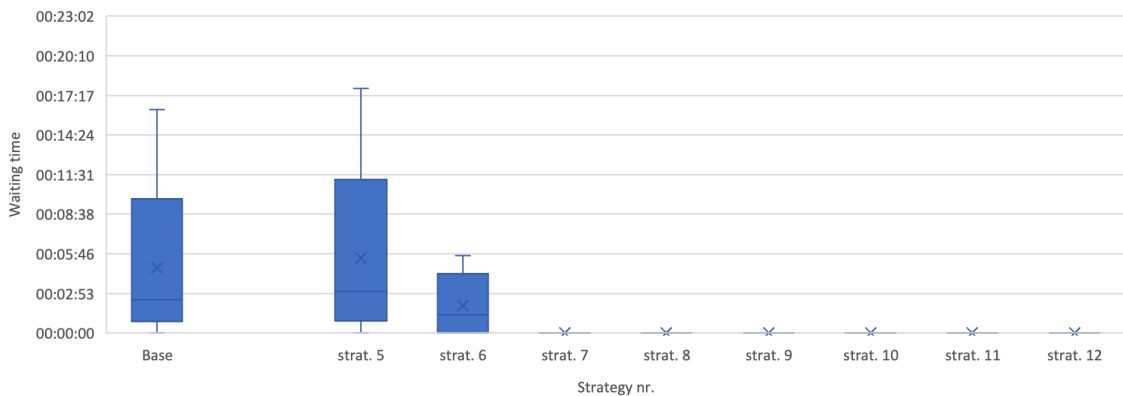


Figure 6.11: Results of individually strategies: Waiting time per truck in queue during the enter process, KPI 3 (source: author)

After a thorough analysis of the results of experimenting with the strategies in which the certain variables are combined, several patterns and insights have been emerged which leads to the following conclusions. First, it can be concluded that with combining the adjustments of truckloads with the reduction of the service time (strategy 6 and 7), the negative impact on the unload process due to the reduction of the service time can be resolved and results in a 0% probability for both waiting areas. This is attributed to the reduction of the arrival rate to 35 or lower. Additionally, this combination ensures a lower waiting time for trucks and shows a lower variability in the number of trucks parked due combination of the reduction of service time compared to implementing these individually. Second, it can be concluded that combining the reduction of unloading time, which not have an impact on the arrival process, with the adjustments of truckloads results in a 0% probability for both waiting areas as the reduction of the arrival rate impacts the arrival process (strategy 10). Relatively, it does not results in the lowest variability of the number of trucks parked and waiting times. Third, it can be concluded that combining the reduction of service time and reduction of unloading time in strategy 11, results in a 0% probability for both waiting areas as they complement each other. Additionally, it provides a strategy in which there is no reduction of the arrival rate required. Finally, the combinations of the even distribution with the 50% adjustment in truckloads which results in the lowest variability of number of trucks parked as it reinforces each other.

6.5. Conclusion

This chapter focused on answering the sub-question 7: ***To what extent can these strategies improve the system performance of the inbound system of the Bol Fulfillment Center?*** In order to answer this sub-question, the results of the 16 potential strategies resulting from the experimental plan in Chapter 5 have been tested and analyzed. The system performance is analyzed and interpreted by three KPIs, namely, the probability of exceeding the waiting area at both port and dock (KPI 1), the number of trucks parked at the waiting area at both port and dock (KPI 2) and the waiting time per truck during the arrival and enter process (KPI 3). The primary aim is to eliminate the rejected trucks and thereby reducing the pressure on the waiting areas. Following a comprehensive analysis of the experimental results, in which various strategies have been tested, several patterns and insights have come to light. Only the results for SC3 have been discussed in the main text since it shows the worst-case scenario. However, the other results for SC1 and SC2 can be found in the Appendix G and H, and follow the same explanations as described for SC3.

First, the results of the base cases of the future scenario analysis have been shown. These have shown that in the next coming years, there will be a significant increase in the elimination of rejecting trucks. A 49.2% increase in 2025 has been shown compared to 2023 regarding the probability of exceeding the capacity at the waiting area at the port. This is caused due the increase in the truck arrival rate, especially resulting in a higher morning peak. A 13.9% increase is observed in 2025 compared to a 0% in 2023 for the waiting area at the dock. It has been analyzed that this is due having a throughput rate of trucks from the arrival to enter process equal to 40 or more in which the unload process can't keep up with. This happens when the arrival rate of trucks is 35 or higher. Also, regarding KPI 2 and KPI 3, a significant increase can be seen in which there is an escalated situation between 7 a.m. and 11 a.m. This shows that if the current situation remain unchanged, the issues will escalate quickly.

From the 16 tested strategies it can be concluded that 7 strategies have been identified to improve the system performance of the inbound system across all KPIs and scenarios. An improvement of the system performance across all KPIs can first be achieved by applying certain strategies in which the arrival rate of trucks can be reduced to 30 or lower. This can be achieved by strategy 1.3, in which there is a 50% adjustment of truckloads and the even distribution of truck arrivals throughout the day in strategy 4. These strategies positively impacts the arrival, enter and unload process. Only reducing the service time in strategy 2.1 and 2.2, negatively impacts the unload process and only reducing the reduction time in strategy 3.1 and 3.2 hasn't impact the arrival process at all. However, combining these two has resulted in another set of strategies that improve the system performance across all KPIs. First, combining the reduction of the arrival rate to 35 or lower with the adjustments of truckloads in strategy 6 (40%) and 7 (50%), resolves the negative impact of the reduction of service time on the unload process as it keeps the throughput rate of trucks from arrival to enter process to 40 or lower. Additionally, the variability in the number of trucks parked is lower compared to strategy 1.3 and 4. Second, as the reduction of the unloading time does not impact the arrival process, it can be combined with the reduction of the arrival rate by the 50% adjustment in strategy 10 which resulted in a 0% probability for both waiting areas. Third, combining the reduction of the service time and the reduction of the unloading time in strategy 11, which both impact different processes in the inbound process has shown to be an effective strategy in achieving the 0% probability for both waiting areas in which the reduction of the arrival rate is not even necessary. Finally, strategy 12 which is the combination of the 50% adjustment with the even distribution of trucks throughout the day which results in the lowest and constant number of trucks parked throughout the day as these reinforce each other. It has also been shown that the waiting time is reduced compared to the bases cases in all these strategies, especially when it involves the reduction of the service time as it ensures faster processing of trucks. To conclude, 7 strategies (1.3, 4, 6, 7, 10, 11 and 12) have been identified that all improve the system performance across all KPIs and scenarios, but a distinction can be made regarding the extent in which they improve the inbound system and therefore an evaluation is required.

7. Evaluation

This chapter will address the final sub-question 8. In order to answer this sub-question, an evaluation of the best 7 strategies resulting from Chapter 6 will be performed in order to select the most appropriate strategy for bol.com to implement. Section 7.1 will describe a brief implementation plan of each strategy combined with the implications involved for stakeholders. Then in Section 7.2, a Multi-Criteria Analysis (MCA) will be performed taking into account the implementations, in order to evaluate these strategies. Section 7.3 will provide the ranking of the strategies and Section 7.4 conclude this chapter and will give answer to sub-question 8.

7.1. Implementation & Implications

Before selecting the most suitable strategy for improving the current inbound system of BFC, it is essential to gain a comprehensive understanding of how these strategies will be implemented and to assess the implications involved for important stakeholders. This evaluation is crucial since it impacts the effectiveness of the strategy for bol.com. The strategies are based on the key variables as explained in Chapter 5, and this will be translated into a brief implementation plan. This gives a clear indication on how to implement them separately and can be applied when combining them. Additionally, implications for partners and carriers will be given since it is important to take into consideration.

7.1.1. Increase of the number of trucks arriving with a large truckloads (40% / 50%)

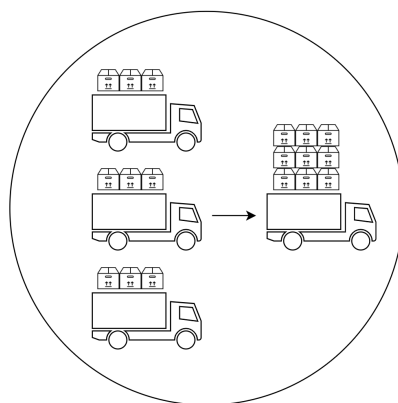


Figure 7.1: Increase truckloads (source: author)

The strategies (1.3, 6, 7, 10 and 12) that involve increasing the number of trucks arriving at BFC with large truckloads, by either 40% or 50% is based on the implementation of the already existing system Ampère as explained before in Chapter 3.6. This system is based on the consolidation of shipments from various partners in the same surroundings brought to a consolidation center in order to maximize truckloads, ultimately resulting in less trucks arriving at BFC. Bol.com will make use of their own logistics carrier, Ampère. The proven success of the Ampère system, which has already reduced the number of trucks arriving for parcel deliveries at BFC, combined with the experimental findings in Chapter 6 resulting in the elimination of rejected trucks, shows that the Ampère system shows potential for the pallet shipments in order to achieve the improved system performance. For the partners this means that there will be no risk anymore of products not being unloaded since there is no risk anymore of rejecting non-unloaded trucks. This will increase the reliability between partners, BFC and end-customers. However, there are also some implications for the partners which is important to take into account when assessing the effectiveness of the strategy that involves this adjustment. Partners will give the initial stage of their products supply chain out of control to the logistic carrier of bol.com. However, for some partners this is difficult since they express concerns for potential delay in deliveries or damaged products during transportation. Additionally, there are also costs associated with this, which could impact partners' overall profitability. However, as explained before, the benefits resulting from this for partners will hopefully outweigh the implications involved. From a technical perspective it does not require a lot of effort since bol.com already has the Ampère system in place. However, from an operational perspective, a lot of effort is required. This includes, convincing 40% or 50% of the partners to participate in this new system, locating a sufficient number of partners in specific surroundings and

optimize route planning. Bol.com will also need to hire an adequate number of truck drivers to expand its own logistics carrier network and ensure timely pickups to avoid delays. Lastly, there are also some implications for the carriers. Currently, partners take the responsibility of transporting their products to BFC with their own carriers. However, when implementing this method, those carriers will not be necessary anymore since they will use the logistic carriers of bol.com.

7.1.2. Evenly distribution of truck arrivals

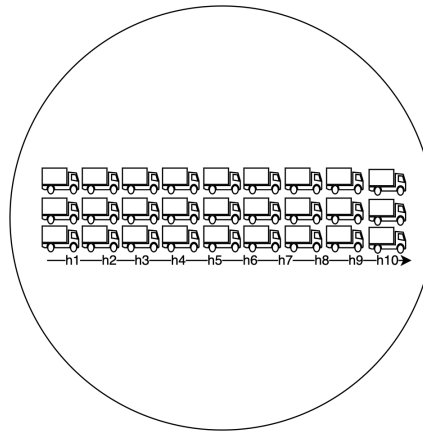


Figure 7.2: Even distribution of trucks arrivals (source: author)

The strategies (4 and 12) that involve the even distribution of truck arrivals throughout the day, will be based on a truck appointment system (TAS) as described in Chapter 2. Many studies have already proven that a TAS is an effective system and therefore is known as a popular strategy among logistic facilities. This research has proven that it also could work for FCs when trying to eliminate rejected trucks. The implementation plan is based on designing a truck appointment system in which each partner can book a specific time-slot for their carrier to deliver the products. Bol.com has never worked with such a TAS for all carriers and therefore will require a lot of technical and operational effort. From a technical perspective, a whole new software system and infrastructure need to be designed which need to include scheduling algorithms. Additionally, this appointment system need to be integrated with the existing BFC software and need to be accessible for all partners. From an operational perspective, personnel schedules need to be changed since there will be a constant workload in the inbound system and to ensure that there is enough personnel and enough incentives for partners and carriers to take part of the TAS. Regarding the implications for the partners, they may need to adjust their shipping schedules to align with the new appointment system of BFC, which could potentially impact their own system which might be risky for them. However, since the TAS is already known and used at a lot at other logistic facilities, it is expected that partners will accept this new change relatively quickly. For the carriers there will change a lot since they must adhere to the specific time slot and therefore probably need to adjust their own delivery schedules. As mentioned before in Section 2.4, there is the risk that carriers not meet this specific time slot and therefore a clear incentive need to be created for the carriers.

7.1.3. Reduction of the service time during the arrival process

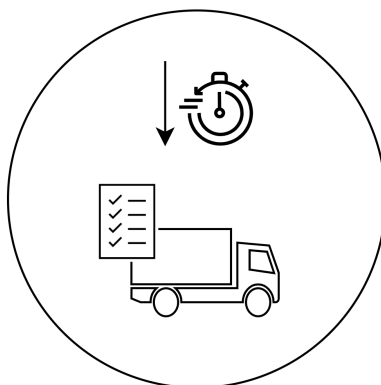


Figure 7.3: Decrease service time during the arrival process (source: author)

The outcomes of the root-cause analysis in the current state analysis of Chapter 3, has shown that the service time during the arrival process is increased due to not having standardized paperwork, strict DTC and no standardized way of working by port operators. Therefore, the strategies (6, 7 and 11) that involves the reduction of the service time during the arrival process are based on the standardization of certain procedures during the arrival process. Firstly, forcing a standardized form of paperwork for all partners. This would save a lot of time for port operators serving trucks, as the required information is consistently and accurately documented. Secondly, standardized working procedures for all port operators. This would streamline the tasks that port operators need to do and makes it easier and faster to serve trucks. Furthermore, it ensures that each truck is served in a consistent manner, which enhance the overall experience for truck drivers. This strategy is mainly focused on improving the internal systems and therefore requires relatively less technical and operational effort compared to the other strategies. The implications for bol.com from a technical perspective may include updating their existing systems to align with the new way of working. However, it is not expected that this would require an extensive effort since from an IT perspective not so much need to change. From an operational perspective, it may require some more effort. Training's need to be developed and given to all BFC employees to ensure that employees can execute the standardized working procedure. Additionally, a new paperwork template needs to be designed and shared with all partners and carriers to ensure consistent adoption. As for carriers and partners, they may need to adjust their procedures to align with the standardized working protocols. Partners must ensure that their carriers bring and provide the required paperwork and carriers need to bring those at all times. This could be quite challenging for carriers, but it is expected that it won't imply to much effort for them.

7.1.4. Reduction of the basic duration during the unload process

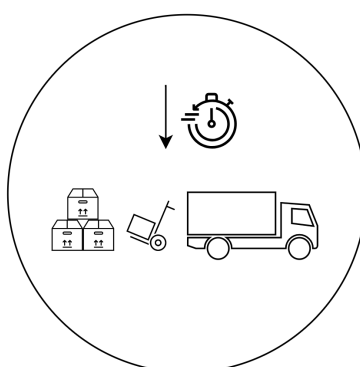


Figure 7.4: Decrease unloading time (source: author)

The strategies (10 and 11) that involve the reduction of the basic duration during the unload process is based on the implementation of skipping the process of truck drivers that unload their trucks themselves and replacing it by dock operators doing the unloading. This would save a of time in the total unloading time since truck drivers don't need to leave their trucks for the unloading. Also, dock operators are trained, experienced and follow specific unloading procedures and safety protocols which makes the

unloading of trucks go faster. This leads to a more efficient unloading process, reduced unloading time and eventually reducing the congestion at the waiting area at the dock. Although this strategy is mainly internally based, there are still some technical and operational implications which need to be considered. From a technical perspective not so much effort is required from bol.com other than adjusting the contracts between partners and bol.com in which it is stated that dock operators will unload their trucks. From an operational perspective, more effort is required. An increase in dock operators need to be allocated in order to have enough manpower to unload trucks which also involves training new employees. There are also some implications for carriers. The fact that they are not allowed anymore to unload their own trucks will not satisfy every truck driver. However, it will also save them a lot of time contributing to a lower TTT, saves labor costs and creates more focus on their core activities such as transportation and route planning. For the partners, apart from adjusting the contracts, there will mainly be benefits since unloading will be done in a more reliable and timely manner by experienced dock operators. Additionally, they can plan their shipping schedules more accurately as the predictability of unloading times improves.

7.2. Multi-Criteria Analysis

In order to rank the 7 best strategies resulting from the previous section 6, a Multi-Criteria Analysis (MCA) have been performed to compare these strategies and recommend which strategy would be the best to apply (Majumder and Majumder, 2015). It gives insights into the trade-offs between the strategies based on the different criteria. A MCA is a structured decision-making approach which is used to evaluate and rank the set of strategies based on a set of formulated criteria. Weights will be assigned to each of these criterion, which indicate how important each criterion is for bol.com. Based on the significant to bol.com, weights are assigned on a numeric scale from 1 to 5 to each of the criterion. Subsequently, the strategies are evaluated by giving them a score for each criterion. This is done by using again the numerical score from 1 to 5 in order to assess how well each strategy performs on each criterion based on the results of Chapter 6. Then, the scores of each strategy are multiplied by the weights of the criteria and summed up in order to derive at the total weighted score of each strategy. This will result in a ranking of the strategies which will be given in the next Section 7.3. The set of criteria used in the MCA, is based on the objective of this research, the formulated KPIs, the implementation plan and the involved implications described in Section 7.1. Also, ancillary criteria will be used which do not align directly with the primary objective of this research, but still contribute to the overall performance of the system. These are used in order to provide valuable insights in making a more comprehensive decision. An overview and explanation of the criteria used can find below. For the first 4 criteria: a high score means an extreme well performance and a low score means less performance. For the other 4 criteria, a high score means less risk and less effort and a low score means a high risk and more effort. The result of the MCA can be seen in Table 7.1.

- **Number of rejected trucks** = The number of rejected trucks determined by KPI 1 and is extremely important for the system performance of the inbound process of BFC. Therefore the weight assigned is 5.
- **Waiting time per truck** = The waiting time per truck is determined by KPI 3. While this is not the top-priority criterion for BFC since they are not really concerned about the waiting times for trucks, it does have an indirect impact on the overall performance of the inbound process. This is because it provides insights into the flow of truck logistics. Moreover, an improvement in waiting times for trucks contribute to an improved TTT. Consequently, the weight in the evaluation is relatively low and has been assigned a value of 1.
- **Buffer for unexpected events** = The buffer for unexpected events is determined by KPI 2, which determine the number of trucks parked at the waiting areas and therefore the pressure on the waiting areas. When the number of trucks parked is low, there is a higher buffer available for unexpected events at the arrival and enter process which mitigate the consequences. Therefore, this criterion is important for BFC and has an assigned weight of 3.
- **Productivity employees BFC** = The productivity of BFC employees is influenced by the arrival pattern of trucks at BFC. While this productivity may not be the primary goal and it is considered as an ancillary criterion, it is valuable to consider when evaluating various strategies. A consistent productivity for the employees of BFC results in a steady workflow in which tasks are handled more efficiently. Additionally, it allows for better planning of the logistic operations. A constant productivity is reached when the arrivals of trucks per hour is evenly distributed throughout the day. The assigned value for the weight of this criterion is 2.

- **Risk of no participation partners** = Certain strategies can significantly affect partners, making their implementation potentially challenging. Therefore, it is crucial for BFC to consider the risk of no participation of the partners, as it directly influences the strategies impact. The assigned value of the weight for this criterion is 4.
- **Risk of no participation carriers** = As explained above for partners, this also hold for carriers as some strategies affect the carriers which makes the implementation challenging for BFC. Carriers, in this context, refer to those under contract with partners, responsible for transporting products from partners to BFC. Since this criterion is very important for the effectiveness of the strategy for BFC, it has an assigned value of 4.
- **Technical implementation effort** = This criterion assesses the level of effort and resources required for the successful technical implementation for bol.com of the strategy. It considers factors such as the complexity of IT infrastructure changes, the need for specialized skills and upgrading existing systems. The level of effort required for this strategy significantly influences the feasibility and potential success. The weight assigned to this criterion is 3.
- **Operational implementation effort** = This criterion is focused on all the operational effort bol.com needs to take to realise this strategy. Factors such as, required training's for employees regarding the use of new technology, safety protocols and best practices. The effort required for this strategy impact the feasibility and success of the strategy. The assigned value of weight for this criterion is 3.

Table 7.1: MCA (source: author)

Criterion	Weight	Strategy							
		1.3	4	6	7	10	11	12	
Number of rejected trucks	5	5	5	5	5	5	5	5	
Waiting time per truck	1	1	2	3	5	3	5	3,5	
Buffer for unexpected events	3	2	1	3	4	2	3	5	
Productivity employees BFC	2	1	5	1	1	1	1	5	
Risk of no participation partners	4	2	3	2	1,5	1,5	3	1	
Risk of no participation carriers	4	4	2	3,5	3,5	2,5	3	2	
Technical implementation effort	3	4	2	3	3	3,5	4	1	
Operational implementation effort	3	2	3	2,5	2	1	2	1	
Total		64	72	68	69,5	58,5	73	71,5	

7.3. Ranking Of The Strategies

After performing the MCA as explained in Section 7.2 and visible in Table 7.1, the weighted score of the different strategies can be calculated as explained earlier. The results of the weighted total scores will result in a ranking of the strategies. The highest weighted score will result in the highest rank and the lowest weighted score in the lowest rank. Table 7.2 shows the total weighted scores and the ranking of each strategy that holds for all scenarios (1, 2 and 3). When analyzing the ranking of the strategies it can be observed that, although each of the strategies results in an improved system performance of the inbound system, a trade-off is involved when selecting the most appropriate strategy for bol.com, weighing the improvements on the inbound system's performance against the associated risks and implementation efforts. When the risks and effort will be too high, this will impact the effectiveness of the strategy and risks the possibility of not achieving the desired outputs for the system. Therefore, it can be seen that the ranking of the strategies may not result in the most optimal system performance for the inbound system of BFC, but in the most realistic strategy. The highest ranking belongs to the implementation of strategy 11 and appears to be the most appropriate strategy for bol.com to apply. It covers the reduction of the service time to 1.36 minutes and the reduction of basic duration of unloading time to 5 minutes. This strategy ensures a faster truck processing rate during the arrival process by the the port operators, leading to reduced congestion at the waiting area at the port. When paired with the expedited unloading time due to the reduction of the basic duration, it ensures a faster unloading speed of trucks which meet the faster throughput rate of trucks during the arrival process. This combination

within the strategy is focused on optimizing the internal resources which is beneficial for bol.com as they have already direct control over these resources. It also requires less implementation effort as the systems are already in place and needs limited adjustments. Moreover, this strategy is associated with low risks of no participation of partners and carriers. This results in a strategy that finds a good balance between managing risks, ease of implementation, and effectively addressing the issue of rejecting non-unloaded trucks. The second best strategy, is strategy 4, which focus on the even distribution of truck arrivals. Although it requires quite some technical and operational effort, the risks regarding partners and carriers are expected not that high since it is already a widely known method which a lot logistic facilities already use. Furthermore, it creates a huge improvement for the productivity for BFC employees since it results in a constant arrival pattern of trucks. However, the waiting time experienced by trucks is not that low but this is not as much as important for bol.com then the other criteria. The third and fourth best strategy are respectively, strategy 12 and 7. Strategy 12, resulted in the most optimal system performance, but due to the high risks involved for partners and carriers and the technical and operational implementation effort for bol.com, it is currently not the most realistic strategy for bol.com to implement. The risks and implementation efforts, outweighs the benefits of this strategy since it is too risky that the strategy may not have the expected impact due to these reasons. Therefore, these strategies are for the time matter not the best for BFC to implement but do show the potential when these risks and implementation efforts are mitigated. The fifth and sixth best strategies are respectively strategy 6 and 1.3. Their overall performance compared to the other strategies is relatively medium, and combined with the risks and effort required it relatively results in not the best strategy for bol.com to implement. Finally, the least best strategy which is strategy 10. As seen in the results in Chapter 6, this resulted in the least best system performance compared to the other 7 strategies and with the risks and implementations effort it scores the lowest.

Table 7.2: Ranking of the strategies (source: author)

	Strategy	Weighted total score	Ranking
<i>Reduction of service time during the arrival process to 1.36 min and reduction of the basic duration during unload process to 5 min</i>	11	73	1
<i>Even distribution of truck arrivals per hour throughout the day</i>	4	72	2
<i>50% Increase in trucks with large truckloads and even distribution truck arrivals per hour throughout the day</i>	12	71.5	3
<i>50% Increase in trucks with large truckloads and reduction of service time during the arrival process to 1.36 min</i>	7	69.5	4
<i>40% Increase in trucks with large truckloads and reduction of service time during the arrival process to 1.36 min</i>	6	68	5
<i>50% Increase in trucks with large truckloads</i>	1.3	64	6
<i>50% Increase in trucks with large truckloads and reduction in of the basic duration during unload process to 10 min</i>	10	58.5	7

7.4. Conclusion

This chapter has given an answer to the sub-question: ***Which of these strategies can be put into practice to eliminate the possibility of rejecting trucks and reduce the pressure of both of the waiting areas?*** A Multi-Criteria Analysis have been performed in order to evaluate the 7 best strategies resulting from Chapter 6, based on the implementation and implications involved for BFC and their partners in order to select the most appropriate strategy for bol.com to implement based on the current circumstances. It is important to take the implications, implementation efforts and differences in the system performance into consideration as it determines the impact and effectiveness of the strategy. A short implementation plan has been given for all the strategies together with the different implications for partners, carriers and bol.com. These provided input for the criteria used in the MCA on which each strategy will be evaluated. A weight is assigned to each of these criterion based on the significance to bol.com. The criterion with the highest score and therefore most important for bol.com are: number of rejected trucks (5) and the risks of no participation of partners and carriers (4), followed by the buffer for unexpected events (3) and the technical and operational implementations for bol.com (3). The criterion with a lower score and thereby relatively less important for bol.com are: the productivity employees BFC (2) and the waiting time per truck (1). Giving a numerical score to each of the strategies based on how well they perform on each criterion, eventually results in a ranking of the strategies. When analyzing the ranking of the strategies it can be observed that, although each of the strategies results in an improved system performance of the inbound system, a trade-off is involved when selecting the most appropriate strategy for bol.com, weighing the improvements on the inbound system's performance against the associated risks and implementation efforts. When the risks and efforts are too high it may impact the strategy in such a way, that it will not result in the desired results for the system and might not even be an improvement. *Strategy 11, the reduction of the service time during the arrival process and the reduction of the basic duration during unloading, appears to be the best strategy for bol.com to implement.* This combination within the strategy is focused on optimizing the internal resources which is beneficial for bol.com as they have already direct control over these resources. It also requires less implementation effort as the systems are already in place and needs limited adjustments. Moreover, this strategy is associated with low risks of no participation of partners and carriers. This results in a strategy that finds a good balance between managing risks, ease of implementation, and effectively addressing the issue of rejecting non-unloaded trucks. While there are other strategies that might present slightly enhanced outcomes for KPI 2 and KPI 3, those strategies currently pose many risks regarding the lack of participation of partners and carriers and complex technical and operational implementations efforts for bol.com. However, this offers an opportunity for bol.com to determine to what extent adjustments could be made to their current situation to mitigate the associated risks and efforts in order to makes these strategies more viable to be able to implement them in the future.

8. Conclusion, Discussion and Recommendations

This final chapter will provide the conclusion to this research in Section 8.1. Followed by a discussion in Section 8.2, which will include the scientific and practical contributions and the limitations of this research. Finally, in Section 8.3, the recommendations for further research will be provided divided into the practical and scientific recommendations.

8.1. Conclusion

The research in this report was focused on improving the inbound system of fulfillment centers with the objective of eliminating rejecting trucks and reducing the pressure on the waiting areas in the inbound system. By conducting a case study at the logistic company bol.com, in which issues related to rejecting non-unloaded trucks have already been experienced, makes it possible to analyze the system and to identify what potential strategies could be designed. The main research question of this research is:

"How can fulfillment centers eliminate rejecting non-unloaded trucks, by improving their inbound process?"

This main research question have been answered by dividing this research into different sub-research questions which will be answered below.

Sub-question 1: What literature research has already been done on improving the inbound system, in order to reduce the effects of ineffective truck logistics at fulfillment centers?

Several studies in literature have been done on improving the inbound system at many logistics facilities. Logistic facilities have a critical role in the supply chain, as they are the designated locations in which the managements, storage and distribution of goods take place. Logistic facilities are distribution centers, warehouses, fulfillment centers and marine/containers terminals. They differ in terms of function and scale but their logistic operations are all based on an inbound system with truck logistics. The literature studies reviewed have explored the consequences of ineffective truck logistics within the inbound system and have identified it as a significant challenge for the system performance of the inbound system for the logistic facilities. Those studies are designated to distribution centers, warehouses, and container and marine terminals with objectives such as, minimizing waiting times, truck turnaround times, costs or maximizing the number of unloaded trucks. However, to the best of the author's knowledge, the reviewed literature has overlooked the implications of rejecting non-unloaded trucks that are queuing outside on the road due to extreme congestion of trucks within the inbound system, particularly at fulfillment centers. Therefore, this research fills this research gap, by conducting a case study at bol.com with the objective of the elimination of rejecting non-unloaded trucks by improving the inbound system. Nevertheless, the literature review provide valuable insights for this research as the inbound system at fulfillment centers show similarities with the researched logistic facilities.

Sub-question 2: What are the common challenges associated with truck logistics in the inbound system, and which strategies can be applied to improve according to the literature?

The literature review provided several challenges associated with truck logistics. These studies, designated to other logistic facilities then fulfillment centers, show that an uneven truck arrival pattern in which trucks mainly arrive in the morning, having high service times during the arrival process and many trucks arriving with underutilized truckloads are the common challenges regarding the truck logistics in the inbound system. This leads to congestion, high waiting times, and operational delays in unloading trucks which affect the system performance of the inbound system. The proposed strategies, on improving the inbound system are mainly focused on optimizing internal resources, employing truck appointment systems and using queuing strategies and limited studies focus on the increase of truckloads by first-mile pick-up services. Those strategies have proven to be successful, but all have their own pros and cons which needs to be considered when using them.

Sub-question 3: How is the current truck logistics in the inbound system described at Bol Fulfillment Center and what are the logistics bottlenecks that can be identified?

The current inbound system at BFC involves the arrival, enter, unload and departure process including the truck logistics transferring from one process to another. The arrival process consists of the physically arrival of trucks and processing of the paperwork by port operators. A truck continues to the enter process in which truck get a dock assigned and transfer to the unloading docks in the unload process where the trucks are unloaded after which the trucks departs again. Within the arrival and enter process there are two, not officially designated, waiting areas in which trucks park their trucks or wait. Trucks need to queue in the arrival process when both port operators are occupied serving trucks, and in the enter process for the dock assignment when the 30 unloading docks are occupied. By qualitative and quantitative research methodologies, the logistic bottlenecks have been identified which are the following. Firstly, the lack of a standardized working procedure by port operators and having no standardized and often lack of proper shipment paperwork which causes high service time per truck in the arrival process, leading to long queues of trucks. Secondly, the uneven arrival pattern of trucks with a morning peak between 7 a.m. and 11 a.m. in which 56% of the trucks arrive and most of the time with underutilized truckloads. This is mainly caused by the lack of enforcement by bol.com regarding the arrival times and truckloads. Thirdly, there is no capacity determined by bol.com regarding the waiting areas at the port and dock, which could lead to endless queue forming. Furthermore, the waiting area at the dock is not officially pointed out by BFC which could lead to a confused and chaotic situation. Fourthly, during the unload process the paperwork is getting checked again and together with the high preparation time for truck drivers due to self-unloading, the unloading time is increased. The extensive data collection has also brought to the forefront that bol.com has limited data available regarding the truck arrivals which makes it hard for bol.com to get an understanding of the current problem. These logistic bottlenecks contributes to the high congestion of trucks at both waiting areas and therefore the rejection of non-unloaded trucks.

Sub-question 4: What Key Performance Indicators can be used to assess the system performance for the inbound system of Bol Fulfillment Center?

Key Performance Indicators are used to assess the system performance of the inbound system of BFC and to test several potential strategies and their impact on the system. The current state analysis has provided insights into the formulation of the Key Performance Indicators. Combined with different brainstorm sessions with experts of bol.com, the three following KPIs have been formulated. They are listed below and combined with a brief description.

- **KPI 1:** Probability of exceeding the capacity of the waiting area at the port and dock determines the probability of the possible need for rejecting trucks during a peak period of bol.com. It will be presented as a percentage in which a 0% percentage will be equal to an extreme unlikely probability that the capacity of the waiting area at the port and dock will be exceeded.
- **KPI 2:** Number of trucks parked at the waiting area at the port and dock indicates the number of trucks parked at both waiting areas per hour, represented through boxplots. It gives additional information regarding KPI 1 and provides valuable insights into the variability of the number of trucks parked throughout a full operational day. Additionally, it shows the buffer for unexpected events which is created when the number of variability of trucks is low.
- **KPI 3:** Waiting time per truck in the queues in arrival and enter process represents the waiting time experienced by trucks in the queues during the arrival and enter process. The cumulative average waiting time for each truck is presented by hourly boxplots to highlight variability. The waiting time provides additional insights into the system performance.

Sub-question 5: How does the model design look like that will be used to analyze the current and future inbound system of the Bol Fulfillment Center?

For this research, a Discrete Event Simulation model, integrated with the Monte Carlo Simulation, was developed to assess the impact of several potential strategies aimed at eliminating the rejection of non-unloaded trucks and reducing the pressure on both waiting areas. The structure of model is based on the studied inbound system and includes the four main processes: arrival, enter, unload and departure. Using DES to simulate the system allows for the analysis of the interaction between the processes and the truck logistics. Data for the simulation was categorized into input and output data sets based on the collected data during the current state analysis. The model is verified while constructing the model to identify errors and resolve them right away and by doing visual checks of the outcomes. Chi-squared tests validated the model for stochastic parameters, and due to limited historical data, expert consultations were employed for further validation. The verification and validation provided a proper working simulation model that represents the real-world situation of the inbound system at BFC and can be used to test several potential strategies for the future inbound system.

Sub-question 6: *Which potential strategies can be designed to improve the system performance of the inbound system of the Bol Fulfillment Center?*

Potential strategies have been obtained by testing variations and combinations of 4 key variables. The 4 key variables were constructed based on knowledge gained from the literature review, interactive brainstorm sessions, and system requirements which align with the objective of the research. The four variables have been tested within experiments and resulted in 16 potential strategies of which an complete overview can be seen in Table 8.1. Those 16 strategies have been researched in a new set of experiments on the three defined scenarios. The scenarios that have been constructed are based on the year 2023, 2024 and 2025. These scenarios are chosen to show that with the expected growth of BFC and therefore the increase of the number of arriving trucks, the problem will escalate in the future if the current situation remains unchanged. By testing the 16 strategies further in experiments, valuable insights can be provided on they impact the inbound system of BFC in order to eliminate rejecting non-unloaded trucks and reducing the pressure on the waiting areas.

Table 8.1: Overview strategies (source: author)

Strategy	Description
1.1 until 1.3	10% increase of trucks arriving with a large truckload, 5% decrease of trucks arriving with a medium and small truckload
2.1. and 2.2	Reduction of the service time during the arrival process within the port by 2.24 min and 1.36 min
3.1 and 3.2	Reduction of the basic duration during the unload process with 10 and 5 minutes
4	Even distribution of truck arrivals
5	30% Increase in trucks with large truckloads and reduction of service time to 1.36 min
6	40% Increase in trucks with large truckloads and reduction of service time to 1.36 min
7	50% Increase in trucks with large truckloads and reduction of service time to 1.36 min
8	30% Increase in trucks with large truckloads and reduction basic duration during unloading to 10 min
9	40% Increase in trucks with large truckloads and reduction basic duration during unloading to 10 min
10	50% Increase in trucks with large truckloads and reduction basic duration during unloading to 10 min
11	Reduction of service time to 1.36 min and unloading time to 5 min
12	50% Increase in trucks with large truckloads and even distribution truck arrivals

7. To what extent can these strategies improve the system performance of the inbound system of the Bol Fulfillment Center?

The 16 proposed strategies were assessed against the three formulated KPIs, yielding significant insights. Out of these, only seven strategies – namely 1.3, 4, 6, 7, 10, 11, and 12 – enhanced the performance of the inbound system across all KPIs and scenarios. While each of these strategies effectively improve the system performance for both waiting areas, their impact varies in relation to KPI 2 and 3. In strategy 1.3 (50% truckloads adjustment) and strategy 4 (even distribution of truck arrivals) the arrival rate of trucks is reduced to 30 or lower which effectively eliminates the probability of waiting areas getting exceeded since it results in a 0% probability. These strategies both have a positive impact on arrival, enter and unload and can therefore be implemented as individually strategies. Strategy 6 and 7, combining service time reduction in the arrival process to 1.36 min, with 40% (6) and 50% (7) truckloads adjustment, appears to be an effective combination of further improving the system performance which couldn't be achieved implementing the reduction of service time separately as it negatively impacts the unload process. By combining this is resolved by reducing the arrival rate to 35 or lower, which keeps the throughput rate of trucks from arrival to enter process to 40 or lower and resolves the issue of the unloading speed being too lower which resulted in an issue at the waiting area at the dock. Strategy 10, in which the reduction of the basic duration to 5 min during the unload process is combined with the 50% adjustment of truckloads, also effectively enhance the system performance which couldn't be achieved when only reducing the unloading time as it not affects the arrival process. A further improvement has not been achieved. Strategy 11, in which the reduction of the service time to 1.36 min and the reduction of the basic duration to 5 min is combined, appears to be an effective strategy which complement each other in impacting certain processes which couldn't be achieved when implementing them separately. Additionally, it shows that the reduction of the arrival rate is not the only solution. Finally, strategy 12 in which the 50% adjustment of truckloads is combined with the even distribution, which results in the best system performance regarding KPI 2 as it has a reinforcing impact on each other.

8. Which of these strategies can be put into practice to eliminate the possibility of rejecting trucks and reduce the pressure of both of the waiting areas?

A Multi-Criteria Analysis (MCA) evaluated the seven strategies to select the most appropriate strategy for bol.com to implement regarding the current circumstances. This included the technical and operational implementation efforts for bol.com and the implications involved for its partners and carriers as they determine the viability of each strategy and therefore their impact on the system. Criteria for the MCA, derived from the research objective and system requirements, were weighted based on their significance to bol.com. Criteria with the highest score included, the number of rejected non-unloaded trucks and risks of no partner and carrier participation. This shows the trade-off that is involved selecting the most appropriate strategy for bol.com, weighing the improvements on the inbound system's performance against the associated risks and implementation efforts. This evaluation concludes that strategy 11 is the most appropriate strategy for bol.com to implement. It covers the reduction of the service time to 1.36 minutes and the reduction of basic duration of unloading time to 5 minutes. This combination within the strategy is focused on optimizing the internal resources which is beneficial for bol.com as they have already direct control over these resources. It also requires less implementation effort as the systems are already in place and needs limited adjustments. Moreover, this strategy is associated with low risks of no participation of partners and carriers. This results in a strategy that finds a good balance between managing risks, ease of implementation, and effectively addressing the issue of rejecting non-unloaded trucks. While there are other strategies that might present slightly enhanced outcomes for KPI 2 and KPI 3, those strategies currently pose many risks regarding the lack of participation of partners and carriers and complex technical and operational implementations efforts for bol.com. However, this offers an opportunity for bol.com to determine to what extent adjustments could be made to their current situation to mitigate the associated risks and efforts in order to make these strategies more viable to be able to implement them in the future. To conclude, bol.com can eliminate the rejection of non-unloaded trucks by improving the inbound system in which the service time in the arrival process is reduced to 1.36 minutes and reducing the basic duration of the unloading time to 5 min.

8.2. Discussion

This section will provide the discussion in which the scientific and practical contributions will be given. Additionally, the limitations related to this research will be discussed.

8.2.1. Scientific Contributions

This research has provided multiple scientific contributions. The first contribution was adding research to the limited scientific literature available on improving the inbound system at fulfillment centers. Also, this research expanded the field of research on possibilities to the elimination of the rejection of non-unloaded trucks and reducing the pressure on waiting areas within an inbound system. The second contribution was developing a strategy in which the number of arriving trucks could be reduced due to increasing truckloads fill of trucks, also known in literature as the first-mile pick-up service but never has been tested with the aim of improving truck logistics. Most of the time with the objective to minimize costs and CO2 emissions. However, by conducting this research it has been shown that consolidating shipments and increasing the truckloads of trucks, a reduction in the number of arriving trucks could be achieved. The third contribution, is the strategy in which the increase of truckloads fill is combined with the even distribution of trucks arrivals which covers a TAM system. Most of the studies have researched the effects of the TAM systems, but never in combination with reducing the number of arriving trucks. This research has shown that this is an extreme effective method to lower waiting times, reducing the pressure on the waiting areas and eliminate rejecting non-unloaded trucks. All the insights obtained from this research contribute to the knowledge of further optimizing the inbound systems of logistic facilities in order to stay competitive with the growing e-commerce.

8.2.2. Practical Contributions

This research has provided multiple practical contributions for bol.com. The first contribution is drawing attention to significant issues in their existing truck logistics within the inbound system of BFC. By constructing the current truck arrival patterns obtained through measurements, which has never been done before at bol.com, it was revealed that the morning peak accounts for 56.6% of the total truck arrivals and most of the time trucks arriving with underutilized truckloads, indicating a potential bottleneck in their logistic operations. The second contribution is highlighting the absence of bol.com having limited truck arrival data available. This research has made clear that the obtained truck arrival data reveals some valuable insights such as higher waiting times per trucks, many variations in the service times per trucks, the truckloads distributions in which mainly trucks arrive with small and medium truckloads which

wouldn't be known without this data. The third contribution is showing bol.com by performing a future scenario analysis for the next three years (2023, 2024, 2025), that the issues related to truck logistics will escalate if the current situation remains unchanged. Especially, the rejection of non-unloaded truck during a peak period will increase to 65.4% at the waiting area at the port and to 13.9% at the waiting area at the dock in the year 2025, which is a significantly increase and could be a huge impact for the system performance of BFC. Finally, this research not only presents a set of strategies for bol.com to improve their inbound system, but also offers an evaluation on how the company can assess them. This results in the identification of seven strategies that all improve the system performance of the inbound system across all KPIs and scenarios. Taking into account important criterion of bol.com, a ranking of these strategies have been constructed which shows bol.com which strategies are realistic to implement according to the current circumstances. This has shown that some strategies, which actually results in the most optimal system performance, doesn't emerge as the top choice in a MCA due to high risks and implementation efforts for bol.com. However, this provides an opportunity for bol.com to revisit the other strategies to see if any adjustments can be made to mitigate the associated risks. It further indicates that their existing Ampère system, currently focused for parcel deliveries, can also be constructed for pallet shipments when taking the necessary actions regarding their partners and carriers.

8.2.3. Limitations

This research has some limitation which are important to discuss when analyzing the outcomes of this report. The first limitation can be attributed to the limited duration allocated for this research. This was particularly experienced when planning the measurements at BFC in order to derive at the truck arrival data. Due to limited time it was not possible to conduct measurements for a longer period. However, being able to conduct more measurements at BFC will contribute significantly to the validity and reliability of the data. The second limitation, which is also related to the limited duration of this research, is the fact that it was not able to conduct measurements during the actual peak period of bol.com. This is because this research did not take place during the months when the peak period of bol.com occurs. This was resolved by subtracting historical data from the most recent peak period and combining it with the obtained truck arrival characteristics resulted from measurements during an off-peak period, adding some robustness to the research. However, performing measurements at a peak period would result in real-time peak data which make the outcomes more reliable. The third limitation is related to making certain assumptions in this research since truck arrival data was hardly available at bol.com. If these assumptions would differ much from the actual situation, this can lead to deviating results and incorrect conclusions. Nevertheless, the obtained data and the constructed model was successfully verified and validated, lowering the risk of unreliable results of this research. The fourth limitation is that the simulation model has excluded some details due to the scope of this research. However, including these details would contribute to the improvement of this research since the simulation model would better represent the real world situation of the inbound system of BFC. For example, the possible waiting time for truck drivers during the unload process is not taken into consideration, the dock assignment for BFC1 and BFC2 is not taken into consideration and the rejection of trucks due to violating the DTC. However, the scope of this research was to find out which strategies could be constructed in order to eliminate rejecting trucks and reducing the pressure on the waiting areas and this has been accomplished. Fifth, not all combinations of the key variables in the experimental plan have been tested due to the limited time and the complexity of processing the results. Although, clear decisions have been made on whether to test certain combinations, it still can overlook certain combinations which could also improve the system performance of the inbound system. Despite this, the research succeeded in identifying 7 strategies that are able to improve the system performance of the inbound system across all KPIs.

8.3. Recommendations

After concluding the research, certain recommendations can be made for bol.com and future science research. Therefore, the recommendations will be divided into two sections. First, the practical recommendations will be given to bol.com. After which the recommendations for further science research will be given.

8.3.1. Practical Recommendations

This section will discuss the recommendations for bol.com. First of all, bol.com record hardly any data regarding the truck logistics. This has led to the situation in which most of the bol.com employees are not precisely aware of the current challenges within the inbound system regarding the truck logistics and how they impact the operational logistics. The first recommendations will therefore be, to start focusing on performing data-measurements and analysis of the truck logistics within the inbound system and

also the outbound system of the fulfillment centers of bol.com. Having this kind of information, would contribute to their knowledge regarding the truck logistics and would make it easier to detect challenges earlier on. It would also create better understanding for bol.com of the flow of truck logistics and the consequences for the workflow of employees at BFC. This would improve communication and strengthen the relationship between employees and employers. The second recommendation will be to start doing research into the needs and preferences of the carriers. By doing this, a better understanding will be created and could result in new insights of possible solutions. The third recommendation is related to the capacities of the waiting areas which is not officially determined by bol.com which leads to a situation in which there is the risk of endless queue forming because BFC does not know what the capacities of the waiting areas are. Therefore, the recommendation would be to set a certain capacity to those waiting areas in order to avoid situations in which the capacity could be exceeded. The fourth recommendation is related to the strategies that have not been ranked as the best strategies for bol.com resulting from the performed MCA. This has shown that there are relatively a lot of strategies that improve the system but are not useful yet due to the high risks and implementation efforts involved. However, this shows a huge opportunity for bol.com to improve their current inbound system. It has been observed that a lot of other big fulfillment centers already deal with specific systems to control the arrivals of trucks in which the partners and carriers already participate on. So, why would this not be possible for BFC? Therefore, the recommendation is focused on taking the strategies into consideration and taking into account the partners and carriers, to inform them on how the problem will escalate further when nothing is done and how important their participation is.

8.3.2. Recommendations for Future Science Research

During this research which lasted for almost 7 months, several subjects for further research have emerged. This research has limited the inbound system to a part of the inbound system and excluded the processes receiving and putaway. This choice was made since those processes do not include the truck logistics. However, these processes are an essential part of the inbound system since these are focused on the processing of items and determine one of the main KPIs of BFC the on-time KPI which determines the time a product is put on stock from the moment it is unloaded. For future research it would be interesting to add these two processes in the model in order to analyze what the impact is of the truck logistics on these two processes. The second recommendation is to do further experiments with all the possible combinations of key variables that are available. Due to time constraints it was not realistic to investigate all the possible combinations, but for scientific purpose it would be highly recommended to test the combinations. Additionally, within the context of this research, by doing the case study at bol.com, certain decisions have been made on how to select potential strategies. However, these may not apply for every logistic facility. Therefore, for further science research, it is recommended to test the combinations which were not considered in this research as they were not realistic for bol.com, but can be for other logistic facilities. Third recommendation, is to perform the exact same research again, but then with real-time data from an actual peak period in which measurements will be taken during the full three months in order to derive a big enough and reliable data-set.

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Appendix

A. Scientific Paper

Improving the inbound system at fulfillment centers by designing potential strategies to eliminate rejecting trucks and reducing the pressure on the waiting areas within the inbound system

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Abstract

This paper contributes to the research of improving the inbound systems at fulfillment centers. Fulfillment centers are facing logistics challenges due to increasing truck arrivals caused by the rapid growth of the e-commerce. Inefficient truck logistics within the inbound system of fulfillment centers is a huge problem due to the increased truck arrivals. As a consequence there is high congestion of trucks within the inbound system which could lead to queuing of trucks outside on the road. Whenever this happens there is the possibility of fulfillment centers being forced by the municipality to reject non-unloaded trucks which harm the system performance of the inbound system.

Keywords: Fulfillment centers, Truck logistics, Capacity problem, Rejecting non-unloaded trucks, Inbound system, Increase truckloads, Overfull waiting areas, High congestion, E-commerce

1. INTRODUCTION

The continuing growing economy and increase in global trade has led to the rapid growth of the e-commerce (Guan and Liu, 2009); (Taher, 2021). The covid-19 pandemic has further contributes to the growth of this sector since in-store shopping was restricted (Bhatti et al., 2020); (Sardjono et al., 2021); (Kawasaki et al., 2022). This forces logistic companies to continuously improve their supply chain in order to stay competitive (Alvarez-Placencia et al., 2020); (Ramaa et al., 2012). The rapid growth of the e-commerce has also led to an increase in trucks transportation as they serve as the primary mode of transporting products from suppliers to Fulfillment Centers (FCs). This highlights the importance of truck logistics which encompass all the different movements trucks make within the system of a logistic facility, such as the arrival of trucks, the yard movements to the different processes and the departure of trucks. Truck logistics have a significant impact on the flow of the inbound system as they proceed through the processes of the inbound system in chronological order. Therefore, poor organized truck logistics can have many consequences to the operational logistics of the inbound system and therefor impact the system performance of the inbound system. Several literature research is already done regarding the consequences of ineffective truck logistics in the inbound system of distribution centers, warehouses, marine and container terminals. These studies are focused on minimizing the resulting high waiting times for trucks, congestion of trucks, high Truck Turnaround Times (TTT) and the associated increased costs (Smith and Srinivas, 2019). However, to the best of the author's knowledge, the ma-

jority of the published research addressing improvements in inbound systems related to truck logistics does not target FCs. Moreover, no study has specifically addressed the elimination of rejecting non-unloaded trucks because they were queued on the road due to inefficiencies in truck logistics within the inbound system. This paper will fill this research gap by conducting a case study at bol.com at one of their FCs, in order to research the elimination of rejecting non-unloaded trucks by improving the inbound system at their Bol Fulfillment Center (BFC). The reason why a case study at bol.com is chosen, is because they occasionally experienced situations in which they were forced by the municipality to reject non-unloaded trucks due to trucks needed to wait outside on the road. With the expected increase in number of arriving trucks the next coming years it is relevant to conduct this research. Rejecting trucks means that those trucks can't be unloaded and need to be rescheduled, leading to potential delays in stock replenishment or order processing. Additionally, continuously rejecting trucks can strain the relationships with the partners and carriers which can affect certain collaborations. By conducting a case study at an e-commerce company facing issues with truck rejections at their FCs, their data can be used to develop a simulation model. This will help identify potential strategies to enhance the performance of the inbound system and eliminate truck rejections. With the focus on the case study at bol.com, the objective of this research is to design strategies to eliminate rejecting non-unloaded trucks and reducing the pressure on the waiting areas within the inbound system by improving their inbound process. Eventually, by taking into account the implementation and the

involved implications for relevant stakeholders of the strategies, an evaluation will be done regarding these strategies in order to select the best suitable strategy for bol.com. The main research question that will be addressed is as followed:

"How can fulfillment centers eliminate rejecting non-unloaded trucks by improving their inbound process?"

This paper will only focus on a part of the inbound system: arrival, enter, unload and departure since these cover the truck logistics. Also, this paper takes only the transportation of pallets into account, leaving the parcel transportation's out of scope since the pallet industry covers a huge part of the truck arrivals at BFC. Costs of setting up new strategies are not taken into account. By dividing the research into different sub-questions this main research question will be answered at the end of this paper.

2. LITERATURE REVIEW

2.1. Logistic facilities

Since literature is lacking on how fulfillment centers can eliminate the rejection of non-unloaded trucks by improving their inbound system, literature research focused on other logistic facilities is used which are mainly designated to distribution centers, warehouses, marine and container terminals. Distribution centers are primarily focused on the distribution of products and act as intermediaries in the supply chain. Warehouses serve as long-term storage facilities for products until further distribution. Marine and container terminals are specialized facilities located at ports, where cargo ships unload containers on trains and trucks. Fulfillment centers are focused on store, pick, pack and shipping products directly to end-customers. These logistic facilities differ from each other in their specific function and purpose, but they all have in common that their logistic operations are based on an inbound and outbound system in which truck logistics have a vital role. Therefore, insights gained from these studies can be used as input for this research.

2.2. Inbound system

The inbound system involves the processes of the arrival of trucks, the unload, receive and putaway process. The truck logistics, that is part of the inbound system, covers the arrival, enter, unload and departure process. It is desired that the trucks go through this system as quick and efficient as possible. Since these processes take place in chronological order, any inefficiencies with the truck logistics can affect each other and therefore impact the system performance of the entire inbound system. Many published studies, designated to other logistic facilities than FCs, have proven that inefficient planning of the truck logistics in the inbound system has severe consequences for the system performance. As shown in studies of Ambrosino and Peirano (2016); Carlan et al. (2022); Phan and Kim (2015); Phan and Kim (2016), the ineffective truck logistics has leads to truck

congestion and many trucks queuing in front of the gate. In a study of Kim et al. (2003), designated to a container terminal, it is shown that not precisely know when trucks will arrive, has also led to truck congestion and the increase in the TTT which causes delay in the entire inbound system. The big variation in the truck arrival pattern throughout the day leads to peak arrivals, which mainly occurs in the morning as shown in studies of Dekker et al. (2013); Wibowo and Fransoo (2021) and Smith and Srinivas (2019). This also leads to the queuing of trucks, especially in the morning which also impact the operational productivity of processes throughout the day. The reviewed literature shows the consequences of ineffective truck logistics within the inbound system on the system performance. However, none of these studies mention the possibility of the increase in rejecting non-unloaded truck due to high congestion.

2.3. Strategies in literature

Many strategies have been researched in literature to minimize the consequences of inefficient truck logistics by improving the inbound system. In studies with the objective of minimizing the TTT, van der Steenhoven (2016) have tested strategies regarding the efficient use of the internal resources at a distribution center, de Oliveira et al. (2022) has tested the impact of different check-in strategies at the port at a warehouse and Guan and Liu (2009) has tested the impact of changing the lay-out such as increasing the number of port. These strategies have proven to be successful at these logistic facilities. Studies with the objective of minimizing the waiting time have looked into changing the truck arrival pattern of trucks by implementing the even distribution of trucks by a Truck Appointment System (TAS) or Truck Arrival Management system (TAM). Many studies (Ambrosino and Peirano, 2016); (Phan and Kim, 2015); (Gracia et al., 2017)) have chosen this approach since it have proven to be successful in creating an even arrival pattern of trucks throughout the day which decreases the waiting times. However, those studies also show that the effectiveness of such a system depends heavily on the incentives created by the logistic facilities. There are also some studies who have looked into the possibilities of first-mile pick-up services that focus on the strategies in which the truckloads of trucks will be increased. This will reduce the total movements of carrier trucks and could potentially decrease the number of trucks arriving at the logistic facilities. This strategy is focused on the initial stage of a products supply chain in which a single logistic carrier manage the logistics of multiple retailers in the same surroundings (Giménez-Palacios et al., 2022). The retailers are asked to bring their shipments to a consolidation center in which the trucks can be loaded with as much shipments as possible. Studies of Dai and Chen (2012), Wang and Huang (2021) and Pan et al. (2013) have proven that this strategy could be a solution to the problem of underutilized truck loads and would reduce the costs for retailers and also contributes to the reduction of CO₂-emissions. However, it is not widely used already since the implementation can be quite challenging since partners would loose control on the first stage of their products supply chain.

2.4. Modelling techniques

Several modelling techniques are available to analyze the current system and to design potential strategies to assess their impact on the performance of the inbound system. In this research the chosen approach is simulation, which provides a dynamic and adaptable method of evaluating strategy outcomes within a virtual environment prior to real-world implementation. Various simulation techniques exist, of which the most common are: Discrete Event Simulation (DES) and Agent Based Modelling (ABS). Based on the characteristic of the system that is studied, a decision can be made of which simulation technique is the most appropriate. The literature review highlights DES as the predominant method for modeling the interactions within logistics processes. DES forms a powerful methodology with the focus on a network level in which the interaction between the processes can be analyzed (Özgün and Barlas, 2009). It is an event-driven technique which makes it possible to simulate events as such truck arrivals, unloading and departures. It also allows for simulating different entities which are objects that move through the system which would present the trucks. Those entities can have different states at discrete time steps that are requested by the simulation code. This makes it possible to study the behavior of such a logistics system in a controlled and virtual environment. Since the DES will be used including stochastic parameters to replicate the real-world situation as much as possible, the Monte Carlo simulation is used to deal with these uncertain parameters. The Monte Carlo simulation is a powerful tool to mitigate the impact of randomness which leads to more reliable results (Chen et al., 2011). It is based on the Law of Large Numbers (LLN) and the Central Limit Theorem (CLT) which ensures that the simulation results become more reliable and accurate as the number of iterations increases.

From the literature review it can be concluded that several studies have been performed regarding the improvement of truck logistics by improving the inbound system at distribution centers, warehouses, and marine/container terminals. These studies showed that an inefficient truck logistics leads to several consequences, such as high waiting times, high TTT and delays in unloading products and could impact the system performance of the inbound system. Several strategies have been tested and proven to be successful. These studies provide valuable insights which can be used for as input for this research in which the research gap will be filled since those studies are not focused on FCs and it is not specifically focused on eliminating rejecting trucks.

3. CASE STUDY

Within the case study a current state analysis has been performed of the inbound system of BFC. With qualitative and quantitative methods logistic bottlenecks have been identified and data has been obtained for the simulation model. The inbound system consists of four main processes which are arrival, enter, unload and departure of which truck logistics are a part of. Two waiting areas, associated with the arrival and enter

process, accommodate parked and waiting trucks. When these waiting areas get too full, it can lead to queuing outside on the road which leads to the rejection of non-unloaded trucks.

3.1. Logistic bottlenecks

The identified bottlenecks contribute to higher waiting times and increased congestion within the two waiting areas, and therefore a higher probability of rejecting non-unloaded trucks. These are the following:

- Having no official capacity set by BFC to the waiting areas results in the possibility of endless queue forming.
- The inconsistent paperwork received from the carriers and varying service times during the arrival process is a result of non-standardized carrier documentation and working procedures for port operators. This leads to higher and varying service times which leads to lower processing rate of trucks in the arrival process which results in more congestion of trucks in the waiting area.
- From the total truck arrivals per day, 56.6% of daily arriving trucks concentrate in the morning, causing congestion, longer waiting times, and delays in dock assignment in the morning. Fourth, many trucks are arriving with an underutilized truckload, increasing the overall number of trucks arriving.
- Many trucks arriving with an underutilized truckload, increasing the overall number of trucks arriving per day.
- High preparation time for truck drivers regarding the self-unloading of trucks and double checking the paperwork leads to high unloading times of trucks.

3.2. Identification of system requirements and Key Performance Indicators

The simulated inbound system should satisfy some system requirements which align with the objective of the research and model: the system should eliminate non-unloaded trucks, should reduce the amount of trucks parked and waiting in the waiting area at the port and dock, should reduce the waiting time experienced by trucks in the queues, should have a certain buffer to handle the unexpected events and should make it possible to unload all arriving trucks within one day. These requirements align with the Key Performance Indicators which are used for the assessment of the system's performance (KPI.org, 2000) (Cluster, 2022). Based on the objective, literature review and expert consultation the following KPIs have been determined:

1. **Probability of exceeding the capacity of the waiting area at the port and dock** = KPI 1 determines the probability of the possible need for rejecting trucks during a peak period of bol.com. It will be presented as a percentage in which a 0% percentage will be equal to an extremely unlikely probability that the capacity of the waiting area at the port and dock will be exceeded.

2. **Number of trucks parked at the waiting area at the port and dock** = KPI 2 gives the number of trucks parked at both waiting areas per hour represented in boxplots. It gives additional information regarding KPI 1 and provides valuable insights into the variability of the number of trucks parked throughout a full operational day. Additionally, it shows the buffer for unexpected events which is created when the number of variability of trucks is low.
3. **Waiting time per truck in queue during arrival and enter process** = KPI 3 represents the waiting time per experienced by truck in the queues during the arrival and enter process. The cumulative average waiting time for each trucks is presented by hourly boxplots to highlight variability. The waiting time provides additional insights into the system performance.

4. MODELLING

A simulation model was developed using the DES modelling technique, integrated with the Monte Carlo Simulation (MCS). With this model it was able to design and assess the impact of several potential strategies aimed at eliminating the rejection of non-unloaded trucks and alleviating the pressure on both waiting areas. The structure of the model is based on the studied inbound system of BFC and includes the four main processes: arrival, enter, unload and departure. The DES allows for the analysis of the interaction between the main processes, subprocesses and the truck logistics that move through this system in chronological order. Data for the simulation was gathered and structured into input and output data in order to finalize the construction of the simulation model. By integrating stochastic parameters, the model acknowledges uncertainties in truck arrivals and service times enhancing its realism. Verification and validation techniques ensure the model's functionality and accuracy which resulted in a proper working simulation model.

4.1. Conceptual design model

After defining the objective of the simulation model, the conceptual model is designed which is visible in Figure 1.

The four main processes of the inbound system are indicated at the left side of the figure. First, the *"arrival process"*, in which trucks physically arrive at BFC and enter one of the two available arrival lanes, which also indicates the imaginary 'waiting area at the port'. This waiting area at the port is filled by trucks parked while getting served and/or wait inside the porter lodge. After they park their trucks, they transfer from the truck to the porter lodge to get served by a port operator. When both of the port operators (2) are occupied, the truck driver enters the queue at the porter lodge. During the service by a port operator, the paperwork is getting checked and if everything is correct the truck needs to get a dock assigned which marks the beginning of the following process: *"the enter process"*. When all 30 unloading docks are occupied the truck drivers need to enter the second queue until a dock becomes available which is located just after the porter lodge and indicates the waiting area at the dock. When the truck gets a dock assigned, the truck

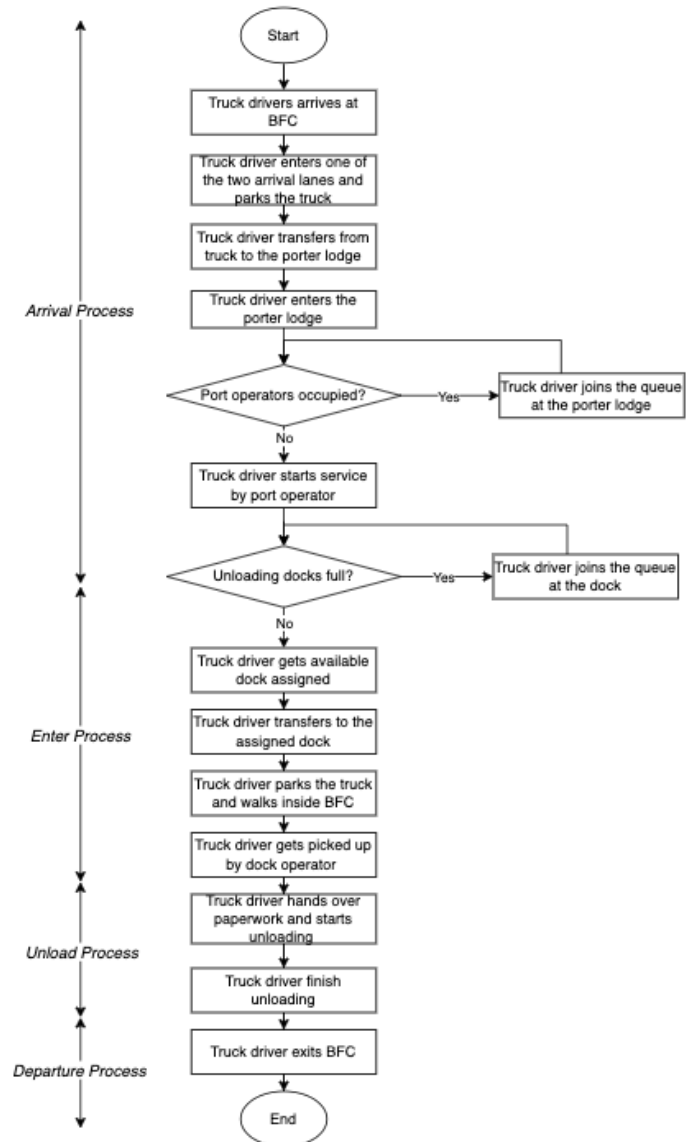


Figure 1: Conceptual Model

driver is allowed to continue to the unloading docks where the preparation starts for unloading and he or she will get picked up by a dock operators. *"The unload process"* start when the first items is scanned and finish until the whole shipment is done. *"The departure process"* is the final process and includes the leaving part of the truck drivers when it exit is BFC.

4.2. Input and output parameters

The input parameters are gained by an extensive data analysis and collection of the available historical data through the data-systems of bol.com. Any missing required data was obtained through interviews with experts and measurements at BFC. A complete overview of all the input data can be seen in Table 1. Some input parameters will be explained below the table.

Table 1: Input parameters DES

Parameter	Unit	Value	Process
<i>Truck.Arrival.Rate</i>	[min]	<i>Poisson</i> (λ), <i>Poisson</i> (λ), <i>Poisson</i> (λ)	<i>Arrival</i>
<i>Transfer.BFC.PorterLodge</i>	[min]	2	<i>Arrival</i>
<i>Port.Operators</i>	[#]	2	<i>Arrival</i>
<i>Server.Time.Port</i>	[min]	<i>Logn</i> (0.945, 0.646)	<i>Arrival</i>
<i>Transfer.PorterLodge.Gate</i>	[min]	1.45	<i>Arrival</i>
<i>Transfer.Gate.Dock</i>	[min]	15	<i>Enter</i>
<i>Unloading.Docks</i>	[#]	30	<i>Unload</i>
<i>Number.Of.Pallets</i>	[#]	3 (S), 13 (M), 33 (L)	<i>Unload</i>
<i>Truckload.Distribution</i>	[#]	40% (S), 40% (M), 20% (L)	<i>Unload</i>
<i>Basic.Duration</i>	[min]	15	<i>Unload</i>
<i>Pallets.Per.Minute</i>	[#/min]	1	<i>Unload</i>
<i>Departure.Duration</i>	[min]	5	<i>Departure</i>

Firstly the truck arrival rate which was gained by measuring the truck arrival pattern at the port at BFC. The data set of 66 arriving trucks with their precise arrival times, service times, truckloads and departure times was combined with the historical data of the most recent peak period 2022, in order to derive at the full truck arrival pattern during a peak period. This resulted in the determination of three time intervals on an operational day in which 56.6% of trucks arriving in the morning (peak), 37.8% trucks arriving in the afternoon (sub-peak) and only 5.6% arrive at the end of the day (non-peak). A visual representation can be seen in Figure 2. When the total arriving trucks per day is known, these determined percentage can be applied to derive at the exact truck arrival rate per time interval. The arrival of trucks is a stochastic process, and therefore implemented as three separated Poisson distributions described by the arrival rate of trucks per hour by the parameter lambda λ .

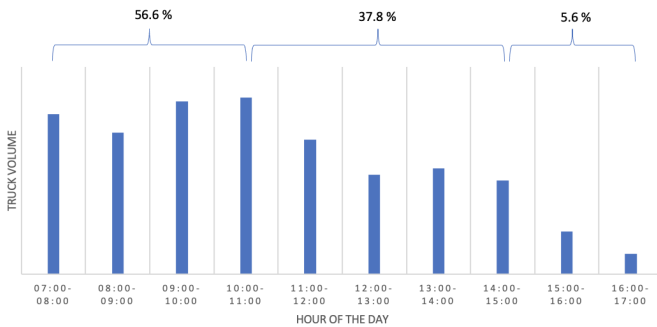


Figure 2: Truck Arrival Pattern

Secondly, the service time per trucks during the arrival pro-

cess, that was also obtained by the measurements since this data was available at bol.com. It can be concluded that there is a variation in service time per trucks due to factors such as: no standardization of paperwork, no standardization of working procedure port operators and language barriers. This significantly increases the service time as observed during the measurements. To incorporate this variation in service times, the lognormal probability function is chosen based on it is characteristics. By dividing the service times into different time intervals, the corresponding frequencies could be determined which resulted in a lognormal function with a mean of (μ) 0.945 and a standard deviation (σ) of 0.646. Thirdly, the unloading time which is determined by the formula visible in equation 1. The unloading time is based on the basic duration, number of pallets and the pallets processed per minute, of which it is characteristics are visible in Table 1.

$$Unloading.Time = Basic.Duration + \frac{60 * Number.Of.Pallets}{Pallets.Per.Minute} (1)$$

The amount of pallets per truck is divided into small, medium and large truckloads and is equal to respectively, 3, 13 and 33 pallets. The truckloads of trucks is assigned of trucks based on percentages determined with the empirical and historical data and can be seen in the table.

5. RESULTS

5.1. Experimental plan

After constructing the simulation model, an experimental plan could be set up in order to identify potential strategies that have could have a significant impact on the system performance of the inbound system of BFC. The strategies have been identified by examining four key variables derived from literature reviews, brainstorm sessions, and expert consultation. These four variables serve as input parameters for the simulation model which appears to show potential to construct several potential strategies and are the following: reducing the amount of trucks arriving by increasing the truckloads of trucks (1); reducing the service time per truck during the arrival process (2); reducing the basic duration of the unload process (3); even distribution of truck arrivals per hour throughout the day. The experiments will include three different scenarios (SC1 = 2023, SC2 = 2024, SC3 = 2025), which covers a future year scenario analysis since BFC expects to grow and therefore the number of arriving trucks will increase. These scenarios have made clear that from there will be increase of 49.1% percent between the peak period of the year 2023 and 2025 regarding the probability of rejecting non-unloaded trucks. After testing several variations and combinations of these variables, 16 potential strategies have been identified based upon the system requirements that show a significant impact on the system performance in all three scenarios. All the strategies with a short description can be seen in Table 1. These 16 potential strategies will be tested in another set of experiments in order to analyze what their impact is on the system performance and to what extent they can improve the inbound system.

Table 2: Overview strategies

Strategy	Description
1.1 until 1.3	10% increase of trucks arriving with a large truckload, 5% decrease of trucks arriving with a medium and small truckload
2.1. and 2.2	Reduction of the service time during the arrival process within the port by 2.24 min and 1.36 min
3.1 and 3.2	Reduction of the basic duration during the unload process with 10 and 5 minutes
4	Even distribution of truck arrivals
5	30% Increase in trucks with large truckloads and reduction of service time to 1.36 min
6	40% Increase in trucks with large truckloads and reduction of service time to 1.36 min
7	50% Increase in trucks with large truckloads and reduction of service time to 1.36 min
8	30% Increase in trucks with large truckloads and reduction of basic duration during unloading to 10 min
9	40% Increase in trucks with large truckloads and reduction of basic duration during unloading to 10 min
10	50% Increase in trucks with large truckloads and reduction basic duration during unloading to 10 min
11	Reduction of service time to 1.36 min and reduction of basic duration during unloading to 5 min
12	50% Increase in trucks with large truckloads and even distribution truck arrivals

5.2. Interpretation results

The results have been interpreted by the three formulated KPIs as explained before. **KPI 1: the probability of exceeding the capacity of the waiting area at the port and dock** is presented in a table showing the probability as a percentage. The objective of this research is to eliminate the possibility of rejected trucks, which corresponds to a 0% probability for KPI 1. However, in theory, it is difficult to say that there is 0% probability because there may always be an extremely small change practically. When the results of the simulation model gives a 0% probability, it can be considered as a probability so small that it can effectively be considered as zero. So, although in theory a 0% probability will never be zero, a 0% probability for KPI 1 in this research corresponds to an extremely unlikely occurrence that the capacity is being exceeded. it is important to emphasize this in order to enhance the research's validity. **KPI 2: the number of trucks parked at the waiting area at the port and dock** which will be presented in a graph with boxplots for every hour of the operational day. A boxplot is used to emphasize the variability in the number of trucks parked every hour. Due to the statistics such as the min., median, first/third quartile and max. values insights can be obtained to get a better understanding for the system performance. **KPI 3: Waiting time per truck in queue during arrival and enter process** will also be given in a boxplot due to the same reason as KPI 2. After analyzing the results of the 16 strategies across all scenarios, it appeared that 7 strategies have resulted in an enhanced system performance across all KPIs and scenarios. Differences between these strategies can be observed in to what extent they enhance the system performance. The results of the 7 strategies will be given and interpreted by the three formulated KPIs visible for scenario 3 to limit the amount of results and as it shows the worst-case scenario. Important to mention is only those strategies are

chosen when they improve the system performance in all scenarios.

5.3. Base Case Scenarios

The three scenarios that are defined represent the next coming years, 2023 (SC1), 2024 (SC2) and 2025 (SC3). These scenarios have been chosen as it replicates the expected growth that bol.com may face. within these scenarios the number of arriving trucks increases each year. By including these three scenarios in this study, it will be made clear the problem will escalate if the current situation remain unchanged. The number of trucks arriving in those scenarios is determined by forecast data regarding the expected inbound items at BFC. By knowing the amount of items per truck, together with the distribution of truckloads, the number of arriving trucks could be calculated with the determined truck arrival pattern. Looking at Table 3 which represents the results for KPI 1, the probability of exceeding the capacities for both waiting areas, it can be observed that in the next coming years there is significant increase and higher probabilities of rejecting non-unloaded trucks for both waiting areas. This increase is attributed to the higher arrival rate and the throughput rate of trucks from the arrival to enter process equal to 40 or more in which the unload process can't keep up with the speed of the arrival process.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table 3: Results of the base case scenarios: KPI 1

Scenario nr.	Strat. nr.	Prob. of exceeding capacity	
		Port	Dock
SC1	Base: 2023	16.3 %	0%
SC2	Base: 2024	33.4%	6.7%
SC3	Base: 2025	65.4%	13.9%

The results for KPI 1 are also reflected in KPI 2, which show the number of trucks parked at both waiting areas which is visible in Figures 3 and 4. The variability in the number of trucks parked will increase resulting in more uncertainty for BFC and negative impact on the system performance of the inbound system. Additionally, it can be seen that the issue mainly occurs between 7 a.m. and 11 a.m. which covers the morning peak.

KPI 2: Number of trucks parked at the waiting area at the port and dock

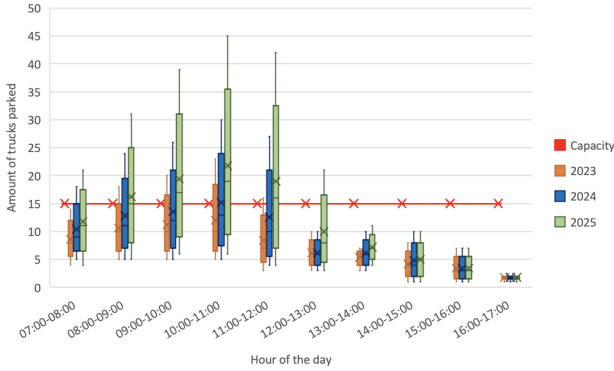


Figure 3: Results of the base scenarios: number of trucks parked in waiting area port (KPI 2)

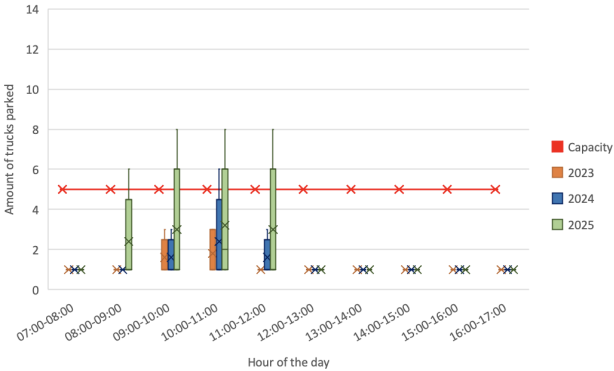


Figure 4: Results of the base scenarios: number of trucks parked in waiting area dock (KPI 2)

Finally, when observing the results for KPI 3, the waiting time per truck as visible in Figures 9 and 10, the same trend can be seen which shows that the waiting time will increase significantly to a maximum of 54 minutes waiting time in the queue in the arrival process, and 16 min waiting time in the queue in the enter process.

KPI 3: Waiting time per truck in queue during arrival and enter process

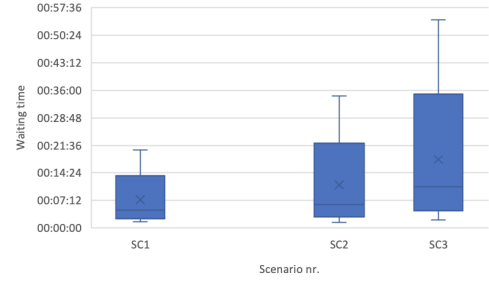


Figure 5: Results of the base scenarios: waiting time per truck in queue during arrival process (KPI 3)

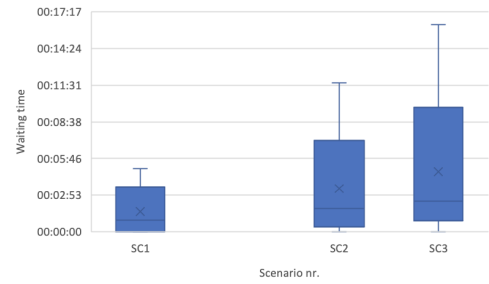


Figure 6: Results of the base scenarios: waiting time per truck in queue during enter process (KPI 3)

5.4. Results - Individually strategies

First, the results of the individually experiments will be explained interpreted by the three KPIs.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Examining KPI 1, which assess the probability of exceeding the capacities, it can be seen that the strategies 1.3 and 4 results in a system performance across all KPIs. Strategy 1.3 is focused on the 50% adjustment of trucks arriving with a larger truckload which results in the reduction of truck arrivals in scenario 3 from 277 trucks to 191 trucks per dag. Strategy 4 is focused on the even distribution of truck arrivals throughout the day resulting in an arrival rate of 28 trucks per hour. Both strategies have in common that it reduces the truck arrival rate to 30 or lower, which appears to be an effective strategy to effectively eliminate the probability of truck rejections at both waiting areas at it results in a 0% probability. These strategies have a positive impact on the arrival, enter and unload process. Strategies 1.1 and 1.2 which covers the 30% and 40% in truckloads adjustments does show an improvement compared to the base case but are not effective enough to reduce the probability to 0% due to the arrival rate of trucks being higher then 30. Strategies 2.1 and 2.2 are focused on the reduction of the service time during the arrival process which increases the processing time per truck and therefore results in a smoother flow of trucks in

the arrival process and achieves a 0% probability with the reduction to 1.36 min. However, a significant increase for the waiting area at the dock can be observed. This is attributed to the fact that the throughput rate of trucks ready for dock assignment is equal to 40 or more with the arrival rate begin higher then 35. Within this situation the processing rate in the arrival process is too fast for the processing rate in the unload process and becomes a problem. Strategy 2 positively impacts the arrival process, but negatively impacts the unload process. Strategy 3.1 and 3.2 are focused on the reduction of the basic duration during unloading and only improves the probability for the waiting area at the dock, as the probabilities for the waiting area at the port remain the same.

Table 4: Results individually strategies for KPI 1

Scenario nr.	Strategy nr.	Prob. of exceeding capacity	
		Port	Dock
Base	-	65.4%	13.9%
SC3	1.1	26.5%	11.1%
SC3	1.2	6.1%	0%
SC3	1.3	0%	0%
SC3	2.1	12.2%	38.1%
SC3	2.2	0%	41.4%
SC3	3.1	65.4%	0%
SC3	3.2	65.4%	0%
SC3	4	0%	0%

KPI 2: Number of trucks parked at the waiting area at the port and dock

The same trend as explained for KPI 1, is also reflected when examining KPI 2 as can be seen in Figure 7 and 8. Differences can be observed when analyzing the strategies that result in a 0% probability for both waiting areas. Due to the even distribution of truck arrivals in strategy 4 there is constant range of number of trucks parked every hour which improves the productivity of the employees at BFC. However, compared to strategy 1.3, a varying range can be observed in which the range decreases towards the end of the day as there are less truck arrivals.

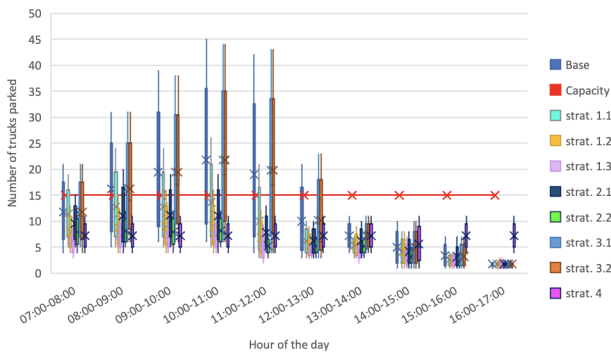


Figure 7: Results individually strategies: Trucks parked in waiting area port (KPI 2)

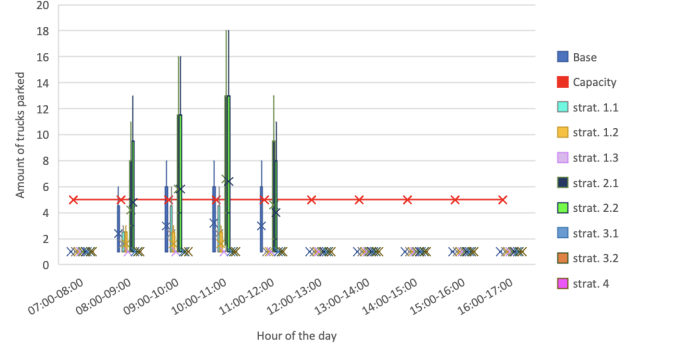


Figure 8: Results individually strategies: Trucks parked in waiting area dock (KPI 2)

KPI 3: Waiting time per truck in queue during arrival and enter process

Focusing on the waiting time per truck in the queue in the arrival process in Figure 9 it can be seen that except for strategy 3.1 and 3.2, the waiting time has been reduced compared to the base case. This reduction can be attributed to the reduction of truck arrivals, faster processing rate of trucks and the even distribution which eliminates peak arrival. It can also be seen that when reducing the service time during the arrival process, the relatively smallest waiting time is achieved due to the faster processing rate of trucks which cause less congestion.

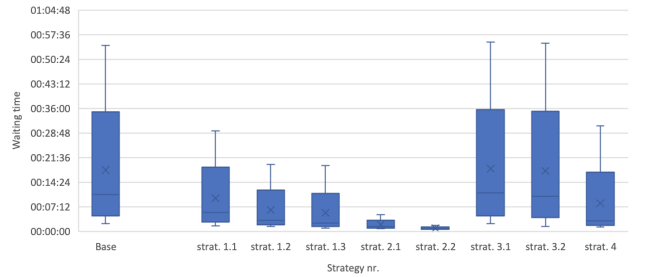


Figure 9: Results individually strategies: waiting time per truck in queue during arrival process (KPI 3)

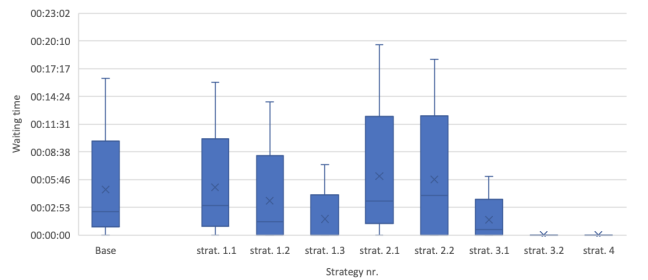


Figure 10: Results individually strategies: waiting time per truck in queue during enter process (KPI 3)

5.5. Results - Interactive experiments

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Analyzing the strategies in which variables are combined resulted in some interesting results. Examining KPI 1 in Table 5, it can be seen

that there are more strategies that results in an extreme unlikely probability that non-unloaded trucks need to be rejected at both waiting areas. First, it can be concluded that with combining the adjustments of truckloads with the reduction of the service time (strategy 6 and 7), the negative impact on the unload process due to the reduction of the service time can be resolved and results in a 0% probability for both waiting areas. This is attributed to the reduction of the arrival rate to 35 or lower. Second, it can be concluded that combining the reduction of unloading time, which not have an impact on the arrival process, with the adjustments of truckloads results in a 0% probability for both waiting areas as the reduction of the arrival rate impacts the arrival process (strategy 10). Third, it can be concluded that combining the reduction of service time and reduction of unloading time in strategy 11, results in a 0% probability for both waiting areas as they complement each other. Additionally, it provides a strategy in which there is no reduction of the arrival rate required. Finally, the combinations of the even distribution of trucks with the 50% adjustment as it reinforces each other.

Table 5: Results of the interactive strategies for KPI 1

Scenario nr.	Strategy nr.	Prob. of exceeding capacity	
		Port	Dock
Base	-	65.4%	13.9%
SC3	5	0%	17.9%
SC3	6	0%	0%
SC3	7	0%	0%
SC3	8	23.4%	0%
SC3	9	11.3%	0%
SC3	10	0%	0%
SC3	11	0%	0%
SC3	12	0%	0%

KPI 2: Number of trucks parked at the waiting area at the port and dock

When examining KPI 2, difference in the enhanced system performance can be seen regarding the ranges of the number of trucks parked at both waiting areas when looking at the 0% probabilities resulting strategies for KPI 1 for both waiting areas. The results can be seen in Figures 11 and 12. It can be observed that looking at the strategies that involves the reduction of the service time in strategy 6, 7 and 11, a lower range of trucks parked is observed than the strategy which involves the reduction of unloading time in strategy 10. This is attributed to the fact that the service time ensures faster processing and thus results in a smooth flow of trucks in the arrival process which keeps the congestion low at the waiting area at the port. It can also be observed that the 50% adjustments of truckloads (strategy 7 and 10) results in a lower range of trucks parked than the 40% adjustments since there are less trucks arriving (strategy 6). The range of parked trucks in strategy 11, is almost equal to the range in strategy 6 and 10 in which there is a reduction of the arrival rate. This indicates, that this combination is a highly effective strategy to lower the number of trucks parked throughout the day without even decreasing the arrival rate. Strategy 12, the even distribution of trucks throughout the day combined with the 50% adjustments in truckloads, results in the lowest and constant number of trucks parked throughout the day. This can be attributed to the fact

that the arrival rate of trucks is equal to 19 every hour which causes the low range but also the constant range. This improve the productivity of the employees at BFC. So, although all some of these strategies results in a significant reduced pressure in the number of trucks parked which is lower than the capacity of 15, differences can be seen regarding the variability of the number of trucks parked. Looking at the variability in the number of trucks parked at the waiting area at the dock, it can be seen except for the adjustments of 30% and 40% in truckloads, all the other strategies results in just 1 truck parked every hour. This can be attributed to the fact that the throughput rate of trucks from arrival to enter stays below the 35 in all the other strategies. Therefore, the issue of the waiting area at the dock will be no issue as explained before.

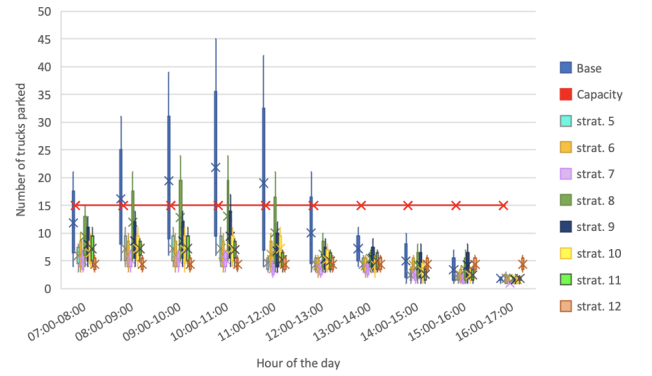


Figure 11: Results interactive strategies: Trucks parked in waiting area port (KPI 2)

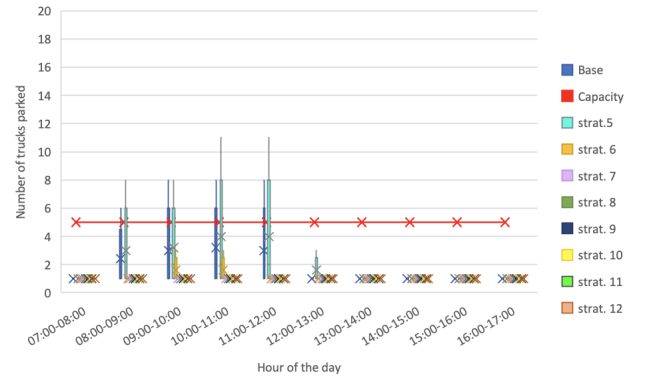


Figure 12: Results interactive strategies: Trucks parked in waiting area dock (KPI 2)

KPI 3: Waiting time per truck in queue during arrival and enter process

Focusing at KPI 3, the waiting time per truck in queue during the arrival and enter process can be analyzed. Focusing at the queue in the arrival process, it can be seen that every strategy results in a lower waiting time compared to the base. The lowest waiting time for trucks can be seen in strategy 5, 6, 7 and 11. This can be attributed to the fact that these strategies involve the reduction of the service time which decreases the waiting time in the arrival process significantly due to faster processing of trucks. The lower waiting times in strategy 8, 9 and 10 are attributed to the reduction of the arriving trucks, but are not impacted by the reduction in unloading time. As for strategy 12, the waiting time is relatively higher compared to strategy 7 in which there is

also a 50% adjustments of truckloads and therefore less trucks. However, strategy 12 does not involve the reduction of service time but is combined with the even distribution of truck arrivals. This lowers the number of trucks arriving per hour but remains constant throughout the day which could contribute to the overall relatively higher waiting time. Shifting the focus to the waiting time per truck in queue during the enter process, it can be seen that all strategies except for strategies 5 and 6, results in a zero waiting time. This indicates the situation in which no trucks are waiting for dock assignment. Strategy 5 results in a higher waiting time compared to the base case which is logical results since there will be more trucks waiting in the dock area.

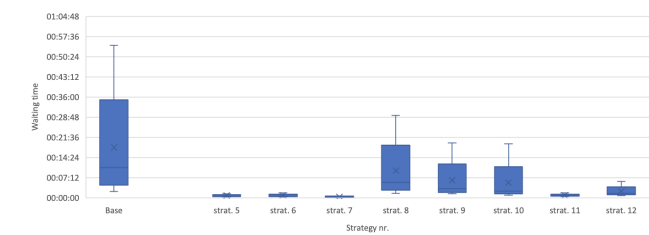


Figure 13: Results individually strategies: waiting time per truck in queue during arrival process (KPI 3)

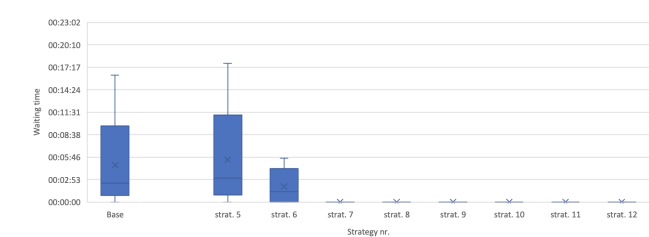


Figure 14: Results individually strategies: waiting time per truck in queue during enter process (KPI 3)

6. EVALUATION

A Multi-Criteria Analysis (MCA) have been performed in order to evaluate the 8 strategies that are able to enhance the system performance of the inbound system of BFC across all KPIs. The MCA consist of different criteria that are based on the research objectives and the system requirements such as the technical and operational implementation efforts and implications involved for partners and carriers. This is extreme important to take into consideration, since it determines the impact and effectiveness of the strategy.

6.1. Criteria

The criteria are the elements that are important for bol.com to take into account to rank the strategies. Based on the implementation plan and implications, the objective of the research and the KPIs, 8 criteria have been determined. A weighted is assigned to each of these criterion based on the level of importance to BFC. The criterion with the highest score and therefore most important for Bol.com are: number of rejected trucks (5), which is related to KPI 1, and the risks of no participation partners and carriers (4), followed by the buffer for unexpected events (3) which is related to KPI 2, and the technical and operational implementation (3). The criterion with a lower score and thereby relatively less important for BFC are: the productivity employees BFC (2), related to KPI 2, and the waiting time per truck (1), related to KPI 3.

6.2. MCA

Scores will be assigned to the 7 strategies based on how well they perform on each criterion which is determined by the results of the experiments and expert consultation. This resulted in a ranking of the strategies of which the results can be seen in Figure 15. When analyzing the results of the MCA it can be observed, that although each of the strategies results in an enhanced system performance of the inbound system, a trade-off is visible between the enhancement of a strategy and the associated risks and efforts. When the risks and efforts become too high, it may negatively impact the strategy in which the intended improvement is not achieved. Therefore, it is important to carefully consider the risks and efforts involved. It can be concluded that strategy 11, which covers the reduction of the service time during arrival to 1.36 minutes and the reduction of the basic duration during unload to 5 minutes, appears to be the best strategy for bol.com the implement. This strategy is focused on optimizing the internal resources which is beneficial for bol.com as they have already direct control over these resources. It also requires less implementation effort as the systems are already in place and needs limited adjustments. Furthermore, this strategy is associated with low risks of no participation of partners and carriers. This combinations makes this strategy the best for bol.com to implement in order to eliminate the rejection of non-unloaded trucks and reducing the pressure on both waiting areas. While strategy 12 offers the most optimal system performance of the inbound system, it involves high risks for partners and carriers that won't participate and highly complex technical and operational implementation efforts for BFC. Focused on the objective of the research, this strategy will be to risky to select in the current circumstances. However, it provides an opportunity for bol.com to determine to what extent adjustments could be made to mitigate the associated risks making this strategy more viable.

Criterion	Weight	Strategy							
		1.3	4	6	7	10	11	12	
Number of rejected trucks	5	5	5	5	5	5	5	5	
Waiting time per truck	1	1	2	3	5	3	5	3,5	
Buffer for unexpected events	3	2	1	3	4	2	3	5	
Productivity employees BFC	2	1	5	1	1	1	1	5	
Risk of no participation partners	4	2	3	2	1,5	1,5	3	1	
Risk of no participation carriers	4	4	2	3,5	3,5	2,5	3	2	
Technical implementation effort	3	4	2	3	3	3,5	4	1	
Operational implementation effort	3	2	3	2,5	2	1	2	1	
Total		64	72	68	69,5	58,5	73	71,5	
Ranking		6	2	5	4	7	1	3	

Figure 15: MCA

7. CONCLUSION

This research has assessed the impact of the increasing number of arriving trucks at the fulfillment centers regarding the elimination of rejecting non-unloaded trucks. A simulation model was developed which measures the performance of the inbound system regarding the probability of exceeding the capacities of the waiting areas, the number of trucks parked in the waiting areas and the waiting time experienced by trucks in both queues. This model allows for a thorough analysis of the impact of potential strategies and to what extent the performance could be improved to eliminate the rejection of non-unloaded trucks and reducing the pressure on both waiting areas. By conducting a case

study at bol.com and using their data, it can be stated that the next coming years bol.com will face some significance challenges regarding their performance of the inbound system. The probability of rejecting non-unloaded trucks during a peak period at the waiting area at the port will be increased to 65.4% and for the waiting area at the dock it will be increased to 13.9% in the year 2025. Seven strategies have proven to be successful in improving the system performance across all KPIs and scenarios, but differences between those strategies were observed regarding to what extent these could further improve the system performance. Performing an evaluation of these 7 strategies, the most appropriate strategy for bol.com could be selected given their current operational circumstances. This evaluation concluded that strategy 11 is the most appropriate strategy for bol.com to implement. It covers the reduction of service time during the arrival process to 1.36 min and reduction of the the basic duration during the unload process to 5 min. This strategy offers bol.com a realistic, affordable method to improve their inbound system by making more effective use of their own internal systems, in order to eliminate the rejecting non-unloaded trucks.

8. FUTURE RESEARCH

By conducting this research, several subjects for further research has emerged. First of all, it would be valuable to implement the receiving and putaway process of the inbound system in future research. This has been excluded in this research due to time limits and since it didn't contain truck logistics. However, receiving and putaway are also processes that needs to deal with the consequences of ineffective truck logistics. By including these processes in future research, a bigger impact on the system performance can be analyzed. Secondly, it is recommended in future research, to take more time for this research than only 7 months. This makes it able to perform more measurements within the FC in order to derive at bigger and more reliable data sets regarding the truck logistics. This would contribute significantly to the validity and reliability of the data. Thirdly, in future research it is recommended to experiment with all the possible combinations of variables that are available for potential improvement of the system performance. Due to time constraints, it was not able to investigate all the possible combinations, but for scientific purpose this would be highly recommended as other logistics may be analyzed with different characteristics. Additionally, within the context of this research focused at the case study of bol.com, certain decisions have been made on how to select potential strategies. However, these do not may apply for every logistic facility. Therefore, for further research it is recommended to test the combinations of variables that were not considered in this research as they were not realistic for bol.com but could show potential for further improvements.

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B. Measurements at BFC

The measurements were performed inside the porter lodge where a clear view can be obtained on the arrival lanes in order to see all the trucks arriving. A picture of the situation can be seen in Figure B.1. With a pre-made template in Excel and a stopwatch, several data was recorded regarding the truck arrivals. In Figure B.2 a complete overview of the measured data at 23/05/2023 is visible. In this figure, different columns are visible with two different colours. The blue coloured columns indicate the data that is obtained during the measurements, and the green coloured columns indicate the data that is extracted from the data system SCP. Of 66 trucks arriving at BFC, the following data was recorded:

- Number of arriving trucks
- Start time (Lane) = Time at which a truck enters the arrival lanes of BFC
- Start time (Port) = time at which the trucks drivers enters the porter lodge and get served by a port operator
- End time (Lane) = Time at which the truck exits the porter lane through the gates
- Carrier = The name of the carrier

After this day, the measured data was linked to the data from SCP in order to obtain additional information which is the following:

- End time (Port) = This time stemp recorded in the data systems of SCP defines the time at which the port operator has finished checking the paperwork of the truck driver
- Linked Shipment = In SCP it was visible which shipments were brought by the each truck
- First unloading scan = The moment at which the first pallet is scanned during unloading
- Pallets = The total amount of pallets a truck contains
- Truck size = With the amount of pallets the truck sizes could be determined



Figure B.1: Photo taken during the measurements inside the porter lodge

Truck	Start Time (Lane)	Start Time (Port)	End Time (Lane)	End Time (Port)	Carrier	Shipping ID	Linked Shipment	rstUnloadingSc	Pallets	Truck Size
1	07:19:00	07:23:20	07:25:20	07:23:53	GVT	2325934	2325042, 2325077	07:49:08	53	L
2	07:23:30	07:23:55	07:34:40	07:34:04	AC Trans?	2325940	2324321	07:46:22	1	S
3	07:31:00	07:34:50	07:44:00	07:39:05	SNEL Shared Logistic	2325943	2325524	08:05:26	1	S
4	07:40:45	07:42:30	07:48:30	07:46:53	Raben	2325945	2323197, 2324269	08:00:52	10	M
5	07:47:00	07:48:15	07:53:30	07:52:28	Claassen	2325948	2323738, 2325108	08:05:34	2	S
6	07:50:05	07:51:35	08:01:15	07:59:15	C van Doesburg	2325954	2323898, 2324259	08:38:30	23	M
7	07:51:00	07:53:15	07:59:45	07:57:06	ID Logistics , GVT	2325953	2325109	//	2	S
8	07:53:00	07:58:45	08:03:00	08:00:59	Cargo Logistics	2325955	2319218, 2324217	08:16:54	3	S
9	08:00:50	08:02:25	08:05:00	08:04:15	Transmission, HST G	2325957	2323662	08:38:56	7	M
10	08:10:00	08:11:00	08:24:30	08:22:08	CTS Group	2325973	2324898, 2325476	08:51:58	8	M
11	08:10:20	08:12:20	08:16:45		Heuvel Transport					
12	08:11:30	08:12:00	08:21:45	08:20:00	Dummy (verkerk)	2325971	2323114	08:41:27	1	S
13	08:20:00	08:23:00	08:27:00	08:26:01	VAN DIEVEL	2325975	2323829	08:47:17	33	L
14	08:21:00	08:22:15	08:25:45	08:23:36	MainFreight	2325974	2325769	08:39:06	1	S
15	08:29:00	08:30:30	08:34:15		ID Logistics , GVT					
16	08:34:30	08:35:30	08:39:50	08:36:50	Centraal Boekhuis	2326000	2325152, 2325379	08:51:14	2	S
17	08:35:00	08:42:50	08:49:00	08:46:05	Van der Heijden	2326016	2323874, 2324001	09:11:45	6	M
18	08:39:40	08:40:00	08:43:00	08:42:11	DGO Express	2326012	2324053	08:51:13	2	S
19	08:55:00	08:55:55	08:59:30		Veenstra					
20	08:57:55	08:58:10	08:59:00	08:59:26	Eigen Vervoer, 2 doc	2326027	2323566	09:08:36	3	S
21	09:01:15	09:02:00	09:04:00	09:03:20	Visser					
22	09:02:00	09:04:35	09:07:10	09:06:31	(Eigen vervoer) Van R	2326032	2325618	09:22:46	3	S
23	09:05:00	09:05:15	09:09:30	09:07:56	RHENU	2326034	2321243, 2321302	09:22:59	21	M
24	09:10:15	09:12:30	09:15:50	09:14:30	DAVERO				3	S
25	09:10:45	09:11:35	09:14:15	09:13:03	Amacom flash delive	2326038	2325919	09:35:17		
26	09:17:00	09:19:30	09:22:00	09:21:07	Tailormade logistics	2326052	2325456	09:40:15	15	M
27	09:20:30	09:22:15	09:26:15	09:23:17	Van Dievel Transport	2326056	2323823	09:39:07	33	L
28	09:24:15	09:25:00	09:31:50	09:29:00	Main Freight					
29	09:26:30	09:27:30	09:30:30	09:29:30	Van Schijndel transp	2326095???				
30	09:27:30	09:28:50	09:34:30	09:32:23	Jan de rijk	2326075	2325947	09:57:33	10	M
31	09:27:50	09:32:00	09:37:59	09:37:47	De Koomen	2326084	2325886	10:08:32	1	S
32	09:28:00	09:34:00	09:39:00	09:35:42	Eigen Vervoer	2326081	2324376	09:55:39	2	S
33	09:37:10	09:38:40	09:42:00	09:40:17	Transmission truck,	2326089	2324535	10:01:58	2	S
34	09:39:00	09:39:50	09:51:45	09:49:16	Koopman	2326106	2322070, 2323714	10:01:23	2	S
35	09:39:10	09:39:55	09:44:20	09:42:40	Van Houten	2326091	2325189	10:15:51	3	S
36	09:40:00	09:43:10	09:49:00	09:45:39	DI Middelkoop (Fru	2326096	2323987	10:10:40	1	S
37	09:41:00	09:48:00	09:55:06	09:53:15	Dachser	2326114	2321569, 2322004	10:39:31	15	M
38	09:50:35	09:53:50	10:02:50	09:56:46	GLS	2326120	2322616, 2324228	10:15:24	4	S
39	10:00:00	10:01:00	10:13:15	10:10:43	Sander Logistics	2326153	2325193, 2325481	10:24:07	24	M
40	10:07:25	10:11:20	10:15:00	10:14:47	Wim Claes Transport	2326160	2325958	10:30:32	5	S
41	10:16:50	10:17:50	10:20:00	10:20:40	Electronic logistics	2326166	2325766	10:31:23	1	S
42	10:22:30	10:23:30	10:33:45	10:33:03	Keunen	2326196	2323627, 2325776	10:48:51	7	M
43	10:23:00	10:33:55	10:37:00	10:35:38	KEMPEN	2326200	2323546	10:37:06	27	L
44	10:27:35	10:35:50	10:39:30	10:37:13	Dummy Carrier, WEN	2326206	2325595	10:52:04	1	S
45	10:36:00	10:37:00	10:41:30	10:39:23	GLS	2326211	2324920	11:03:49	5	S
46	10:41:00	10:42:40	10:47:00	10:44:31	AAB Courines	2326218	2325418	10:58:55	1	S
47	10:58:50	10:59:30	11:00:00	11:00:39	DB Schenker	2326236	2322522	11:12:45	1	S
48	11:19:30	11:20:20	11:23:00	11:22:14	Den becker	2326275	2323922, 2324214	11:31:07	2	S
49	11:30:10	11:30:55	11:34:00	11:32:55	Kivits Drunen	2326300	2323638, 2323639	11:56:15	27	L
50	11:46:00	11:47:00	11:51:30	?	?					
51	12:05:00	12:06:00	12:11:35	12:10:06	DAS Koerier, 23263	2326366	2323689	12:17:38	5	S
52	12:09:55	12:11:30	12:14:30	12:13:24	Eigen Vervoer	2326372	2324537	12:24:40	1	S
53	12:11:15	12:14:45	12:21:00	12:18:15	BROUWERS	2326380	2323961, 2323967	12:31:27	3	S
54	12:16:00	12:17:00	12:19:50	12:18:46	Keine witte truck (W	2326381	2320168	12:33:31	4	S
55	12:21:50	12:22:20	12:25:00	12:24:16	Eigen vervoer (TIP Eu	2326387	2321991	12:38:03	9	M
56	12:24:00	12:27:00	12:30:00	12:29:02	Eigen Vervoer, 2 doc	2326392	2322802, 2323452	12:49:16	25	L
57	12:47:00	12:48:00	12:52:00	12:50:38	Kleine witte truck	2326426	2322510	13:07:03	4	S
58	12:58:15	12:59:55	13:06:35	13:04:30	GVT, Tristar	2326437/B	2325042	13:33:38	96	L
59	12:59:00	13:00:30	13:05:45		Transmission	2326437	2322240, 2323236			
60	13:02:45	13:09:20	13:17:00	13:11:41	De klok Logistics	2326440	2322087	13:26:55	3	S
61	13:18:00	13:19:00	13:23:00	13:21:02	Dachser	2326484	2325837	13:51:02	14	M
62	13:51:55	13:54:15	13:59:00	13:57:37	Van Reenen	2326552	2325040	14:04:53	1	S
63	13:52:10	13:53:15	13:56:00	13:54:22	MICODO	2326545	2323151, 2324325	14:04:47	2	S
64	14:21:00	14:22:00	14:24:00	14:22:29	KSW	2326581	2323845	14:31:41	3	S
65	14:38:15	14:39:00	14:43:00	14:40:47	BROUWERS	2326616	2323944	14:55:37	1	S
66	14:46:50	14:48:50	14:52:55	14:51:29	VONK & CO, sda	2322603				

Figure B.2: Excel overview of the measured data at the porter lodge

Transfer.PorterLodge.Gate	Transfer.BFC.PorterLodge
00:01:27	00:04:20
00:00:36	00:00:25
00:04:55	00:03:50
00:01:37	00:01:45
00:01:02	00:01:15
00:02:00	00:01:30
00:02:39	00:02:15
00:02:01	00:05:45
00:00:45	00:01:35
00:02:22	00:01:00
	00:02:00
	00:00:30
00:00:59	00:03:00
00:02:09	00:01:15
	00:01:30
00:03:00	00:01:00
00:02:55	00:07:50
00:00:49	00:00:20
	00:00:55
/	00:00:15
	00:00:45
00:00:39	00:02:35
00:01:34	00:00:15
	00:02:35
00:01:12	00:00:50
00:00:53	00:02:30
00:02:58	00:01:45
00:02:50	00:00:45
00:01:08	00:01:00
00:02:07	00:01:20
00:00:12	00:04:10
00:03:18	00:06:00
00:01:43	00:01:30
00:02:29	00:00:30
00:01:40	00:00:45
00:03:21	00:03:10
00:01:51	00:07:00
00:06:04	00:03:15
00:02:32	00:01:00
00:00:19	00:03:55
/	00:01:00
00:00:42	00:01:00
00:01:22	00:10:55
00:02:17	00:08:15
00:02:07	00:01:00
00:02:29	00:01:40
/	00:00:40
00:00:46	00:00:50
00:01:05	00:00:45
	00:01:00
00:01:29	00:01:00
00:01:06	00:01:35
00:02:45	00:03:30
00:01:04	00:01:00
00:00:44	00:00:30
00:00:58	00:03:00
00:01:22	00:01:00
00:02:05	00:01:40
	00:01:30
00:05:19	00:06:35
00:01:58	00:01:00
00:01:23	00:02:20
00:01:38	00:01:05
00:01:31	00:01:00
00:02:19	00:00:45
00:01:26	00:02:00
Transfer.PorterLodge.Gate	Transfer.BFC.PorterLodge
00:01:53	00:02:15

Figure B.3: Excel overview of the transfers

ServiceTime_Port
00:00:33
00:10:09
00:04:15
00:04:23
00:04:13
00:07:40
00:03:51
00:02:14
00:01:50
00:11:08
00:02:32
00:08:00
00:03:01
00:01:21
00:01:52
00:01:20
00:03:15
00:02:11
00:01:42
00:01:16
00:01:20
00:01:56
00:02:41
00:02:00
00:01:28
00:01:37
00:01:02
00:04:00
00:02:00
00:03:33
00:05:47
00:01:42
00:01:37
00:09:26
00:02:45
00:02:29
00:05:15
00:02:56
00:09:43
00:03:27
00:02:50
00:09:33
00:01:43
00:01:23
00:02:23
00:01:51
00:01:09
00:01:54
00:02:00
00:02:37
00:04:06
00:01:54
00:03:30
00:01:46
00:01:56
00:02:02
00:02:38
00:04:35
00:03:22
00:02:21
00:02:02
00:03:22
00:01:07
00:00:29
00:01:47
00:02:39

Figure B.4: Excel overview of measured service times

C. Data-Analysis

C.1. Arrival Pattern Peak Season

This section shows the exact Excel calculations in which the arrival pattern during the peak season is calculated. These calculations are based on the historical data sets of the peak season 2022. Due to the complexity and time intensity of these data-analysis, its chosen to extract 10 samples of each month (October, November and December). From each of these samples the exact amount of trucks arrivals are calculated per hour. Subsequently, the totals are cumulative summed up. An overview of these Excel calculations can be seen in Figure C.1. The results of the summations per hour are given in Figure C.2 and are converted into percentages. This results in the complete arrival pattern for trucks for each day during the peak period which is visible in the main text. This arrival pattern can be used for further calculations.

Figure C.1: Excel calculations for truck arrival pattern

Figure C.2: Excel calculations for truck arrival pattern

Figure C.3 shows the Excel calculations from the Chi-Square test of the Poisson truck arrivals.

Figure C.3: Excel calculations of the chi-squared test for truck arrivals

C.3. Service Time Trucks

This section shows the calculation of the service times of trucks as input for the simulation model. The service time is calculated with the data obtained from the measurements, which is visible in Figure B.2. By subtracting the columns 'Start Time (Port)' with the column 'End Time (Port)', the service time of each truck can be derived. For example, for truck 1 in the data set this means the following calculation: 07:23:52 - 07:23:20 = 00:00:33 seconds for truck 1. From the data out of this table the mu and the standard deviation can be calculated in Excel.

$$Service.Time.Port = End.Time(Port) - Start.Time(Port) \quad (C.1)$$

Service time	Trucks
00:00<00:30	1
00:30<01:00	1
01:00<01:30	9
01:30<02:00	12
02:00<02:30	11
02:30<03:00	9
03:00<03:30	6
03:30<04:00	2
04:00<04:30	5
04:30<05:00	1
05:00<05:30	1
05:30<06:00	1
06:00<06:30	0
06:30<07:00	0
07:00<07:30	0
07:30<08:00	1
08:00<08:30	0
08:30<09:00	0
09:00<09:30	1
09:30<10:00	2
>10:00	3

Figure C.4: Different service times of the trucks

C.4. Chi-Squared test Service Time

Figure C.5 shows the Excel calculations from the Chi-Square test of the Lognormal service times.

Chi-square test service time						
		Observed	Expected			
Service time	N	Service time	per truck	O-E	(O-E)^2	X^2
00:00<00:30		1	1		0	0
00:30<01:00		2	1		-5	25
01:00<01:30		3	9		1	1
01:30<02:00		4	12		2	4
02:00<02:30		5	11		-2	4
02:30<03:00		6	9		5	25
03:00<03:30		7	6		2	4
03:30<04:00		8	2		1	1
04:00<04:30		9	5		0	0
04:30<05:00		10	1		1	1
05:00<05:30		11	1		0	0
05:30<06:00		12	1		0	0
06:00<06:30		13	0		-1	1
06:30<07:00		14	0		0	0
07:00<07:30		15	0		-1	1
07:30<08:00		16	1		0	0
08:00<08:30		17	0		-1	1
08:30<09:00		18	0		0	0
09:00<09:30		19	1		1	1
09:30<10:00		20	2		1	1
>10:00		21	3		2	4
Chi-square	21,25					
Degrees of freedom	20					
Significance level	0.05					
Critical value	31,41					
Chi-square < critical value	21.25 < 31.42					

Figure C.5: Excel calculations of the chi-squared test for service time

C.5. Chi-Squared Test Table

Percentage Points of the Chi-Square Distribution								
Degrees of Freedom	Probability of a larger value of χ^2							
	0.99	0.95	0.90	0.75	0.50	0.25	0.10	0.01
1	0.000	0.004	0.016	0.102	0.455	1.32	2.71	6.63
2	0.020	0.103	0.211	0.575	1.386	2.77	4.61	9.21
3	0.115	0.352	0.584	1.212	2.366	4.11	6.25	11.34
4	0.297	0.711	1.064	1.923	3.357	5.39	7.78	13.28
5	0.554	1.145	1.610	2.675	4.351	6.63	9.24	15.09
6	0.872	1.635	2.204	3.455	5.348	7.84	10.64	16.81
7	1.239	2.167	2.833	4.255	6.346	9.04	12.02	18.48
8	1.647	2.733	3.490	5.071	7.344	10.22	13.36	20.09
9	2.088	3.325	4.168	5.899	8.343	11.39	14.68	21.67
10	2.558	3.940	4.865	6.737	9.342	12.55	15.99	23.21
11	3.053	4.575	5.578	7.584	10.341	13.70	17.28	24.72
12	3.571	5.226	6.304	8.438	11.340	14.85	18.55	26.22
13	4.107	5.892	7.042	9.299	12.340	15.98	19.81	27.69
14	4.660	6.571	7.790	10.165	13.339	17.12	21.06	29.14
15	5.229	7.261	8.547	11.037	14.339	18.25	22.31	30.58
16	5.812	7.962	9.312	11.912	15.338	19.37	23.54	32.00
17	6.408	8.672	10.085	12.792	16.338	20.49	24.77	33.41
18	7.015	9.390	10.865	13.675	17.338	21.60	25.99	34.80
19	7.633	10.117	11.651	14.562	18.338	22.72	27.20	36.19
20	8.260	10.851	12.443	15.452	19.337	23.83	28.41	37.57
22	9.542	12.338	14.041	17.240	21.337	26.04	30.81	39.92
24	10.856	13.848	15.659	19.037	23.337	28.24	33.20	42.98
26	12.198	15.379	17.292	20.843	25.336	30.43	35.56	45.64
28	13.565	16.928	18.939	22.657	27.336	32.62	37.92	48.28
30	14.953	18.493	20.599	24.478	29.336	34.80	40.26	50.89
40	22.164	26.509	29.051	33.660	39.335	45.62	51.80	63.69
50	27.707	34.764	37.689	42.942	49.335	56.33	63.17	76.15
60	37.485	43.188	46.459	52.294	59.335	66.98	74.40	88.38

Figure C.6: Chi-square distribution table

D. Number of Simulation Runs

The simulation model used in this report contains a lot of probability distributions. However, this randomness in these distributions can lead to variations in the simulations between different runs. By performing different replications, which leads to the execution of the simulation model multiple times, the accuracy of the results will increase. By running the model multiple times and averaging the results, the impact of randomness on the results will reduce and results in a more stable estimate of the KPIs. A higher level of replications, means a higher level of accuracy, however, it is also very time consuming. Therefore, its important to determine the optimal minimum number of replications for the simulation. There are multiple methods for determining the number of replications. In this research the graphical method is used. With the graphical method the cumulative maximum number of trucks parked at the waiting area at the port are visualised against the number of replications in a graph (Delft, 2030). At a certain point in the graph, the results becomes 'flat', which indicates the number of replications that needs to be used. The determination of the number of replications is determined for the total maximum number of trucks parked at the waiting at the port and dock. It can be seen that below a number of replication of 600, big differences can be observed in the results. However, at a number of replications equal to 700 it can be seen that the graph becomes flat. Therefore, its chosen to set the number of replications at 700.

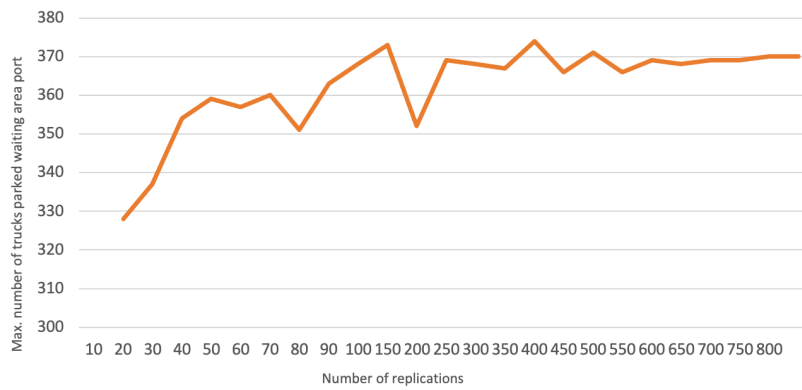


Figure D.1: Number of replications - max. number of trucks parked waiting area port

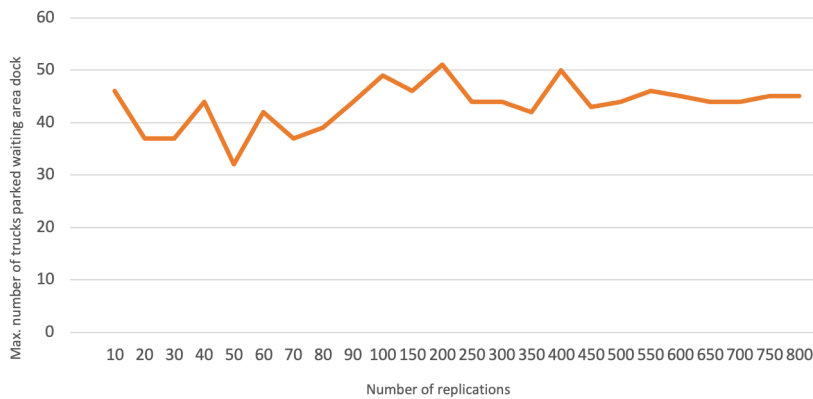


Figure D.2: Number of replications - max. number of trucks parked waiting area dock

E. Insights Experimental Plan

This chapter gives more insights in into the calculations regarding the input parameters for the different scenarios used in the experiments. Between these scenarios all of the input parameters, except for the arrival rates, remains the same. The total amount of trucks arriving in the different scenarios are calculated based on a forecast of the expected inbound items at BFC available at bol.com.

E.1. Required Amount Of Trucks In The Scenarios

Based on the forecast model available at bol.com of the amount of items expected at BFC, an estimation can be made about the amount of trucks that is required to bring the items each year during the peak period. Several calculations have been done in order to derive at the necessary data. In the simulation, BFC1 and BFC2 are combined and no distinction is made between those. However, in the calculations, this difference is taken into account since BFC1 is mainly meant for larger items and BFC2 for smaller items. Therefore, its first important to collect the expected total amount of items for both BFC1 and BFC2 for the years 2023, 2024 and 2025. This is visible in Figure E.1. These values indicated with the totals, indicate the number of items per peak period for BFC1 and BFC2 which is divided into the months October, November and December.

E.1. Required Amount Of Trucks In The Scenario 2016-2033 - Improving the inbound system at fulfillment centers

Warehouse	Sizegroup	2023 Peak	2024 Peak	2025 Peak
BFC1	3XS	277.358	335.478	434.739
	XXS	98.919	154.186	239.618
	XS	1.043.919	974.282	865.809
	S	1.192.075	1.153.469	1.194.028
	M	1.376.273	1.300.024	1.361.487
	L	706.333	597.963	633.759
	Total	4.694.876	4.515.402	4.729.439
BFC2	3XS	3.542.121	4.266.997	4.806.427
	XXS	1.016.428	1.379.810	1.551.598
	XS	2.548.266	2.918.415	3.484.749
	S	3.809.544	3.879.871	4.374.185
	M	2.321.052	2.423.797	2.213.364
	L	74.750	85.117	85.194
	Total	13.312.160	14.954.007	16.515.516

Figure E.1: Forecast amount of items expected at BFC1 and BFC2

Subsequently, the amount of expected items are converted into the number of trucks based on the information of the number of pallets per truck and items per pallet. This is done by the truck characteristics explained in Section 5.2.1. The calculations are performed in Excel of which an overview is given in Figure E.2. A random month is picked during the peak period which is the month November.

Key ratio's	nov-23 nov-24 nov-25		
Peak months	12		
Operational days in one month	21		
Amount of items per pallet BFC1	150		
Amount of pallets per truck based on truckload (L/M/S)	33 13 3		
Amount of items per truck (L/M/S)	4.950 1.950 450		
Amount of items per pallet BFC2	250		
Amount of pallets per truck based on truckload (L/M/S)	33 13 3		
Amount of items per truck (L/M/S)	8.250 3.250 750		
Truckload distribution percentages			
Large	20%	0,2	
Medium	40%	0,4	
Small	40%	0,4	
Key figures			
Total items per month			
BFC1 - Peak		1.564.959	1.505.134 1.576.480
BFC2 - Peak		4.437.387	4.984.669 5.505.172
Amount of items based on truckload distribution			
BFC1 - L		312.992	301.027 315.296
BFC1 - M		625.983	602.054 630.592
BFC1 - S		625.983	602.054 630.592
BFC2 - L		887.477	996.934 1.101.034
BFC2 - M		1.774.955	1.993.868 2.202.069
BFC2 - S		1.774.955	1.993.868 2.202.069
Required amount of trucks per month - peak			
BFC1 - L		63	61 64
BFC1 - M		321	309 323
BFC1 - S		1391	1.338 1.401
BFC2 - L		108	121 133
BFC2 - M		546	613 678
BFC2 - S		2367	2.658 2.936
Total required amount of trucks per month			
BFC1 - Peak		1.775	1.707 1.788
BFC2 - Peak		3.020	3.393 3.747
Total required amount of trucks per day			
BFC1 - Peak		85	81 85
BFC2 - Peak		144	162 178
Total required amount of trucks per day BFC		228	243 264

Figure E.2: Excel calculations: Required arriving trucks

The calculations result in the total number of required trucks per day, during the peak period at BFC in the years 2023, 2024 and 2025 which can be used as the inputs for the different scenarios. An example of the calculations will be shown for November 2023 for BFC1. First, the total expected amount of items per year during the peak season is divided by 3 to derive at the items per month. Which is $4.694.876/3 = 1.564.959$ for BFC1. Second, the total amount of items expected at BFC is

multiplied by the percentage of the truckloads distribution to know how much items will be brought by the different truck sizes (S, M, L). Which is $1.564.959 \times 0.2 = 312.992$. Then, knowing how much items fits in a large truck, which is 4950 for BFC1, the 312.992 will be divided by 4950 which results in 63 trucks with a large truckload arriving per month in November 2023. Finally, this number can be divided by the number of operational days in one month which is equal to 21 which results in the number of trucks required per day. As the final step, a margin is applied to the total amount of trucks, since not all data is based on real-time data. By adding this margin, potential fluctuations can be taking into account or unexpected changes in the variables that could affect the calculations. Also, it leaves room for unforeseen challenges and helps to mitigate the impact of risks. Together with BFC employees, a margin of 5% have been chosen. Combining the total trucks arriving at BFC together with the resulting arrival pattern of Section 3.7.2, results in the trucks arrivals per peak period for each scenario which are presented in the next section.

E.2. Scenario 1: Peak-Season 2023

In the year 2023, which is covered by scenario 1, a total of 240 trucks are expected to arrive at BFC. The different truck arrivals according to the arrival pattern can be seen in Table E.1.

nov-23	Margin (5%)	
Total required amount of trucks per day	228	240
	Trucks [#]	Trucks per hour [# /h]
Peak	136	34
Sub-Peak	91	23
Non-Peak	13	7

Figure E.3: Excel calculations: Trucks arrivals in 2023

Table E.1: Poisson distributions truck arrival rate scenario 1

Measurement	Distribution
Truck arrivals: Peak	<i>Poisson</i> (34)
Truck arrivals: Sub-peak	<i>Poisson</i> (23)
Truck arrivals: Non-Peak	<i>Poisson</i> (7)

E.3. Scenario 2: Peak-Season 2024

In the year 2024, which covers scenario 2, a total of 255 trucks are expected to arrive at BFC. The different truck arrivals according to the arrival pattern can be seen in Table E.2.

nov-24	Margin (5%)	
Total required amount of trucks per day	243	255
	Trucks [#]	Trucks per hour [# /h]
Peak	144	36
Sub-Peak	96	24
Non-Peak	14	7

Figure E.4: Excel calculations: Trucks arrivals in 2024

Table E.2: Poisson distributions truck arrival rate for scenario 2

Measurement	Distribution
Truck arrivals: Peak	<i>Poisson</i> (36)
Truck arrivals: Sub-peak	<i>Poisson</i> (26)
Truck arrivals: Non-Peak	<i>Poisson</i> (8)

E.4. Scenario 3: Peak-Season 2025

In the year 2025, which covers scenario 3, a total of 277 trucks are expected to arrive at BFC. The different truck arrivals according to the arrival pattern can be seen in Table E.3.

	nov-25	Margin (5%)	
Total required amount of trucks per day	264	277	
		Trucks [#]	Trucks per hour [# / h]
	Peak	157	39
	Sub-Peak	105	26
	Non-Peak	15	8

Figure E.5: Excel calculations: Trucks arrivals in 2025

Table E.3: Poisson distributions truck arrival rate for scenario 3

Measurement	Distribution
Truck arrivals: Peak	<i>Poisson</i> (39)
Truck arrivals: Sub-peak	<i>Poisson</i> (26)
Truck arrivals: Non-Peak	<i>Poisson</i> (8)

E.5. Detailed calculations regarding variable 1

Variable 1, is focused on increasing the number of trucks arriving at BFC with a larger truckload. Different variations can be made to test around with the different truckloads. The number of trucks that arrive with a large truckload will be increased by 10%, and the trucks that arrive with a medium and small truckload are decreased by 5%. This results in 8 different variations, 1.1 until 1.8, of which an overview can be seen in Table E.4. Since these adjustments in the truckloads impacts the number of arriving trucks, several new calculations needs to be performed in order to calculate the amount of arriving trucks for each scenario and for each variation to experiment with. For the calculations of the required number of trucks, the same approach is used as explained in Appendix F.1 and the resulted Excel calculations can be seen in Figures E.6 and E.7. In this figure its visible what the total number of arriving trucks is per day for each variation in the last line of the Excel overview.

Table E.4: Variable 1: Increase truckload fill

Variation nr.	Truckload Distribution
	S/M/L
Base	40% / 40% / 20%
1.1	35% / 35% / 30%
1.2	30% / 30% / 40%
1.3	25% / 25% / 50%
1.4	20% / 20% / 60%
1.5	15% / 15% / 70%
1.6	10% / 10% / 80%
1.7	5% / 5% / 90%
1.8	0% / 0% / 100%

Key Dates		nov-23	nov-24	nov-25	nov-23	nov-24	nov-25	nov-23	nov-24	nov-25	nov-23	nov-24	nov-25	nov-23	nov-24	nov-25
Operational days in one month																
Amount of items per pallet BFC1																
Amount of pallets per truck based on truckload (LMS)																
Amount of items per truck (LMS)																
Amount of items per pallet BFC2																
Amount of pallets per truck based on truckload (LMS)																
Amount of items per truck (LMS)																
Truckload distribution percentages																
Large					0.30			0.40			0.5		0.6			
Medium					0.35			0.30			0.25		0.2			
Small					0.35			0.30			0.25		0.2			
Key figures																
Total items per month		1,564,959	1,505,134	1,576,480	1,564,959	1,505,134	1,576,480	1,564,959	1,505,134	1,576,480	1,564,959	1,505,134	1,576,480	1,564,959	1,505,134	1,576,480
BFC1 - Peak		4,437,387	4,984,669	5,505,172	4,437,387	4,984,669	5,505,172	4,437,387	4,984,669	5,505,172	4,437,387	4,984,669	5,505,172	4,437,387	4,984,669	5,505,172
Amount of items based on truckload distribution																
BFC1 - L		312,992	301,027	315,296	469,488	451,540	472,944	625,983	602,054	630,592	782,479	752,567	788,240	938,975	903,080	945,888
BFC1 - M		625,983	602,054	630,592	547,736	526,797	551,768	469,488	451,540	472,944	391,240	376,284	394,120	312,992	301,027	315,296
BFC1 - S		625,983	602,054	630,592	547,736	526,797	551,768	469,488	451,540	472,944	391,240	376,284	394,120	312,992	301,027	315,296
BFC2 - L		887,477	996,934	1,101,034	1,331,216	1,495,401	1,651,552	1,774,955	1,993,868	2,202,069	2,218,693	2,492,334	2,752,586	2,662,432	2,990,801	3,303,103
BFC2 - M		1,774,955	1,993,868	2,202,069	1,553,085	1,744,634	1,926,810	1,331,216	1,495,401	1,651,552	1,109,347	1,246,167	1,376,293	887,477	996,934	1,101,034
BFC2 - S		1,774,955	1,993,868	2,202,069	1,553,085	1,744,634	1,926,810	1,331,216	1,495,401	1,651,552	1,109,347	1,246,167	1,376,293	887,477	996,934	1,101,034
Required amount of trucks per month - peak																
BFC1 - L		63	61	64	95	91	96	126	122	127	158	152	159	190	182	191
BFC1 - M		321	309	323	281	270	283	241	232	243	201	193	202	161	154	162
BFC1 - S		1391	1,338	1,401	1,217	1,171	1,226	1,043	1,003	1,051	869	836	876	696	669	701
BFC2 - L		108	121	133	161	181	200	215	242	267	289	302	334	323	363	400
BFC2 - M		546	613	678	478	537	593	410	460	508	341	383	423	273	307	339
BFC2 - S		2367	2,658	2,936	2,071	2,326	2,569	1,775	1,994	2,202	1,479	1,662	1,835	1,183	1,329	1,468
Total required amount of trucks per month																
BFC1 - Peak		1,775	1,707	1,768	1,593	1,532	1,605	1,411	1,357	1,421	1,228	1,181	1,237	1,046	1,006	1,053
BFC2 - Peak		3,020	3,393	3,747	2,710	3,044	3,362	2,400	2,696	2,977	2,089	2,347	2,592	1,779	1,999	2,207
Total required amount of trucks per day																
BFC1 - Peak		85	81	85	76	73	76	67	65	68	58	56	59	50	48	50
BFC2 - Peak		144	162	178	129	145	160	114	128	142	99	112	123	85	95	105
Total required amount of trucks per day BFC		228	243	264	205	218	237	181	193	209	158	168	182	135	143	155

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E.5. Detailed calculations regarding variable 14714393 - Improving the inbound system at fulfillment centers

Key ratios Peak months	1.5			1.6			1.7			1.8	
	nov-23	nov-24	nov-25	nov-23	nov-24	nov-25	nov-23	nov-24	nov-25	nov-23	nov-24
Operational days in one month											
Amount of items per pallet BFC1											
Amount of pallets per truck based on truckload (L/M/S)											
Amount of items per truck (L/M/S)											
Amount of items per pallet BFC2											
Amount of pallets per truck based on truckload (L/M/S)											
Amount of items per truck (L/M/S)											
Truckload distribution percentages											
Large	0.70			0.80			0.90			1.0	
Medium	0.15			0.10			0.05			-	
Small	0.15			0.10			0.05			-	
Key figures											
Total items per month	1,564,959	1,505,134	1,576,480	1,564,959	1,505,134	1,576,480	1,564,959	1,505,134	1,576,480	1,564,959	1,505,134
BFC1 - Peak	4,437,387	4,984,669	5,505,172	4,437,387	4,984,669	5,505,172	4,437,387	4,984,669	5,505,172	4,437,387	4,984,669
BFC2 - Peak											
Amount of items based on truckload distribution											
BFC1 - L	1,095,471	1,053,594	1,103,536	1,251,967	1,204,107	1,261,184	1,408,463	1,354,621	1,418,832	1,564,959	1,505,134
BFC1 - M	234,744	225,770	236,472	156,486	150,513	157,648	78,248	75,257	78,824	-	-
BFC1 - S	234,744	225,770	236,472	156,486	150,513	157,648	78,248	75,257	78,824	-	-
BFC2 - L	3,106,171	3,489,268	3,853,820	3,549,909	3,987,735	4,404,138	3,993,648	4,486,202	4,954,655	4,437,387	4,984,669
BFC2 - M	665,608	747,700	825,778	443,739	498,467	550,517	221,869	249,233	275,259	-	-
BFC2 - S	665,608	747,700	825,778	443,739	498,467	550,517	221,869	249,233	275,259	-	-
Required amount of trucks per month - peak											
BFC1 - L	221	213	223	253	243	265	265	274	287	316	304
BFC1 - M	120	116	121	80	77	81	40	39	40	-	-
BFC1 - S	522	502	525	348	334	350	174	167	175	-	-
BFC2 - L	377	423	467	430	483	534	484	544	601	538	604
BFC2 - M	205	230	254	137	153	169	68	77	85	-	-
BFC2 - S	887	997	1,101	592	665	734	296	332	367	-	-
Total required amount of trucks per month											
BFC1 - Peak	863	830	870	681	655	686	499	479	502	316	304
BFC2 - Peak	1,469	1,650	1,822	1,158	1,301	1,437	848	953	1,052	538	604
Total required amount of trucks per day											
BFC1 - Peak	41	40	41	32	31	33	24	23	24	15	14
BFC2 - Peak	70	79	87	55	62	68	40	45	50	26	29
Total required amount of trucks per day BFC	111	118	128	88	93	101	64	68	74	41	43
											47

Figure E.7: Overview of Excel calculations regarding variable 1: variations 1.5 until 1.8

The exact amount of trucks arriving in each time interval during an operational day also needs to be calculated again. These calculations are also done with the same approach as explained in Appendix F.1. In Figures E.8 and E.9 an overview of the Excel calculations can be seen which results in the truck arrival patterns for each variation and each scenario.

E.5. Detailed calculations regarding variable 14714393 - Improving the inbound system at fulfillment centers

1.1				1.3			
nov-23		Margin 5%		nov-23		Margin 5%	
Total required amount of trucks per day	205	215		Total required amount of trucks per day	158	166	
	Trucks [#]		Trucks per hour [#h]		Trucks [#]		Trucks per hour [#h]
	Peak	122	30		Peak	94	23
	Sub-Peak	81	20		Sub-Peak	63	16
	Non-Peak	12	6		Non-Peak	9	5
nov-24				nov-24			
nov-24		Margin 5%		nov-24		Margin 5%	
Total required amount of trucks per day	218	229		Total required amount of trucks per day	168	176	
	Trucks [#]		Trucks per hour [#h]		Trucks [#]		Trucks per hour [#h]
	Peak	130	32		Peak	100	25
	Sub-Peak	86	22		Sub-Peak	67	17
	Non-Peak	13	6		Non-Peak	10	5
nov-25				nov-25			
nov-25		Margin 5%		nov-25		Margin 5%	
Total required amount of trucks per day	237	248		Total required amount of trucks per day	182	191	
	Trucks [#]		Trucks per hour [#h]		Trucks [#]		Trucks per hour [#h]
	Peak	141	35		Peak	108	27
	Sub-Peak	94	23		Sub-Peak	72	18
	Non-Peak	14	7		Non-Peak	11	5
1.2				1.4			
nov-23		Margin 5%		nov-23		Margin 5%	
Total required amount of trucks per day	181	191		Total required amount of trucks per day	135	141	
	Trucks [#]		Trucks per hour [#h]		Trucks [#]		Trucks per hour [#h]
	Peak	108	27		Peak	80	20
	Sub-Peak	72	18		Sub-Peak	53	13
	Non-Peak	11	5		Non-Peak	8	4
nov-24				nov-24			
nov-24		Margin 5%		nov-24		Margin 5%	
Total required amount of trucks per day	193	203		Total required amount of trucks per day	143	150	
	Trucks [#]		Trucks per hour [#h]		Trucks [#]		Trucks per hour [#h]
	Peak	115	29		Peak	85	21
	Sub-Peak	77	19		Sub-Peak	57	14
	Non-Peak	11	6		Non-Peak	8	4
nov-25				nov-25			
nov-25		Margin 5%		nov-25		Margin 5%	
Total required amount of trucks per day	209	220		Total required amount of trucks per day	155	163	
	Trucks [#]		Trucks per hour [#h]		Trucks [#]		Trucks per hour [#h]
	Peak	125	31		Peak	92	23
	Sub-Peak	83	21		Sub-Peak	62	15
	Non-Peak	12	6		Non-Peak	9	5

Figure E.8: Overview of Excel calculations number of trucks required: variations 1.1 until 1.4

1.5							
nov-23		Margin 5%					
Total required amount of trucks per day		111	117				
		Trucks [#]	Trucks per hour [#h]				
Peak		66	17				
Sub-Peak		44	11				
Non-Peak		6	3				
nov-24		Margin 5%					
Total required amount of trucks per day		118	124				
		Trucks [#]	Trucks per hour [#h]				
Peak		70	18				
Sub-Peak		47	12				
Non-Peak		7	3				
nov-25		Margin 5%					
Total required amount of trucks per day		128	135				
		Trucks [#]	Trucks per hour [#h]				
Peak		76	19				
Sub-Peak		51	13				
Non-Peak		7	4				
1.6							
nov-23		Margin 5%					
Total required amount of trucks per day		88	92				
		Trucks [#]	Trucks per hour [#h]				
Peak		52	13				
Sub-Peak		35	9				
Non-Peak		5	3				
nov-24		Margin 5%					
Total required amount of trucks per day		93	98				
		Trucks [#]	Trucks per hour [#h]				
Peak		55	14				
Sub-Peak		37	9				
Non-Peak		5	3				
nov-25		Margin 5%					
Total required amount of trucks per day		101	106				
		Trucks [#]	Trucks per hour [#h]				
Peak		60	15				
Sub-Peak		40	10				
Non-Peak		6	3				
1.7							
nov-23		Margin 5%					
Total required amount of trucks per day		64	67				
		Trucks [#]	Trucks per hour [#h]				
Peak		38	10				
Sub-Peak		25	6				
Non-Peak		4	2				
nov-24		Margin 5%					
Total required amount of trucks per day		68	72				
		Trucks [#]	Trucks per hour [#h]				
Peak		41	10				
Sub-Peak		27	7				
Non-Peak		4	2				
nov-25		Margin 5%					
Total required amount of trucks per day		74	78				
		Trucks [#]	Trucks per hour [#h]				
Peak		44	11				
Sub-Peak		29	7				
Non-Peak		4	2				
1.8							
nov-23		Margin 5%					
Total required amount of trucks per day		41	43				
		Trucks [#]	Trucks per hour [#h]				
Peak		24	6				
Sub-Peak		16	4				
Non-Peak		2	1				
nov-24		Margin 5%					
Total required amount of trucks per day		43	45				
		Trucks [#]	Trucks per hour [#h]				
Peak		26	7,0				
Sub-Peak		17	5,0				
Non-Peak		3	2,0				
nov-25		Margin 5%					
Total required amount of trucks per day		47	49				
		Trucks [#]	Trucks per hour [#h]				
Peak		28	7,0				
Sub-Peak		19	4,7				
Non-Peak		3	2,0				

Figure E.9: Overview of Excel calculations number of trucks required: variations 1.5 until 1.8

F. Insights Experiments

F.1. Experiments - Not selected variations or combinations

F.1.1. Experiment 1 - Testing variations of the increase of truckloads fill

In this experiment it was tested what the impact was of increasing the number of trucks arriving with a higher truckload. This was done by, as explained before, increasing the number of trucks with a large truckload with 10% and reducing the trucks with a medium and small truckload with 5%. This has resulted in a range from 8 variations from 30% large truckloads trucks in 1.1 to 100% large truckloads trucks in 1.8. The results of this experiments have been provided for KPI 1 for SC1 in F.1, SC2 in F.2 and SC3 in F.3. It can be seen that all variations results in an enhanced system performance in such a way that there is an extreme unlikely probability that the capacity will be exceeded for the waiting area at the port and the dock (0%). As of variation 1.2 and 1.3 there is a 0% probability for every variation. Since the implementation of this could be quite challenging since the partners need to be convinced by bol.com to participate with this strategy, its need to be considered if the variations 1.4 until 1.8 are not too challenging and therefore necessary for bol.com since with variation 1.3 already a system performance is achieved in all scenarios. Therefore, in the context of this research its chosen to only choose for variation 1.1 until 1.3 resulting in the first three strategies.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table F.1: Experiment 1: SC1

Scenario nr.	Variation	Prob. of exceeding capacity		Amount of trucks exceeding	
		<i>Port</i>	<i>Dock</i>	<i>Port >15</i>	<i>Dock >5</i>
Base		16.3 %	0%	[1-8]	[0]
SC1	1.1	2.1%	0%	[1]	[0]
SC1	1.2	0%	0%	[0]	[0]
SC1	1.3	0%	0%	[0]	[0]
SC1	1.4	0%	0%	[0]	[0]
SC1	1.5	0%	0%	[0]	[0]
SC1	1.6	0%	0%	[0]	[0]
SC1	1.7	0%	0%	[0]	[0]
SC1	1.8	0%	0%	[0]	[0]

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock**Table F.2:** Experiment 1: SC2

Scenario nr.	Variation	Prob. of exceeding capacity		Amount of trucks exceeding	
		<i>Port</i>	<i>Dock</i>	<i>Port >15</i>	<i>Dock >5</i>
Base		33.4%	6.7%	[1-15]	[1]
SC2	1.1	8.3%	0%	[1-4]	[0]
SC2	1.2	0%	0%	[0]	[0]
SC2	1.3	0%	0%	[0]	[0]
SC2	1.4	0%	0%	[0]	[0]
SC2	1.5	0%	0%	[0]	[0]
SC2	1.6	0%	0%	[0]	[0]
SC2	1.7	0%	0%	[0]	[0]
SC2	1.8	0%	0%	[0]	[0]

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table F.3: Experiment 1: SC3

Scenario nr.	Variation	Prob. of exceeding capacity		Amount of trucks exceeding	
		Port	Dock	Port >15	Dock >5
Base	-	65.4%	13.9%	[1-30]	[1-3]
SC3	1.1	26.5%	11.1%	[1-11]	[1]
SC3	1.2	6.1%	0%	[1]	[0]
SC3	1.3	0%	0%	[0]	[0]
SC3	1.4	0%	0%	[0]	[0]
SC3	1.5	0%	0%	[0]	[0]
SC3	1.6	0%	0%	[0]	[0]
SC3	1.7	0%	0%	[0]	[0]
SC3	1.8	0%	0%	[0]	[0]

F.1.2. Experiment 2 - Testing the combination of increase truckloads and reduction service times

Testing the different combinations of increasing the trucks arriving with a large truckload together with the reduction of the service time results in the following conclusion. The results are only shown for scenario 3. Using the reduction of service time to 1.36 minutes has more impact than the reduction to 2.24 minutes when examining the results for KPI 2 in Figure H.7 and H.8. The variation in 2.2 results in a bigger reduction of the service time. However, this bigger reduction is considered as realistic for bol.com since its focused on optimizing the internal systems. Therefore its chosen to not consider the variations of 1.1 until 1.3 together with 2.1 in the strategies.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table F.4: Results of experiment 2

Scenario nr.	Variation nr.	Prob. of exceeding capacity (>15)		Amount of trucks exceeding	
		Port	Dock	Port	Dock
BASE	-	65.4 %	13.9%	[1-18]	[1-3]
SC3	1.1+2.1	0%	17.9%	[0]	[1-3]
SC3	1.1+2.2	0%	20.4%	[0]	[1-6]
SC3	1.2+2.1	0%	0%	[0]	[0]
SC3	1.2+2.2	0%	0%	[0]	[0]
SC3	1.3+2.1	0%	0%	[0]	[0]
SC3	1.3+2.2	0%	0%	[0]	[0]

KPI 2: Number of trucks parked at the waiting area at the port and dock

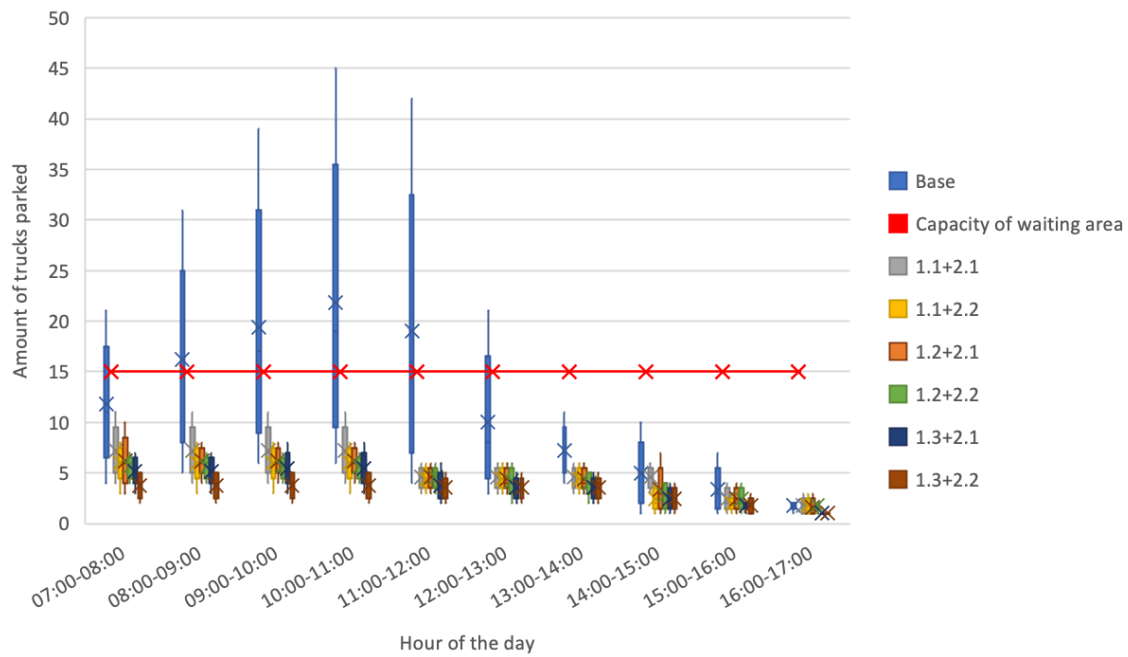


Figure F.1: Results experiment 2: Trucks parked in waiting area dock (KPI2)

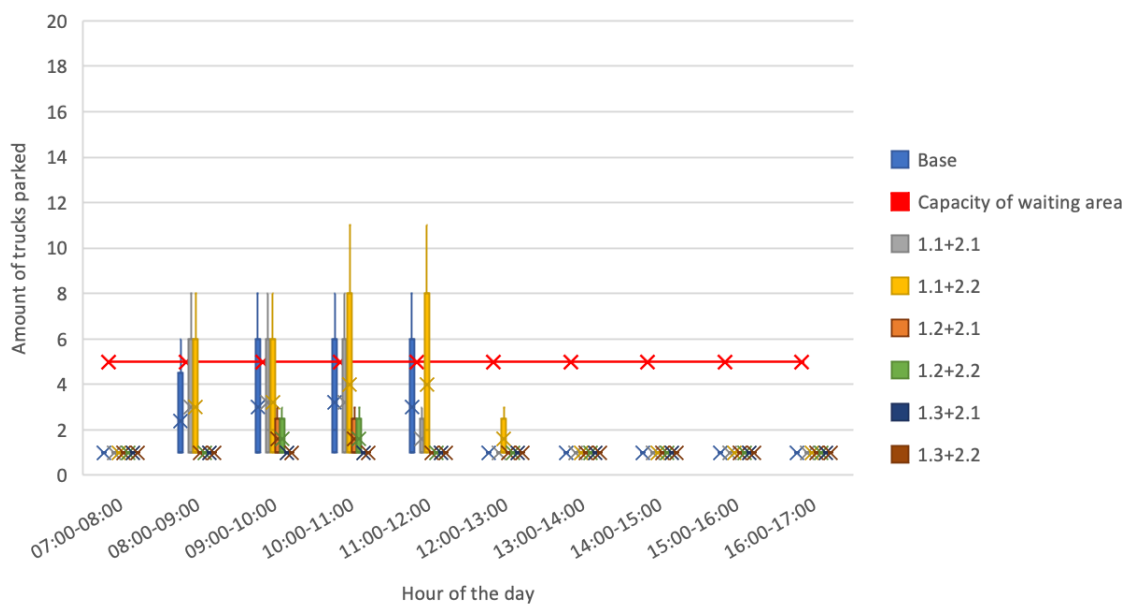
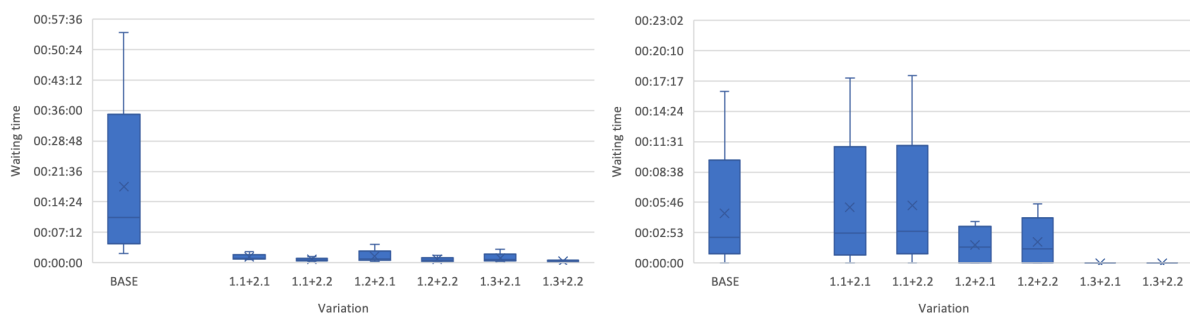


Figure F.2: Results experiment 2: Trucks parked in waiting area dock (KPI2)

KPI 3: Waiting time per truck in queue during arrival and enter process



(a) Results experiment 2: Waiting time per truck during arrival process

(b) Results experiment 2: Waiting time per truck during enter process

Figure F.3: Results experiment 2: Waiting time per truck (KPI 3)

F.1.3. Experiment 3 - Testing the combination of reduction of service time and reduction of the basic duration

While testing the different combinations of the reduction of the service time together with the reduction of the basic duration for KPI 2 as visible in Figure F.4 and F.5, it can be seen that there is not so much variation between the results of 3.1 and 3.2. Also when looking at KPI 3, the waiting time, no differences can be observed. Therefore, its chosen to include 3.1 in the combined strategies.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table F.5: Results of experiment 3

Scenario nr.	Variation nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		Port	Dock	Port	Dock
Base	-	65.4 %	13.9%	[1-18]	[1-3]
SC3	1.1+3.1	23.4%	0%	[1-9]	[0]
SC3	1.1+3.2	23.4%	0%	[1-9]	[0]
SC3	1.2+3.1	11.3%	0%	[1-2]	[0]
SC3	1.2+3.2	11.3%	0%	[1-2]	[0]
SC3	1.3+3.1	0%	0%	[0]	[0]
SC3	1.3+3.2	0%	0%	[0]	[0]

KPI 2: Number of trucks parked at the waiting area at the port and dock

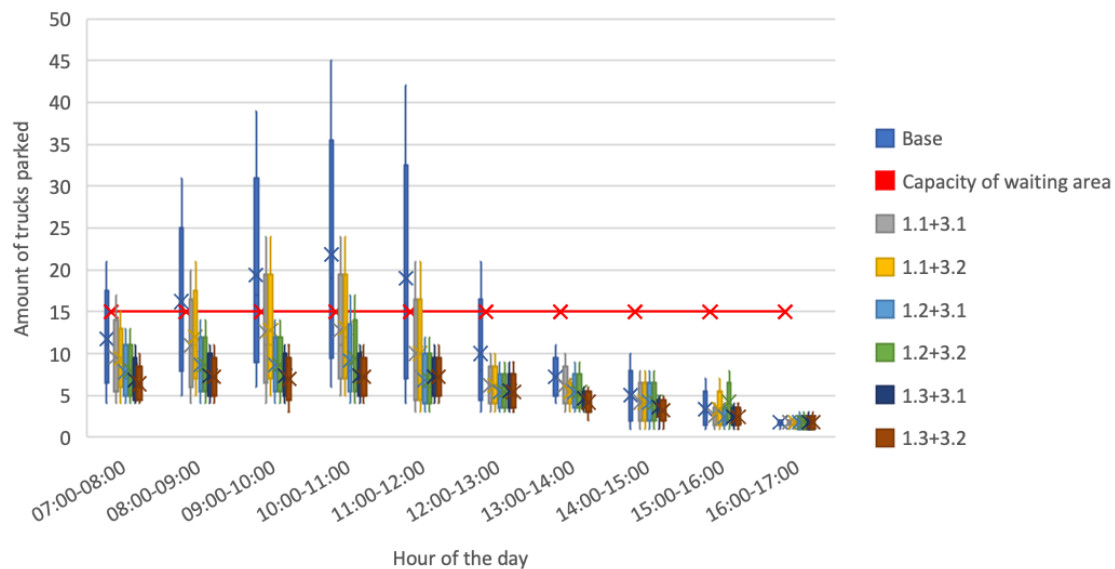


Figure F.4: Results experiment 3: Trucks parked in waiting area dock (KPI2)

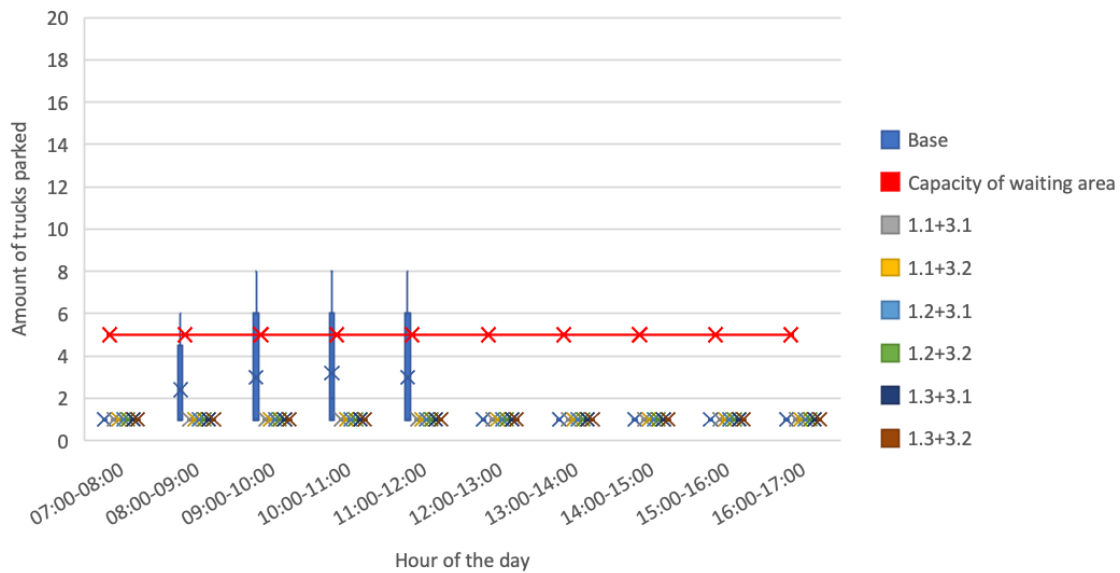
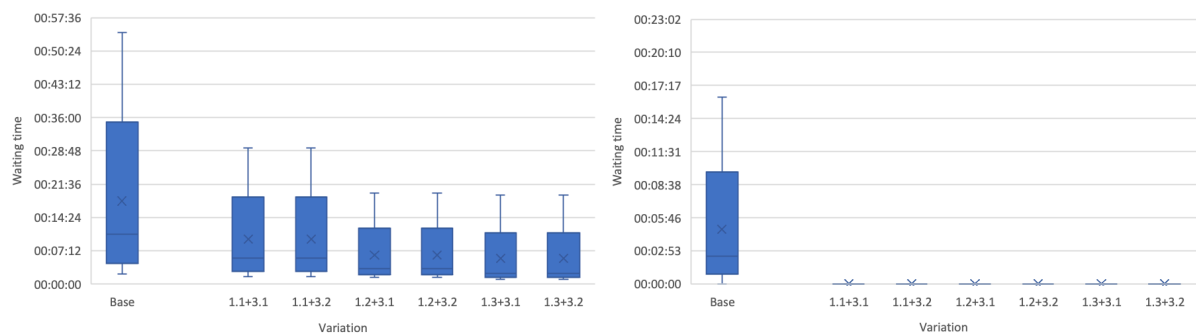


Figure F.5: Results experiment 3: Trucks parked in waiting area dock (KPI2)

KPI 3: Waiting time per truck in queue during arrival and enter process



(a) Results experiment 3: Number of trucks parked in waiting area port (b) Results experiment 3: Number of trucks parked in waiting area dock

Figure F.6: Results experiment 3: Waiting time per truck (KPI 3)

F.1.4. Experiment 4 - Testing reduction of service time and reduction basic duration

It can be seen that testing the different combinations that the reduction of the service time to 1.36 minutes and the reduction of the basic duration to 5 minutes has the biggest impact when analyzing the results for KPI 2 and KPI 3. Therefore, its chosen to choose this combination as input for the strategy.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table F.6: Results of experiment 4

Scenario nr.	Variation nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		Port	Dock	Port	Dock
Base	-	65.4 %	13.9%	[1-18]	[1-3]
SC3	3.1+2.1	0%	0%	[0]	[0]
SC3	3.1+2.2	0%	0%	[0]	[0]
SC3	3.2+2.1	0%	0%	[0]	[0]
SC3	3.2+2.2	0%	0%	[0]	[0]

KPI 2: Number of trucks parked at the waiting area at the port and dock

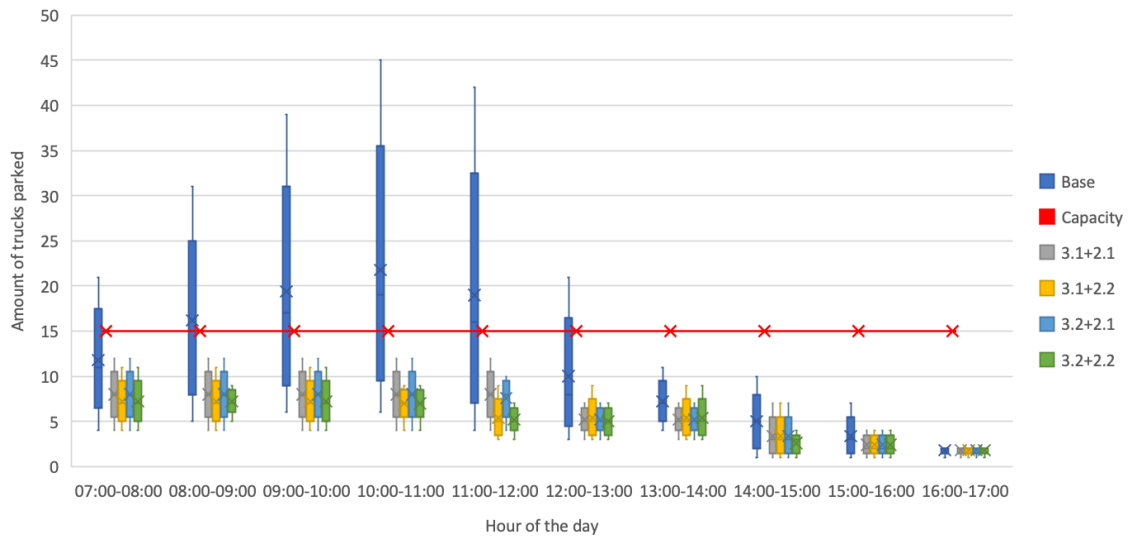


Figure F.7: Results experiment 4: Trucks parked in waiting area dock (KPI2)

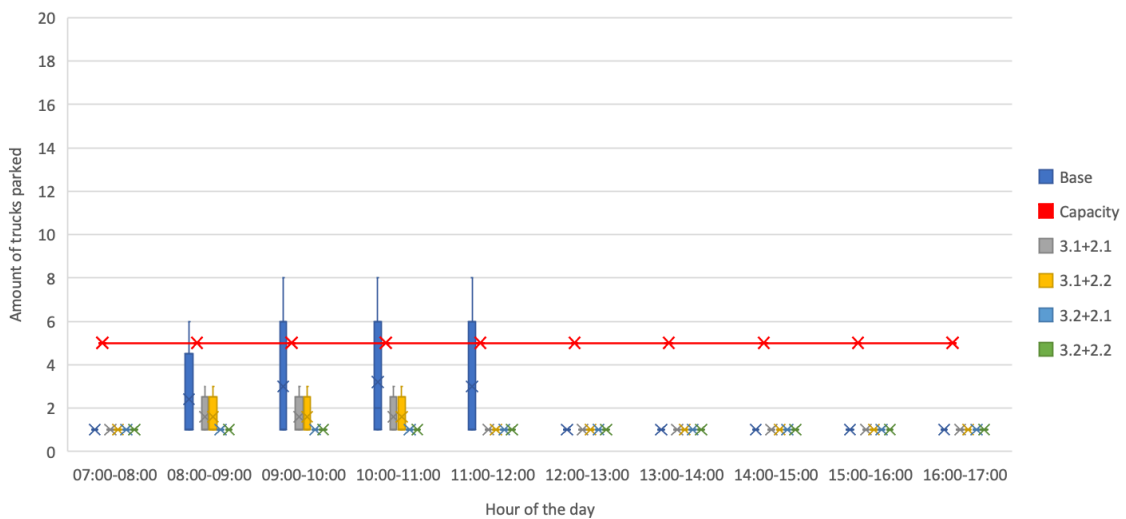


Figure F.8: Results experiment 4: Trucks parked in waiting area dock (KPI2)

KPI 3: Waiting time per truck in queue during arrival and enter process

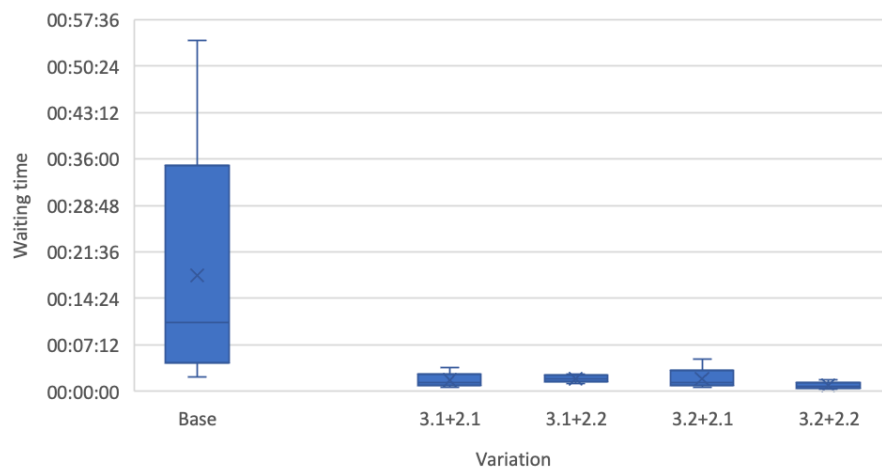


Figure F.9: Results experiment 4: Waiting time per truck during arrival process (KPI 3)

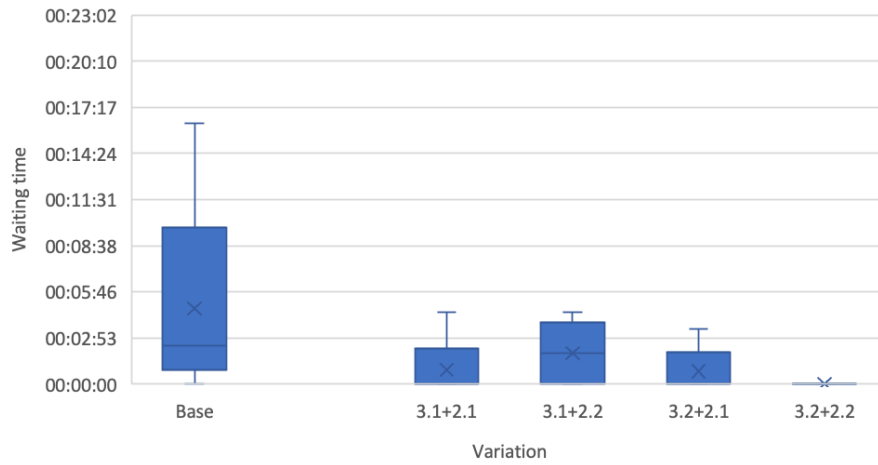


Figure F.10: Results experiment 4: Waiting time per truck during enter process (KPI 3)

G. Results Individually Strategies for SC1 en SC2

In this chapter the results of the experiments of the individually strategies will be shown for scenario 1 and scenario 2. The explanation of the results is the same as for scenario 3 and will therefore not be repeated again. The only difference between the results for scenario 3 and scenario 1 and 2, is that some strategies already result in an improvement compared to scenario 3. This can be attributed to the fact that there are less trucks arriving in scenario 1 and scenario 2.

G.1. Scenario 1

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table G.1: Results individually strategies for SC1 (KPI 1)

Scenario nr.	Strategy nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		<i>Port</i>	<i>Dock</i>	<i>Port >15</i>	<i>Dock >5</i>
Base	-	16.3%	0%	[1-8]	[0]
SC1	1.1	2.1%	0%	[1]	[0]
SC1	1.2	0%	0%	[0]	[0]
SC1	1.3	0%	0%	[0]	[0]
SC1	2.1	0%	0%	[0]	[0]
SC1	2.2	0%	0%	[0]	[0]
SC1	3.1	16.3%	0%	[1-8]	[0]
SC1	3.2	16.3%	0%	[1-8]	[0]
SC1	4	0%	0%	[0]	[0]

KPI 2: Number of trucks parked at the waiting area at the port and dock

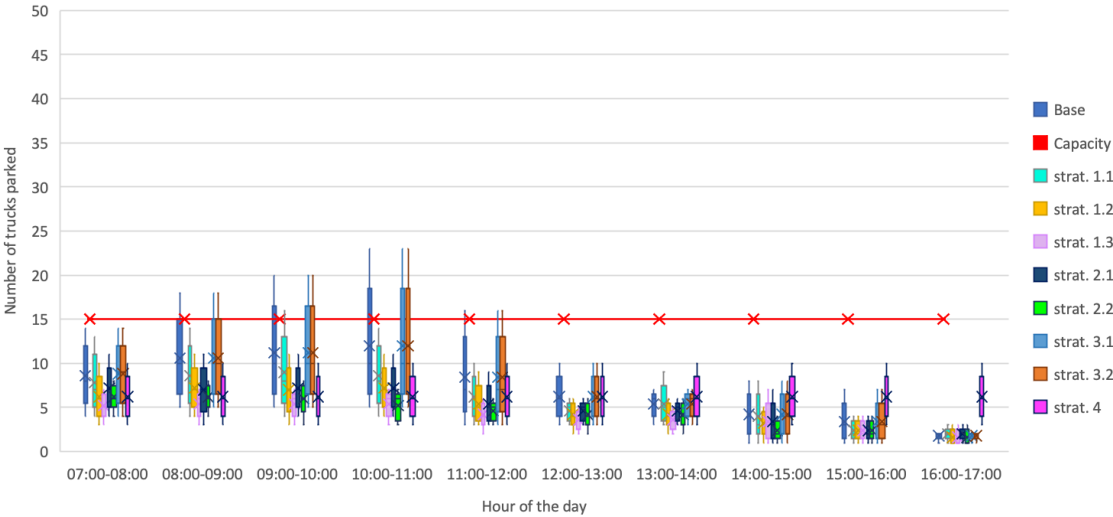


Figure G.1: Results individually strategies for SC1: Trucks parked in waiting area dock (KPI2)

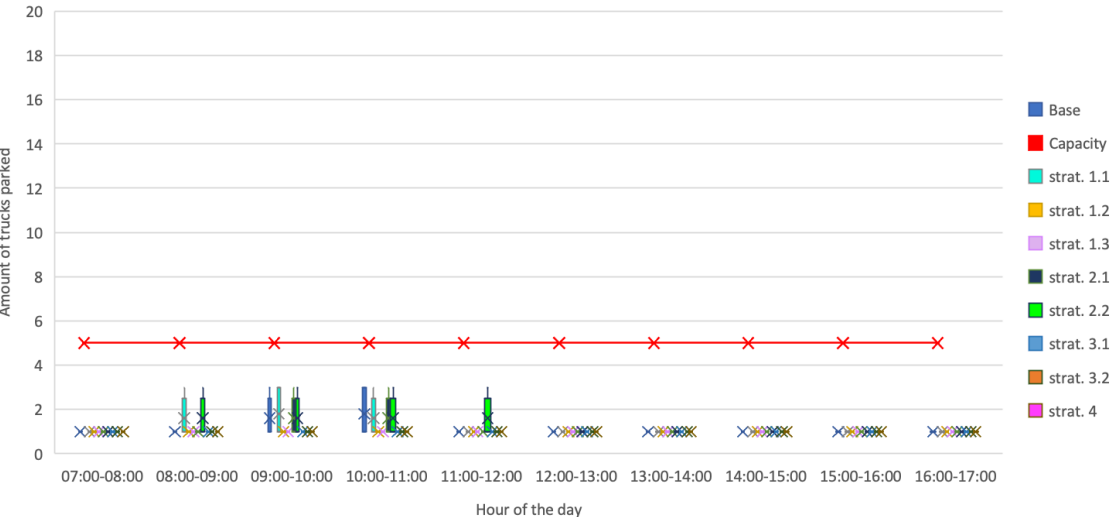


Figure G.2: Results individually strategies for SC1: Trucks parked in waiting area dock (KPI2)

KPI 3: Waiting time per truck in queue during arrival and enter process

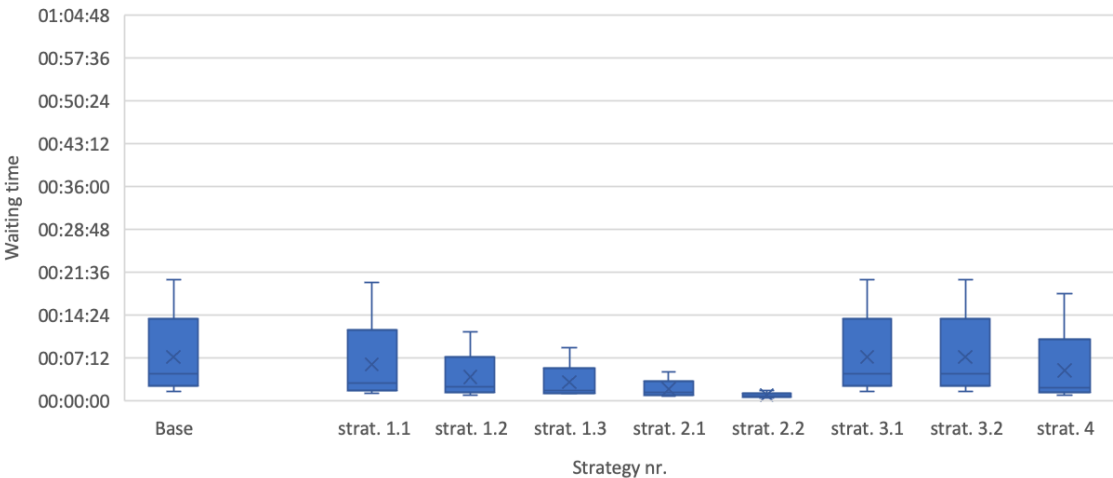


Figure G.3: Results individually strategies for SC1: Waiting time per truck during arrival process (KPI 3)

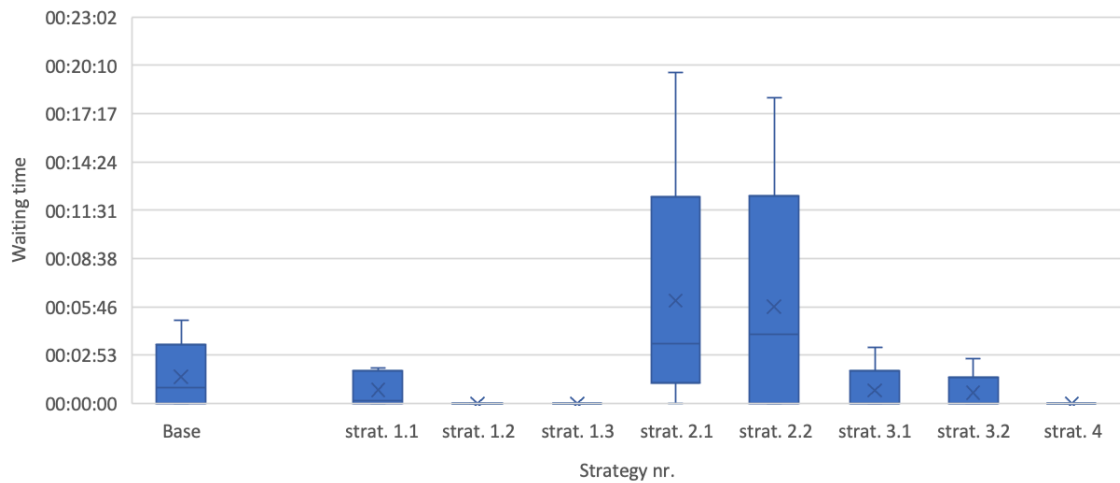


Figure G.4: Results individually strategies for SC1: Waiting time per truck during enter process (KPI 3)

G.2. Scenario 2

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table G.2: Results individually strategies for SC2 (KPI 1)

Scenario nr.	Strategy nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		Port	Dock	Port >15	Dock >5
Base	-	33.4%	6.7%	[1-15]	[1]
SC2	1.1	8.3%	0%	[1-4]	[0]
SC2	1.2	0%	0%	[0]	[0]
SC2	1.3	0%	0%	[0]	[0]
SC2	2.1	0%	12.2%	[0]	[1-3]
SC2	2.2	0%	13.8%	[0]	[1-3]
SC2	3.1	33.4%	0%	[1-15]	[0]
SC2	3.2	33.4%	0%	[1-15]	[0]
SC2	4	0%	0%	[0]	[0]

KPI 2: Number of trucks parked at the waiting area at the port and dock

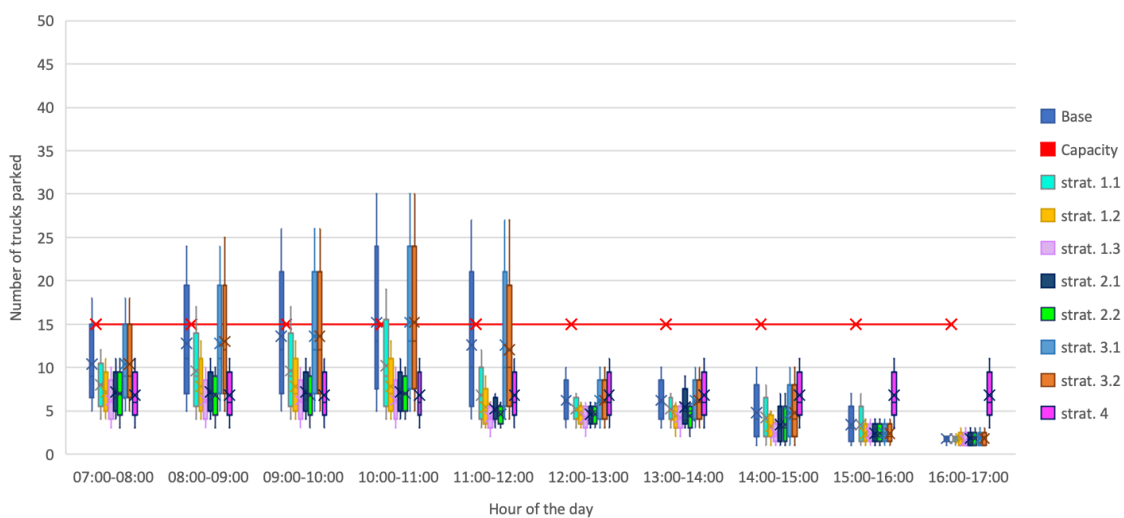


Figure G.5: Results individually strategies for SC2: Trucks parked in waiting area dock (KPI2)

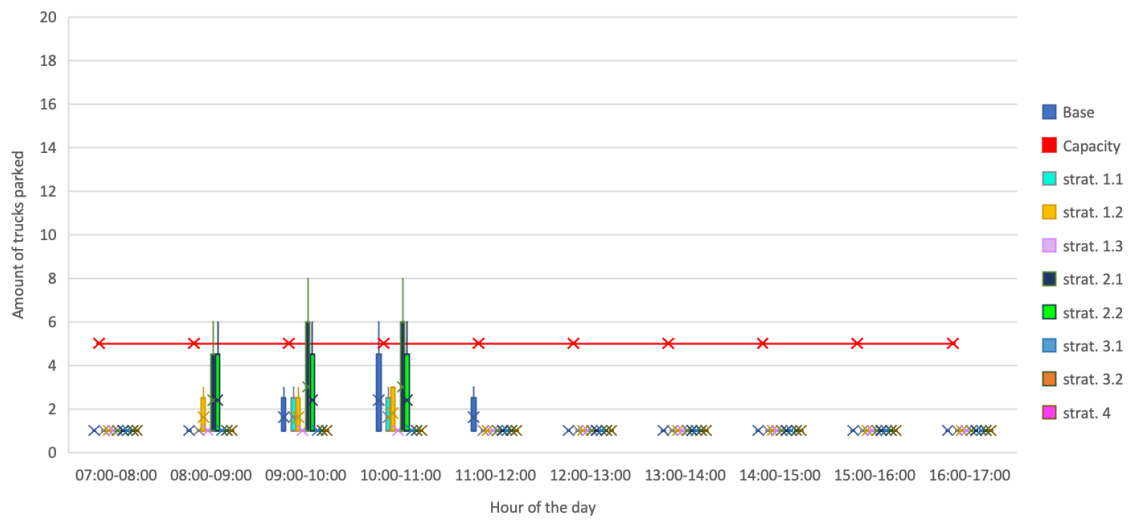


Figure G.6: Results individually strategies for SC2: Trucks parked in waiting area dock (KPI2)

KPI 3: Waiting time per truck in queue during arrival and enter process

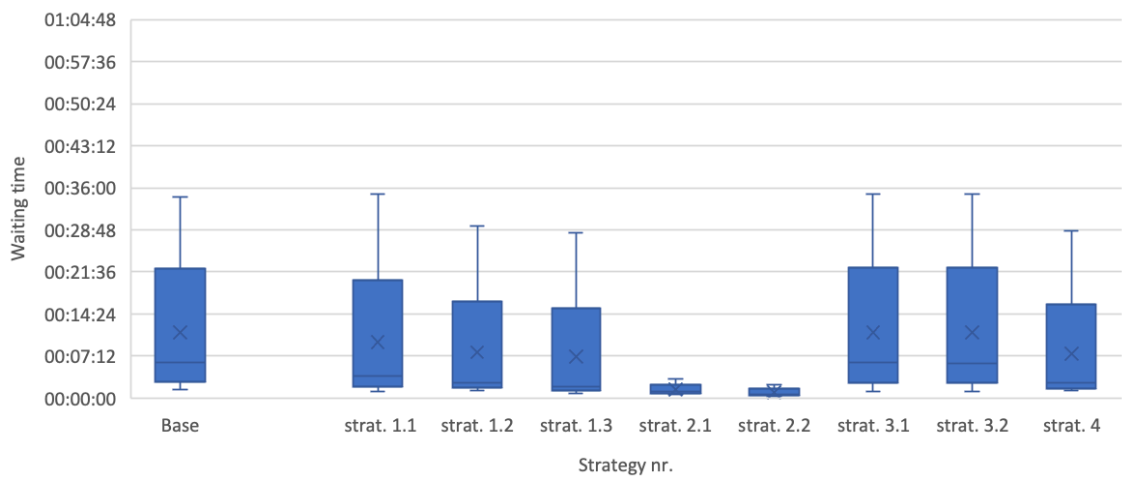


Figure G.7: Results individually strategies for SC2: Waiting time per truck during arrival process (KPI 3)

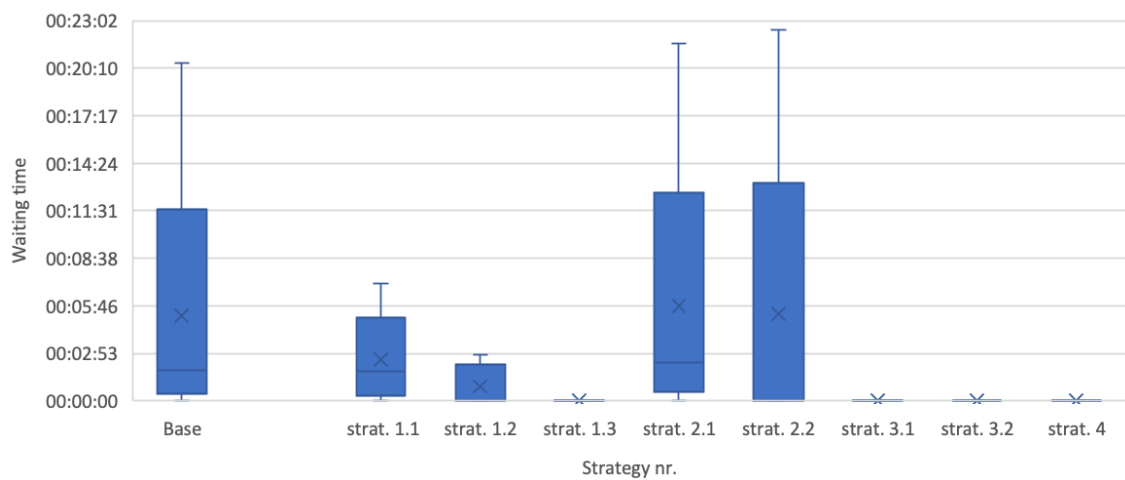


Figure G.8: Results individually strategies for SC2: Waiting time per truck during enter process (KPI 3)

H. Results Interactive Strategies for SC1 and SC2

In this chapter the results of the experiments of the interactive strategies will be shown for scenario 1 and scenario 2. The explanation of the results is the same as for scenario 3 and will therefore not be repeated again. The only difference between the results for scenario 3 and scenario 1 and 2, is that some strategies already result in an improvement compared to scenario 3. This can be attributed to the fact that there are less trucks arriving in scenario 1 and scenario 2.

H.1. Scenario 1

For scenario 1 it can be seen that compared to scenario 3, all strategies result in an enhanced system performance of the inbound system across all KPIs. For strategy 5 this can be attributed to the fact that the arrival rate with the 30% increase in trucks arriving with a large truckload, is equal to 30 or lower in scenario 1. Also, strategy 8 and 9 do result in a system performance and can be attributed to again the reduction of the arrival rate to 30 or lower. Focusing at KPI 3, the waiting time per trucks it can be seen that with the implementation of strategy 8 and 9 there is a reduced waiting time, but still relatively high compared to the other strategies.

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table H.1: Results interactive strategies for SC1 (KPI 1)

Scenario nr.	Strategy nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		<i>Port</i>	<i>Dock</i>	<i>Port >15</i>	<i>Dock >5</i>
Base	-	16.8%	0%	[1-8]	[0]
SC1	5	0%	0%	[0]	[0]
SC1	6	0%	0%	[0]	[0]
SC1	7	0%	0%	[0]	[0]
SC1	8	0%	0%	[0]	[0]
SC1	9	0%	0%	[0]	[0]
SC1	10	0%	0%	[0]	[0]
SC1	11	0%	0%	[0]	[0]
SC1	12	0%	0%	[0]	[0]

KPI 2: Number of trucks parked at the waiting area at the port and dock

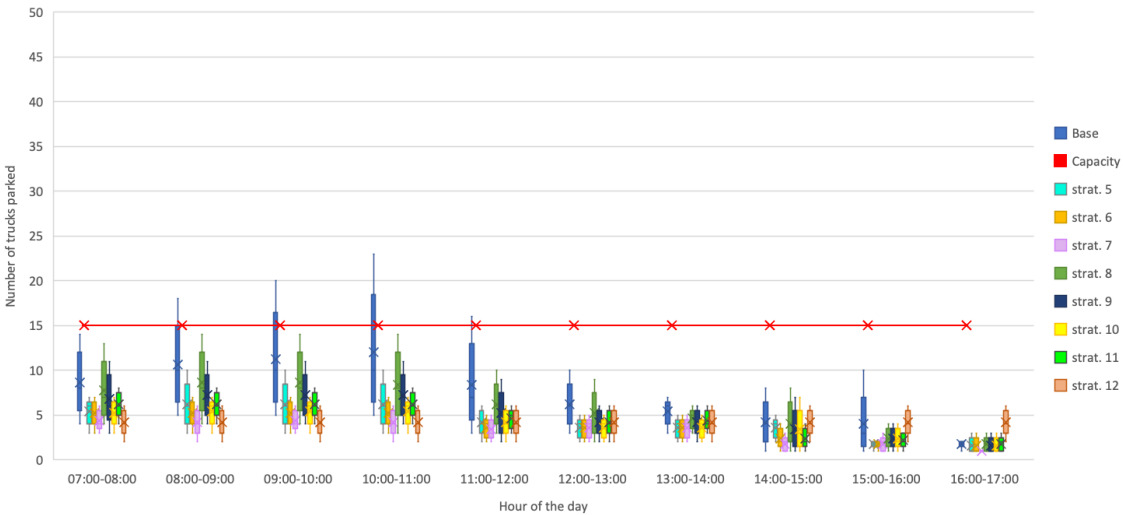


Figure H.1: Results interactive strategies for SC1: Trucks parked in waiting area dock (KPI2)

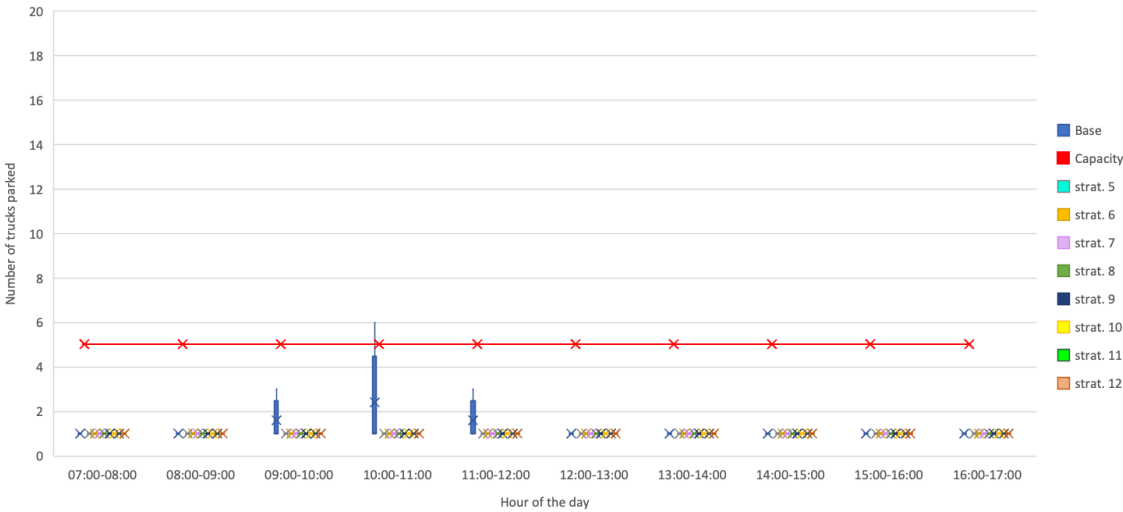


Figure H.2: Results interactive strategies (SC1): Trucks parked in waiting area dock (KPI2)

KPI 3: Waiting time per truck in queue during arrival and enter process

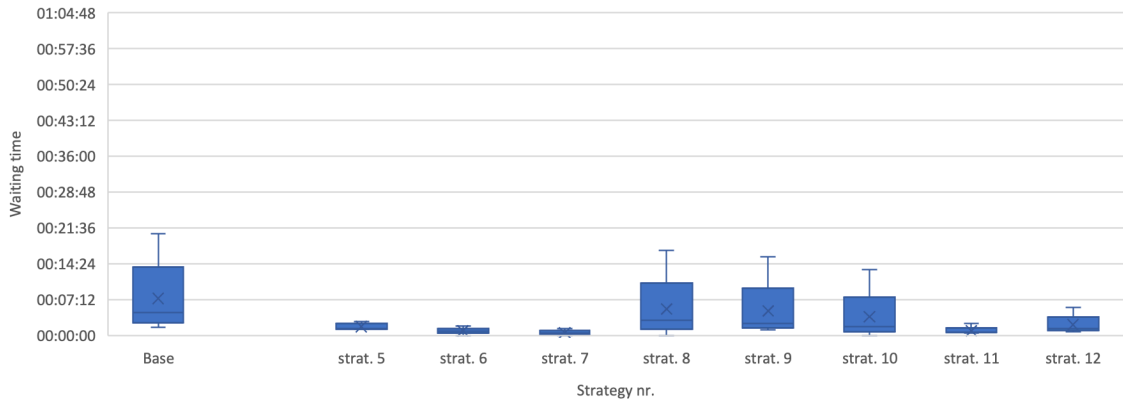


Figure H.3: Results interactive strategies (SC1): Waiting time per truck during arrival process (KPI 3)

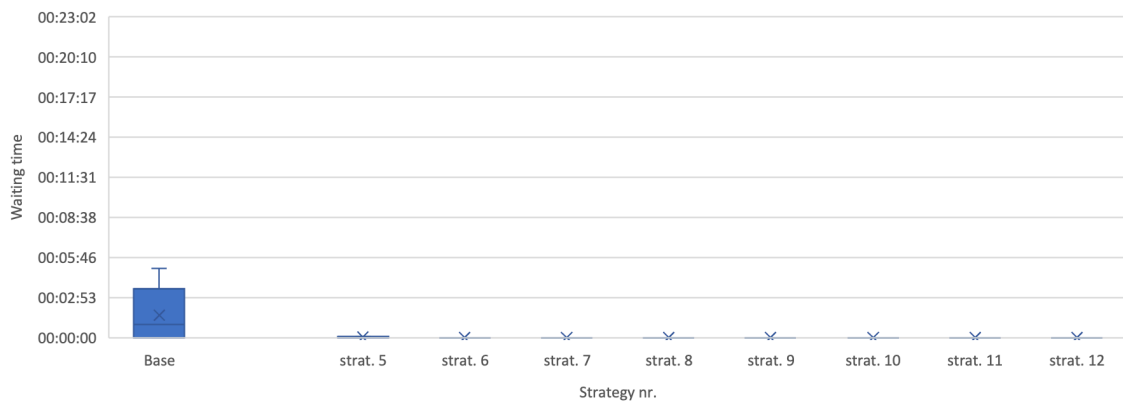


Figure H.4: Results interactive strategies (SC1): Waiting time per truck during enter process (KPI 3)

H.2. Scenario 2

KPI 1: Probability of exceeding the capacity of the waiting area the port and dock

Table H.2: Results interactive strategies for SC2 (KPI 1)

Scenario nr.	Strategy nr.	Prob. of exceeding capacity		Amount of trucks exceeding	
		Port	Dock	Port >15	Dock >5
Base	-	33.4%	6.7%	[1-15]	[1]
SC2	5	0%	0%	[0]	[0]
SC2	6	0%	0%	[0]	[0]
SC2	7	0%	0%	[0]	[0]
SC2	8	10.4%	0%	[1-2]	[0]
SC2	9	0%	0%	[0]	[0]
SC2	10	0%	0%	[0]	[0]
SC2	11	0%	0%	[0]	[0]
SC2	12	0%	0%	[0]	[0]

KPI 2: Number of trucks parked at the waiting area at the port and dock

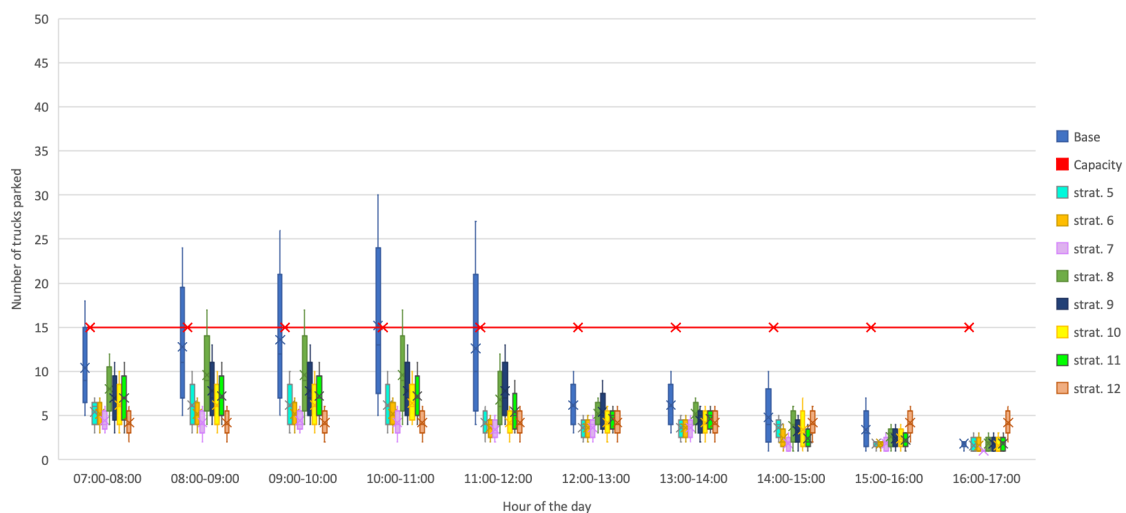


Figure H.5: Results interactive strategies for SC2: Trucks parked in waiting area dock (KPI2)

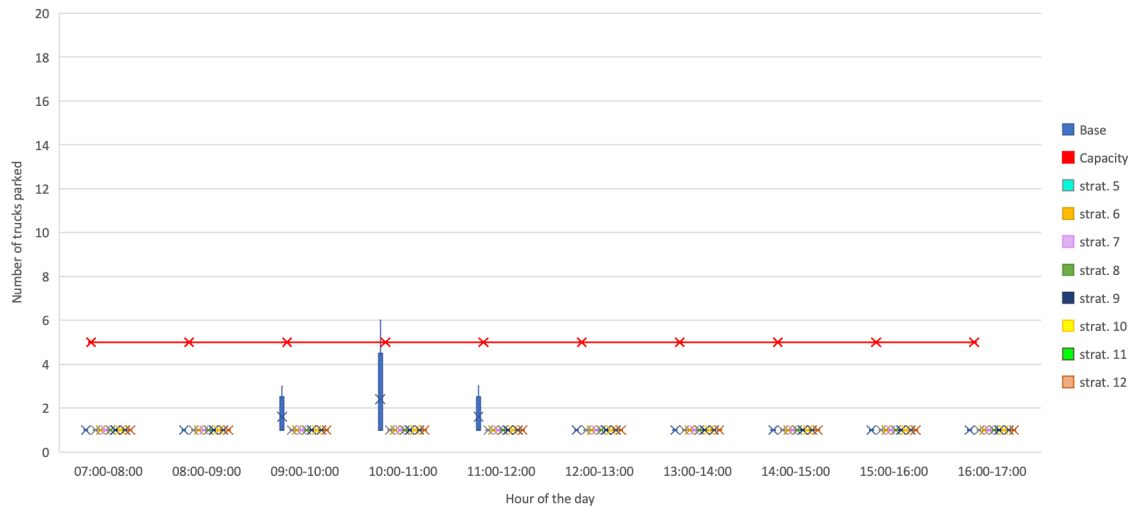


Figure H.6: Results interactive strategies for SC2: Trucks parked in waiting area dock (KPI2)

KPI 3: Waiting time per truck in queue during arrival and enter process

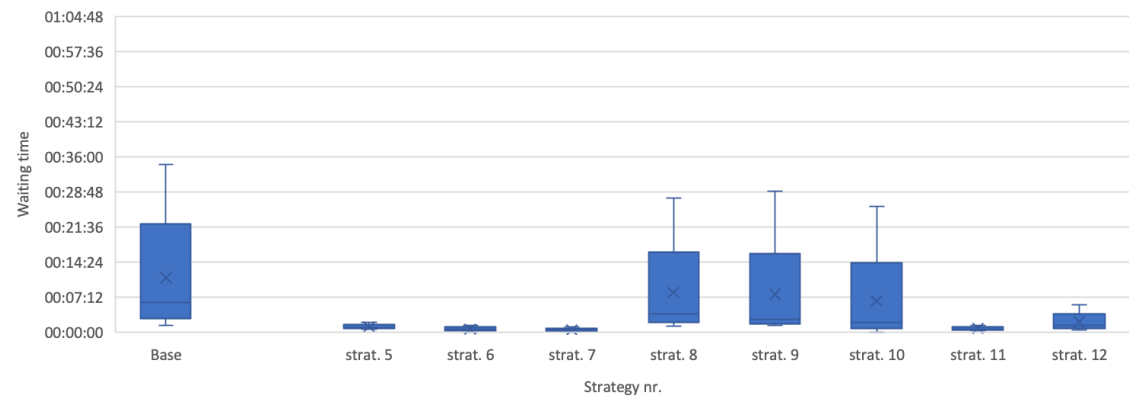


Figure H.7: Results interactive strategies for SC2: Waiting time per truck during arrival process (KPI 3)

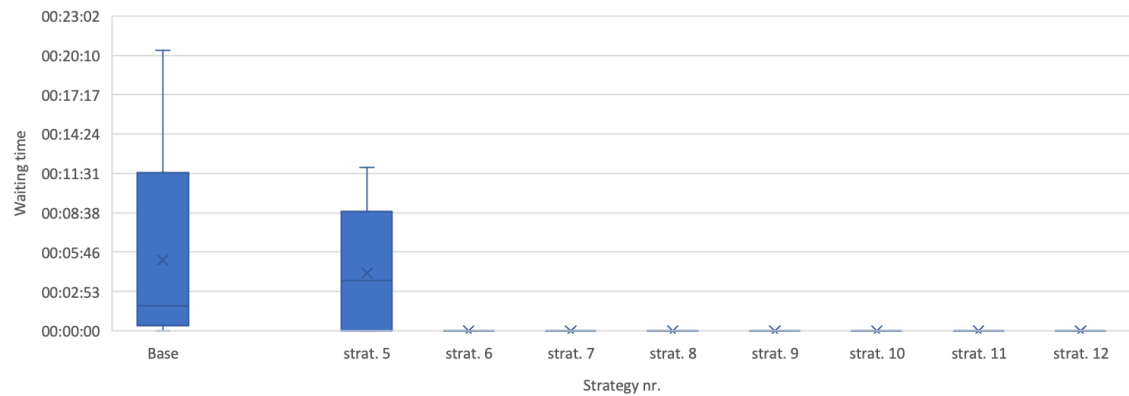


Figure H.8: Results interactive strategies for SC2: Waiting time per truck during enter process (KPI 3)