MASTER

Preventing blocking in intermodal supply chains
a simulation study

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Preventing blocking in intermodal supply chains: A simulation study

by

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Abstract
This study investigates the risk of blocking of production lines, caused by saturated inventory buffers in intermodal supply chains. Such supply chains contain relatively much uncertainty and complexity. The risk of blocking and the underlying causes are therefore analyzed with discrete event simulation. From this analysis, measures that reduce the risk of blocking are determined and evaluated with a scenario analysis.
This study leads to managerial insights for the case study company. Moreover, the research aims at generalizing the results by expressing the required inventory capacity to prevent blocking as a percentage of the average inventory level.
Management summary

Research

Intermodal supply chains include disruptions due to complexity and a stochastic context. These disruptions might cause saturation of a decoupling point. When such a decoupling point is located after production lines, this saturation might lead to blocking of production lines. Intermodal supply chains are complex and include much variability, which makes determining the risk of blocking of production lines difficult. This study aims to determine the risk of blocking, inventory capacity required to prevent blocking and possible improvements to reduce this risk for a case study context and the general case.

Case study

This thesis contains a case study, which is the intermodal export supply chain of Heineken, starting at the brewery in Zoeterwoude, Netherlands. In order to include the complexity and uncertainty in the supply chain, a simulation model is built, based on the eight-step Simulation Model Development Process of Manuj et al. (2009). The simulation model outcome is the inventory level, which is written to a data file. This writing mechanism is crucial in analyzing the inventory level, including a subdivision of inventory, which are:

- Inventory due to blockage goods
- Inventory due to quarantine goods
- Inventory due to inspections
- Conventional inventory (which includes products for road transport only)
- Copack inventory (which includes promotion products with a sample of a new product)
- Inventory due to container unavailability
- Inventory due to delays, which is split into regular and mechanical pallet flows.

Simulation result

The result of the simulation model is a 97.5% confidence bound of the inventory capacity performance, ICP(X), which is defined as the percentage of time that warehouse management employees do not have to intervene to prevent blocking of production lines. This 97.5% confidence bound of the ICP(X) for the current warehouse operation is depicted in figure 1. The current inventory capacity is 4300 pallets and the corresponding ICP(4300) is 69.8%. From figure 1, we can conclude that an ICP of 99% is obtained with an inventory capacity of 6050 pallets, which would require an increase of 1750 pallets compared to the current situation.

Figure 1: ICP(X) in current warehouse operation
Scenario analysis
External warehousing might provide this capacity. In practice, rework, such as transferring goods to other parts of the company’s site, is executed to obtain a better performance. Executing rework and external warehousing are expensive and require (human) resources. Another way to obtain a better ICP(X) is to structurally reduce the inventory level and therefore the risk of blocking. An analysis of the subdivision of inventory in situations of a saturated inventory, shows four factors that contribute most to the total amount of inventory:
1. Conventional goods (62%)
2. Quarantines (15%)
3. Blockages (8%)
4. Copack goods (6%)

Different scenario analyses are conducted to find measures to improve the ICP(X) curve. Varying the throughput time of conventional goods provides the largest improvement of the ICP(X) curve and the result is depicted in figure 2. The current throughput time is regulated by the Heineken drumbeat which means goods can only be transported in the week after the production week. This rhythm causes conventional goods to spend 5,5 days on average in the inventory. Reducing the throughput time results in higher values for the ICP(X), as can be seen in figure 2.

The second important scenario result considers the copack process. Copack goods only account for 0,6% of the total volume, but constitute 6% of the average inventory level when the maximum inventory capacity is exceeded. Moreover, demand planners predict an increase in the amount of copack goods in the coming years. These goods cause much inventory due to the handling process, which includes waiting until the product is transported to the copack company, returning to the brewery and waiting until the product is exported. Changing this process to a process with direct export from the copack company and no return to the brewery (step 1), or even to a process where copack goods do not spend time in the inventory (step 1 + 2), provides an ICP(X) improvement which depicted in figures 3 and 4 respectively.
Decreasing the amount of quarantine arrivals is another measure to improve the ICP(X), as is shown in figure 5. This can be realized by loading and transporting quarantine goods while the quality checks are executed, which is internally known as the “rappido-process”. This scenario provides a warning as well, since the ICP(X) decreases significantly as the amount of quarantine arrivals increases.

The final important result suggests a reduction in the amount of conventional goods that are produced. This is realized by changing the delivery process from transport by truck to containerized transport by barges. The ICP(X) improvement that comes with this measure is relatively large, as is presented in figure 6; however, realizing this can be expensive.

**Conclusion**

In conclusion, a simulation study was used to determine the current inventory capacity performance of the case study’s situation. An analysis of the inventory level, possible measures to improve the ICP(X) and a scenario analysis was conducted.

Moreover, the results might be generalized by expressing the required inventory capacity to prevent blocking as a percentage of the average inventory. The current situation includes an average inventory of 3063 pallets and requires an inventory capacity of 7450 pallets to prevent blocking, which is 243% of the average inventory. When we assume that conventional and copack goods, which do not use the intermodal supply chain, are placed in another warehouse, the case study becomes more representative for the general case. The result is that an intermodal supply chain requires an inventory capacity of 328% of the average inventory to prevent blocking.
Preface

Eindhoven, March 2014

This report is the final result of my Master thesis project which I conducted in partial fulfilment of the degree of Master of Science in Operations Management and Logistics at Eindhoven University of Technology.

With this master thesis project, I was finally able to bring the theories from many bachelor and master courses into practice. I want to thank Wilko Sierksma for the opportunity to do this within the Customer Service and Logistics department at the Heineken brewery in Zoeterwoude, Netherlands. I appreciate the purchase of the professional Arena license which was at my disposal during the project, next to other facilities such as a TPM training.

I want to thank my daily supervisor at Heineken, Ad van Delzen, for his guidance, suggestions and help during the development of the simulation model and interpretation of the results. I enjoyed working with multiple experts in logistics and I am grateful for the inspiring and pleasant environment in which I was allowed to conduct my research.

I would like to thank my first supervisor from the university, Peter de Langen, for his ideas, direction and enthusiasm. Moreover I want to thank you for arranging the initial contact with Heineken, which provided me with their assignment in the first place. Furthermore, I want to thank Remco Dijkman, as my second supervisor, for critical reviews and suggestions.

Conducting the research at Heineken was challenging, but especially the process of writing this report was quite difficult sometimes. I want to thank my wife, Joanne, for encouraging and supporting me during this period. You gave me new energy when I needed it the most and boosted my discipline whenever I lacked it.

With this Master thesis project, my years as a student have ended and a new period commences. I want to thank friends, roommates, fellow students and family for supporting me and enjoying good times during my period as a student. I especially want to thank my parents for their interest and encouragements throughout all my years of schooling.

Wessel de Jager
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1. Introduction

1.1. Context
Manufacturing systems often include a decoupling point at the end of the production line. Produced goods can be placed in inventory when direct transport is unavailable. This way, the decoupling point enables a continued output of products and an improved availability of the manufacturing system as a whole. Due to many reasons, such as failures in the transport process, goods cannot leave the system and the inventory might become saturated. As a result, production lines are blocked and valuable production time is lost. Blocking might be prevented by transferring goods from the inventory to external warehouses. Although this might be less expensive than shutting down production lines, it is still costly and requires much handling. An important variable in examining blocking of production is the maximum inventory capacity available for produced goods, since the risk of blocking decreases when the inventory capacity is increased.

The risk of blocking is an important issue in many supply chains. This study investigates the blocking effect in intermodal supply chains specifically. A supply chain is intermodal when a combination of at least two modes of transport is utilized in a single transport chain, without change of container for the goods (Macharis & Bontekoning, 2004). The main part of the supply chain should be traveled by rail, inland waterway or ocean-going vessel. Only a short part of the transport chain can be traveled by road. Intermodal supply chains (ISC’s) often include much uncertainty and disruption risks due to high complexity (Carvalho et al., 2011). These disruptions negatively influence profitability, operating income, sales, cost structure, assets and inventories (Carvalho et al. 2011). The latter is of much interest for this thesis. Disruptions, such as delays in transportation, might result in a higher inventory level, which increases the risk of blocking. Because of the complexity of ISC’s, it is hard to determine how big the risk of blocking actually is and how much inventory capacity is required to prevent blocking.

In this study, the risk of blocking in an intermodal supply chain, which depends on the inventory capacity, is calculated. This means that the inventory capacity that is required to prevent blocking can be calculated as well. Moreover, measures that reduce the risk of blocking are presented and examined. With these results, the buffer might be redesigned to improve the availability of the system as a whole, which corresponds to the buffer design for availability paradigm presented by Battini et al. (2008).

1.2. Case study
The described situation of an intermodal supply chain with a high risk of blocking can be found in the export supply chain of the Heineken brewery in Zoeterwoude, Netherlands. After the beer is brewed and packaged, a decoupling point is maintained in order to ensure a continued operation. The brewed goods are transported to the harbor of Rotterdam or Antwerp via an intermodal supply chain.

The first part of the supply chain is a 17 minute truck drive from the brewery to the inland terminal Alpherium in Alphen aan den Rijn. At the Alpherium, goods are transferred onto barges that ship the goods to the harbor. The transport continues with ocean-going vessels, however; this part is not included in this case study. Barges that transported the goods to the harbor return to the Alpherium with empty containers that are unloaded and transported back to the brewery by truck where the cycle starts over.
Similar to what was suggested in literature, Heineken encounters disruptions in the supply chain due to intermodal characteristics such as the cooperation with the inland terminal or delays in handling processes. These disruptions sometimes cause high inventory levels because continuing transport is disabled or delayed. Due to these disruptions and other factors that influence the amount of inventory, Heineken faced blocking of production lines during the seasonal peak in May 2012. The goal of the case study at Heineken is to determine the inventory capacity required to prevent blocking and to identify possible measures to reduce the risk of blocking without having to increase the inventory capacity.

1.3. Approach
The complex and stochastic context of this study requires an approach that is able to include these characteristics. Discrete event simulation (DES) is suitable for investigating such complex and stochastic processes, according to multiple researchers (Persson & Araldi, 2007; Manuj et al., 2009; Kelton et al., 2010). Developing a valid simulation model is time-consuming. However, once the model is established, it is relatively easy to change several parameters and conduct scenario analyses of possible improvements (Kelton et al., 2010). These scenarios can often not be tested in reality, because the operation cannot be interrupted (Manuj et al., 2009). Observing results from different scenarios is fast due to the ability to compress time (Kelton et al., 2010), which makes simulation a powerful research and decision making tool (Longo & Mirabelli, 2007).

Discrete event simulation will be used to investigate the case study that was briefly described in chapter 1.2. Conclusions from this research can be used in the case study’s context. Moreover, general conclusions for other intermodal supply chains will be derived from the case study results.

1.4. Structure
This thesis continues with chapter 2, which includes the research design with research questions and steps. In chapter 3, the Heineken context will be described. The simulation model development process will be described in chapter 4. The result of this simulation study will be discussed in chapter 4.7. Different scenarios, including their results, will be discussed in chapter 5. The conclusions are drawn in chapter 6, both for the case study and the general case. Chapter 7 provides suggestions for future research. The references are presented in chapter 8, followed by chapter 9, which includes all abbreviations that were used. Finally, chapter 9 contains appendix A with the conceptual model.
2. Research design

2.1. Problem definition
Intermodal supply chains come with high risk of disturbances due to complexity and involvement of multiple parties. Therefore, the risk of blocking is high in ISC’s, especially when the inventory capacity is relatively low. When inventory capacity is fully utilized, production lines are blocked, since there is no space to accept goods in the warehouse. This can be prevented by external warehousing, which is costly and time consuming. The inventory capacity might be increased to the extent that blocking does not occur. However, determining this capacity is difficult due to the stochastic and complex processes in ISC’s.

Warehouses are often bound to physical constraints and are therefore not able to meet the inventory capacity required to prevent blocking. Other measures to reduce the risk of blocking should be identified and applied.

2.2. Research questions
The problem definition leads to the following research questions.

How much inventory capacity is required to prevent blocking in intermodal supply chains?

What are the underlying causes for high inventory levels in intermodal supply chains?

What measures can be applied to reduce the risk of blocking in intermodal supply chains?

2.3. Research steps
As described in chapter 1.3., the research questions will be initially answered for the case study, followed by general results. This will be done with help of a simulation study. Building a correct simulation model in a proper manner increases the trust that involved parties have in the model and its results (Van der Zee & Van der Vorst, 2005). In order to perform a rigor simulation study and to obtain reliable results, the research steps are based on the Simulation Model Development Process (SMDP), presented by Manuj et al. (2009).

The first step of the SMDP is to define the problem and formulate research questions, which was already performed in chapters 2.1. and 2.3. The subsequent research steps will be briefly presented in the following, including the chapter in which they will be discussed.

Step 1: Specifying independent and dependent variables (chapter 4.1.). These variables should reflect the simulation results and input respectively.

Step 2: Develop and validate conceptual model (chapter 4.2.). The conceptual model includes all assumptions, model components and relationships in the system. A structured walkthrough with subject matter experts (SME’s) is required to validate the conceptual model. This step should be executed carefully, because errors in the conceptual model might lead to time-consuming rework in next stages of the process.

Step 3: Collecting data (chapter 4.3.). Finding input values for the independent variables can be difficult due to unavailability of data in the right format. In ISC’s, data can be divided across different companies
that operate in the supply chain. When information is sensitive, it might be harder to obtain all required data (Terzi & Cavalieri, 2003).

**Step 4: Develop and verify computer-based model (chapter 4.4.).** Building the computer-based model can be executed in multiple simulation tools. According to the literature review of Manuj et al. (2009) there is no strong preference for specific simulation tools. When the computer-based model is built, it needs to be verified, which means ensuring that the model behaves as intended, also known as debugging the model (Kelton et al., 2010). An important aspect of the verification is presenting the model to the client, including SME’s, to ensure that both the client and the model developer are convinced that the model is working as intended (Kelton et al., 2010).

**Step 5: Validate the model (chapter 4.5.).** Validation includes determining whether the simulation model is an accurate representation of the system under scope (Kelton et al., 2010), which is important to obtain accurate results and right conclusions. Manuj et al. (2009) provide four steps of model validation:

1. check whether the simulation model and conceptual model are similar
2. perform a walkthrough of the model and evaluate the reasonableness of results with SME’s
3. execute an input-output validation by comparing simulation output with real data
4. execute a sensitivity analysis by varying input parameters and determining whether the simulation model behaves as expected

When the first two steps are successfully executed, the model is considered face valid. The ideal situation is that all validation steps are executed with a successful result, however; this might not always be possible due to a lack of comparable data. Multiple researchers conclude that validation should be conducted as thoroughly as possible, but that it is most important that all involved parties trust the simulation model and the corresponding results (Manuj et al., 2009; Kelton et al., 2010).

**Step 6: Perform simulations (chapter 4.6.).** Three simulation parameters need to be determined before running the model: the number of independent replications, run length and warm-up period. By increasing the first two, more data will be gathered, which probably leads to a more precise result (Kelton et al., 2010). The warm-up period ensures that unrepresentative data, gathered during the startup of the simulation run, is not included in the results. The warm-up period is based on examining simulation results for stability (Kelton et al., 2010).

**Step 7: Analyze and document results (chapter 4.7.).** This step includes interpreting the results, drawing conclusions and providing insights to the client. Analyzing the results might be performed with help of statistical tools.

**Step 8: Scenario analyses (chapter 5.).** Several scenario analyses will be conducted. When the eight-step SMDP is followed, a proper simulation model is developed and allows for reliable scenario analyses (Van der Zee & Van der Vorst, 2005). The scenario analyses will be executed by repeating step seven and eight of the SMDP with different values for certain parameters. These parameters are derived from the analysis in step eight of the SMDP.
3. Heineken context

The export supply chain of Heineken that was briefly discussed in chapter 1.1. is examined as a case study and will be further described in the following. A more detailed visualization is included in appendix A as a conceptual model.

3.1. Input flows

Four types of pallet flows enter the system under scope and are presented below, including their share of the total input flow.

1) Regular pallets (72,2%)
2) Mechanical pallets (14,9%)
3) Conventional pallets (12,3%)
4) Copack pallets (0,6%)

The context of this case study is the seasonal peak of 2013, which means that the presented flows of pallets account for approximately 730 truckloads and 112,000 hectoliters beer to be exported per week. These goods are produced by eight production lines that finally deliver the goods to the warehouse.

3.1.1. Regular and mechanical pallets

Pallets arrive in the system after being palletized by eight different production lines. Pallets from seven of these lines are automatically transferred to buffer lanes, which are automatic belts that transport pallets to the end of the warehouse. The eighth production line has no automatic transfer and no buffer lane, which means the pallets need to be picked up by a forklift truck and transported to the loading area manually. From the buffer lane, pallets can be loaded into previously ordered empty containers, which are brought to the brewery by truck. The buffer lanes serve as a buffer in case there is a delay in transporting the empty container for example.

Two out of seven buffer lanes use an Automated Truck Loading System (ATLS), which is a machine that automatically loads the pallets into a container. Human interaction is only required when the machine signals an error. The other five buffer lanes require a different loading process. The pallets are automatically transferred to a specific loading station that corresponds to the type of pallet (regular or mechanical). From the loading station, pallets are picked up by a forklift truck and loaded into the container. The eighth production line, from which pallets are manually transferred to the loading area, are loaded by a forklift truck, without use of a loading station.

When loading is delayed, due to disturbances in the supply chain for example, the buffer lanes tend to saturate, which ultimately results in blocking of production lines. Pallets can be transferred from the buffer lane to stock, which creates space on the buffer lanes and prevents blocking of production lines. One of the goals of the logistics department is to transfer as much pallets as possible directly into a container, which minimizes pallet handling activities and optimizes productivity.

Once pallets are transferred to stock, they can be handled similar to the eighth production line, which means that pallets are picked up from stock by a forklift truck, transported to the loading area and loaded into a container.
The overview of the logistic processes in the warehouse is depicted in figure 3.2.

![Forklift truck transport](image1)

**Figure 3.2: Warehouse process**

Loaded containers are transported to the Alpherium by truck. Trucks return from the terminal to the brewery with empty containers, which are placed in docks to be loaded with new goods. This process is visualized in figure 3.3. The distance between the brewery and the terminal is approximately 14 kilometers, which is a 17 minute drive. However, some paperwork and handling is involved, resulting in an average transport time of forty minutes. The Alpherium has limited handling capacity, which might cause delays when trucks and barges need to be handled simultaneously. Moreover, not all container types are always available at the Alpherium, since barges are delayed or not bring the right containers. This affects the Heineken operation, because this specific container type is required for loading pallets.

![Handling in warehouse](image2)

**Figure 3.1: Shuttle operation**

The container unavailability is included in this study, based on historical data. The remaining part of the supply chain is beyond the scope of this project, which ends at the decoupling point at the Alpherium.

### 3.1.2. Conventional goods

As mentioned before, conventional goods, which is internal Heineken terminology, account for 12.3% of the total input flow. These goods follow a different process than regular or mechanical pallets, as they are not transported by barge, but only by truck, often to European countries. Conventional goods are produced and transported according to a drumbeat that Heineken uses for their planning tools. The
drumbeat implies that production and transport is executed in week buckets. For conventional goods, this means that production and packaging happens in the first week and transport happens in the second week, continuing as a rolling horizon. After production in the first week, the pallets are not directly loaded, but placed in the inventory, awaiting transport in the second week. This results in a relatively long time spend in inventory because theoretically, conventional goods can be produced on Monday in week one and transported on Saturday in week two, resulting in nearly two weeks waiting time. In practice, the average time spend in inventory is 5.5 days.

3.1.3. Copack goods
Copack goods are regular goods with special packaging, containing a sample of another product with a commercial goal. Copack goods follow a drumbeat that is quite similar as that of conventional goods. An extra copacking week is added in between the production and transportation week, resulting in a production, copack and transportation week. During the second week, batches of goods are transported to a copack company where the product packaging and sample is added. The batches return to the brewery in the same week and await transport, which takes place in the third week. Although copack goods constitute only 0.6% of the total volume under scope, they have a significant effect on the inventory position, because the time spend in inventory is relatively long.

3.2. Disruptions
One of the goals of Heineken is to load as much products as possible directly into containers. However, this might not always be possible because not all required loading resources, such as a container or loading station, are available. A batch of pallets that awaits loading remains on the buffer lane. Meanwhile, the pallets for the next container are produced and placed on the buffer lane too. When a buffer lane is full, the corresponding production line is blocked, because there is no decoupling point between the production line and the buffer lane. To prevent blocking, pallets are removed from the buffer lane and placed in the inventory as soon as the buffer lane is nearly saturated. When this process is repeated, the inventory capacity might saturate, leading to blocking of production lines. Loading resource unavailability is a major cause for goods to be transferred to the inventory and is further discussed below, however; three important uncertainty factors will be discussed first.

3.2.1. Uncertainty factors

Blockages
Arriving goods in the warehouse might contain production or packaging errors such as badly labeled bottles or damaged packaging material. Goods containing errors are defined by Heineken as blockage goods. The condition of blockage goods needs to be examined before the goods are transported to the customer or destroyed. Meanwhile, blockage goods stay in the inventory, which increases the risk of blocking of production lines. Batches of blockage goods might be large and examining the goods can take weeks, which causes high inventory levels and an increased risk of blocking.

Quarantine
Quarantine goods follow a similar path as blockage goods. Quarantine goods are goods that cannot be transported to the customer yet, because the beer quality needs to be tested first.

Inspections
Certain destinations require a special seal in order to export the product. This seal is provided by an inspector who checks the container and approves the export process. Pallets for inspection destinations are placed in stock until the inspector of the required inspection company arrives. This waiting time might vary from an hour to a day.
3.2.2. Resource availability

Empty container availability
Each destination corresponds to a shipping company and specific container type. Due to delays in the barge cycle, unavailability of containers in the harbor or poor inventory management, not all container types are available at the Alpherium at all time. Another reason for container unavailability is the night operation at the inland terminal. The Alpherium is not permitted to access the entire terminal area during the night. As a result, containers that are required during the night might be present at the terminal, but cannot be accessed. When a requested container type is not available, the goods are placed in the inventory until the required container type becomes available again.

Loading delays
The most important resource required for loading is an empty container. The empty container availability was already discussed, however; empty containers might also be delayed. Underlying factors for empty container delay are traffic congestion, delayed handling at the Alpherium, errors in the container requests or bad container condition. Delayed handling at the Alpherium occurs when barges and trucks arrive at the Alpherium simultaneously, for which the Alpherium does not have sufficient capacity. Errors in container requests often include miscommunications about the required container type or not transporting the correct container, resulting in the delivery of the wrong container type. This is fixed by repeating the container request and returning the wrong container to the terminal. The same process is executed when a container arriving at the brewery is rejected due to a bad condition.

Depending on the production line where pallets are produced, loading requires the automated truck loading system (ATLS) or a handling station and forklift truck. The ATLS is a machine that requires maintenance and suffers from failures, which causes ATLS unavailability and might result in waiting times for goods on the buffer lane. The same might happen on other buffer lanes when a required handling station to pick-up the pallet or forklift truck that executes the loading is unavailable. As described earlier, when the buffer lanes tend to saturate, pallets are transferred to stock, resulting in higher inventory levels.

Once pallets enter the inventory, they need to be rescheduled for loading, but this process might be delayed. The operational planning department is not immediately aware of products that need to be rescheduled; moreover, it is often not possible to plan the loading in the short term. This rescheduling delay is the first element of loading delay.
4. Executing a rigorous simulation study
The research steps that are presented in chapter 2.3. will be applied to the case study in the following chapters.

4.1. Specify independent and dependent variables
Similar to the SMDP of Manuj et al. (2009), the dependent and independent variables are determined with help of subject matter experts. For this purpose, a group of seven subject matter experts was gathered, each having expert knowledge on one or several parts of the logistic process. The group members represent the following roles:
- Strategic planner and data expert
- Team leader logistics
- Senior shop floor control manager (and former team leader logistics)
- Project leader logistics
- Contract manager, involved in cooperation with Alpherium
- Terminal manager Alpherium
- Production technician
These SME’s were asked to explain the logistic processes in the intermodal supply chain. More specifically, they were asked what products are produced and how fast they are produced, why certain products are placed in inventory, and how these products are handled once they entered the inventory. The dependent variables are described in chapter 4.1.1. and the independent variables are described in the subsequent chapters 4.1.2 until 4.1.7.

4.1.1. Dependent variables
The dependent variable is the inventory capacity performance (ICP) and is defined as the percentage of time that the inventory capacity is sufficient and not saturated. The ICP is thus based on comparing the amount of goods (in pallets) in the inventory and the maximum inventory capacity. The latter is an independent variable, which will be discussed in chapter 4.1.2. The amount of pallets in the system is a simulation outcome and a dependent variable in this simulation study.

In order to determine the underlying causes of high inventory levels, the total amount of pallets can be split into different variables corresponding to different reasons why the pallets are placed in the inventory. The possible underlying causes in this study are:
- Inventory due to blockage goods
- Inventory due to quarantine goods
- Inventory due to inspections
- Conventional inventory
- Copack inventory
- Inventory due to container unavailability
- Inventory due to delays, which is split into regular and mechanical pallet flows.
Together, all these dependent variables account for the total amount of inventory in the warehouse.

4.1.2. Inventory capacity
The current inventory capacity performance is based on comparing the total amount of pallets in the inventory and the current inventory capacity. One could also choose the independent variable of inventory capacity as a larger number to calculate how much inventory is required to obtain a certain ICP.
Managers responsible for the warehouse operation intervene as soon as 80% of the inventory is utilized. This allows for some time slack to call a transport company and arrange external warehousing before the inventory is fully utilized and production lines are blocked. The goal is to design a system that does not require human intervention, which occurs at 80% warehouse utilization. The ICP is therefore further specified as the percentage of time that 80% of the inventory capacity is sufficient and not saturated. The results will be presented with the corresponding physical maximum (100%).

4.1.3. Blockage, quarantine and inspection inventory
The time between arrivals, the size of in container quantities and the time spend in inventory contribute to the amount of goods in the inventory. These three independent variables are required for blockage, quarantine and inspection goods, resulting in nine independent variables.

4.1.4. Conventional and copack inventory
The conventional inventory is based on the produced amount of conventional products and the time spend in inventory. The amount of conventional products depends on production speed of different production lines, which will be discussed in chapter 4.2.7. For each production line, a percentage of the goods is conventional. This percentage is an independent variable. The time spend in inventory is the summation of the time left in the production week of the Heineken drumbeat and the time until a product is loaded in the transportation week. Waiting until the production week is finished can be modeled automatically, thus the only required data for the throughput time is the additional waiting time from the start of the second week until the loading moment.

Underlying independent variables for copack inventory are similar to those of the conventional flow. The throughput time in the warehouse of copack goods is somewhat different due to the extra copack week. The extra independent variables are the waiting time from the start of the copack week to the copack moment, the time spend at the copack company and the waiting time from the start of the transportation week to the transportation moment.

4.1.5. Container unavailability
Pallets might enter the inventory because the required container is not available or accessible at the Alpherium. The required data is the time between two events of container unavailability.

4.1.6. Inventory due to loading delays
Loading delay increases the inventory amount and might be caused by multiple factors that are described in chapter 3.3.2. Rescheduling delay is an independent variable, equal for all pallet types, that enhances loading delay. The second factor is empty container delay, which can be caused by traffic delay, delayed handling at the Alpherium, delivery of the wrong container or bad container condition. Traffic delays are included in a variable transport time between the brewery and the Alpherium. The handling delay at the Alpherium requires three independent variables; the arrival rate of barges, the time to handle barges and the delay caused when barges and trucks are handled simultaneously. With these variables, the simulation model is able to check whether a barge is being handled and an extra handling time should be added to truck handling. As described in chapter 3.3.2., the consequences of delivering the wrong container or a container with a bad condition are equal. In both cases, the wrong containers are returned to the Alpherium and a new request is performed. Therefore, both events can be aggregated into one event, requiring two independent variables; the time between successive events of delivering a wrong container or container with bad condition and the delay caused by this event.
The handling station and forklift truck unavailability and ATLS unavailability affect the loading delay too. The latter is determined by the failure rate and time to repair the machine, which are both independent input variables. The unavailability of handling stations and forklift trucks is determined by the loading speed of a forklift truck. Faster loading results in less average waiting time for pallets in the system.

The complex structure of inventory due to loading delay is depicted in Figure 4.1. For example, more rescheduling delay results in more loading delay. When loading delay is increased, the corresponding amount of inventory is increased too. The production speeds acts as a moderator, which is discussed in chapter 4.2.7.

![Figure 4.1: Causes of inventory due to delay](image)

4.1.7. Input flows
The input speed of pallets in the system moderates the effect of loading delays on the amount of inventory. High input speed of pallets means that buffer lanes saturate faster, which increases the chance of transferring pallets to the inventory when a delay occurs. The same delay leads to higher inventory levels when the production speed is increased.

The input flow of pallets is determined by several independent variables for each production line. Four variables are necessary for each production line: production time of one container quantity, the changeover time between production runs, the productmix of a production run and the size of a single production run. The product mix is an independent variable and is defined as the distribution between regular, mechanical, conventional and copack pallets. The production run size depends on whether the productmix of the specific run is copack, because these runs are on average smaller than other production runs. Additional to these production characteristics, each production line requires a shift schedule that includes the shifts at which a production line is turned on.

4.2. Develop and validate conceptual model

4.2.1. Conceptual model
For this case study, an IDEF0 model was developed that serves as conceptual model of the system that is described in chapter 3. The IDEF0 model is a visualization of the supply chain and can be found in appendix A, including a textual description. The conceptual model was validated with help of the
The previously mentioned group of SME’s. The model was presented to the SME’s, who provided feedback on whether the conceptual model correctly represents reality. After adjusting the initial model, the conceptual model was approved by the SME’s.

4.2.2. Assumptions
According to Manuj et al. (2009) this third step of the SMDP requires a list of all assumptions made in the development process. This list is presented below.

1) The pallet quantity that is loaded into a single container is always 24. In reality, this is amount might vary due to different types of products or containers. However, dealing with these different types requires much extra detail. The most common container size is 24 pallets per container. The size of production runs is determined in container quantities; hence the production size is always a multiple of 24 pallets.

2) The second assumption considers the amount of trucks in the truck shuttle operation. This amount is planned, based on the expected amount of containers to be transported and can differ each day. Trucks might be added or excluded during the day when the forecasted workload does not match the reality. Due to the varying amount of trucks, the truck capacity is hard to include in the simulation model. In order to model the truck transport, the assumption is made that trucks are well planned and are always available for transporting containers. With this assumption, truck transport can be simply modeled as a delay instead of seizing an actual truck.

3) In reality, warehouse employees will intervene when the inventory level becomes too high. However, the aim is to design a system that does not need human intervention. In order to measure the performance of the system, even when the maximum inventory capacity is exceeded, the assumption is made that no human intervention occurs in the system.

4) With the same logic, a model without a maximum inventory capacity should be made. This situation enables calculating the ICP for increased inventory capacity.

5) When the transport of an empty container is delayed and the corresponding pallets are transferred to inventory, the empty container can be used by the next batch of pallets. The first new container request is canceled to compensate this effect.

4.3. Collect all data and input values
All values for the independent variables presented in chapter 4.2. are gathered from subject matter experts working for Heineken or the Alpherium. The values have varying formats: a random distribution function, an empirical distribution function or a fixed value. Gathering data from the Alpherium was harder, which corresponds to the warning of Terzi and Cavalieri (2003). The external parties do not share the same goal as Heineken and therefore hesitate to provide detailed information about the transport times. Since these transport times affect the performance indicators of the service provided by the Alpherium, the data is quite sensitive and therefore harder to gather. In order to obtain the data and maintain a good relationship with the Alpherium, employees from the Alpherium were involved in data gathering, model building and evaluating simulation results. Transparency in supply chain simulation is especially important since multiple parties with their own objectives are involved (Van der Zee & Van der Vorst, 2005).
4.4. Build model and verify with process owners

After successfully executing the previous steps, the model building might commence. The simulation tool used in this case study is Arena. This choice is based on previous experience with the software tool, since no explicit preference for certain software exists in literature (Manuj et al., 2009). The model consists of five components that are briefly described and visualized in figure 4.2.

The first component contains mechanisms that control the arrival of pallets, requesting empty containers and the transport on buffer lanes. When simulated pallets arrive at the end of the buffer lanes, a mechanism determines whether a product needs to be placed in the inventory or directly loaded into a container. This first component is duplicated for all pallet input flows from different production lines.

The second component is the next step in the process, which includes the pallet pickup, pallet transfer either to inventory or into a container and sending trucks with full containers to the Alpherium.

All activities at the Alpherium constitute the third component, which includes two mechanisms: The handling of trucks and the arrival of barges. When barges are being handled at the Alpherium, empty containers are often delayed.

The fourth component considers the inventory and includes mechanisms for counting pallets and simulating the right throughput time. After the throughput time, the pallets are returned to component two for loading. The amount of pallets is the simulation study result, which makes the counting component very important. The total amount of pallets is counted, as well as the subdivision of inventory.

The fifth and final component includes mechanisms for writing the (subdivided) inventory amount to excel, regulation of the drumbeat, control of uncertainty factors and control of container delay. Both the drumbeat and the uncertainty factors, such as blockages, quarantine, inspections and container unavailability, influence the arrival process in component one. The container delay includes delays caused by traffic jams or communication errors. It influences the routing decision in component one, because a delayed container might lead to saturation of buffer lanes, followed by pallet transfer to inventory.

The simulation model was verified by extensive walkthroughs of (parts of) the model with the SME’s. Multiple mechanisms were changed and verified again, eventually resulting in the acceptance by all SME’s.
4.5. Validate model results

The first validation step is a comparison between the simulation model and the conceptual model. This was executed together with several SME’s by checking whether the simulation model included all components of the conceptual model in a correct manner. The result of this validation step was positive. While comparing both models, it was noted that the simulation model included more detail than the conceptual model.

The second validation step is reviewing the simulation outcome with a few SME’s that are able to determine whether the results are reasonable. The total inventory and underlying causes measured in the simulation run showed representative levels, according to the teamleaders and data expert. After successfully performing the first two validation steps, the model was considered face valid (Manuj et al., 2009).

The next step in the validating process is performing an input-output validation. For this purpose, a specific version of the simulation model was built that enables to reproduce real pallet arrival times in the simulation model. Real pallet arrivals in the system during six weeks in the high season were simulated and the amount of inventory was written to excel for every virtual hour. The first two weeks were considered as warm-up period, which leaves the last four weeks for comparable analysis.
Figure 4.3. depicts the last four weeks of the analyzed period. The different graphs show various inventory levels in pallets (vertical axis) during the four weeks (horizontal axis). The most important line is the blue line, which shows the total stock level over time. It can be compared to the purple horizontal line, which depicts the amount of pallets at which teamleaders intervene and start preventive actions such as external warehousing. When the blue line is below the purple line, no intervention is needed, which is the wanted situation. As can be seen in figure 4.3, the total stock level is above the purple line during a significant amount of time. The other lines below the blue line show the subdivided inventory level, meaning these lines together result into the blue line. The meaning of each line can be obtained from the legend.

Data on the daily average inventory level in the specific period is available and will be used to validate the simulation results. However, the comparison is difficult since real data is influenced by Heineken employees who intervene to reduce the inventory level. Possible intervention measures are utilizing a different container type when the preferred type is not available or transferring goods to other parts of the Heineken site or to an external warehouse. The latter might even be executed as a precaution when a situation of saturated inventory is expected. This human intervention was not included in the simulation model which creates a discrepancy between the real inventory level and simulated inventory level. Both graphs are depicted in figure 4.4.
Some conclusions can be drawn from the comparison between the two graphs. The real inventory level is significantly lower than the simulated inventory level. This is reasonable due to the earlier described intervention. Figure 4.4. shows that the inventory level of both graphs increases significantly between day 8 and day 12. In this period, the difference between both graphs increases as well, which can be explained by intervention of Heineken employees who foresaw the high inventory level. After this intervention, the real data shows a quite stable inventory level between 2000 and 3000 pallets. The simulated inventory level also shows a trend towards the same level. The comparison between the real and simulated inventory was presented to warehouse management employees. They confirmed the data on the real inventory level; moreover, they stated that the real inventory level would be similar to the simulation inventory level when warehouse employees would not have intervened. Although the input-output validation could not be executed statistically due to the lack of human intervention in the simulation model, this validation step contributed to the reliability of the simulation model due to the explained difference between both graphs presented in figure 4.4.

The final validation step is a sensitivity analysis, which means varying model parameters and examining the effect on the performance indicator in order to derive important variables and discover errors in the model (Manuj et al., 2009). The model was changed from a model with deterministic arrivals and real arrival times to a model with variation in the arrivals of pallets, such that the variables for arrival of pallets could be examined as well. From the sensitivity analysis, four independent variables seemed to have the largest effect on the ICP: percentage of copack goods in the product mix, percentage of conventional goods in the product mix, the throughput time of conventional goods in the amount of quarantines in the system.

The validation step of the SMDP can be concluded as follows. Face validity was obtained after a comparison between the conceptual model and simulation model and a review of results with SME’s. An input-output validation was executed by comparing the simulated inventory level with the real inventory level in the same period. A difference between both graphs was explained and SME’s confirmed the validity of the simulation model. The sensitivity analysis provided important factors that influence the ICP. The most important conclusion after the validation step is that both the client and model builder trust the simulation model and its results (Manuj et al., 2009).
4.6. Perform simulations

The seventh step of the eight-step SMDP is performing the simulation runs. First, the simulation length, number of replications and warm-up period need to be determined. The first two improve the amount of data points collected during the simulation runs and therefore improve the precision of results. The simulation model contains a mechanism that writes the inventory level, including the levels per underlying cause, to an excel file every virtual hour. The simulation length is one year, which results in 365 days * 24 hours = 8,760 data points. The number of independent replications is 10, which means a total of 87,600 data points is collected. The warm-up period is the period until the results stabilize and can be chosen by visual examining the outcome (Kelton et al., 2010). The data gathered during the warm-up should be excluded from for each independent replication. The warm-up period is determined as 14 days, which equals 14 * 24 = 336 data points per replication. This leaves 8,760 – 336 = 8,424 data points per independent replication for analysis, which is a total of 8,424 * 10 = 84,240 data points.

These data points with information about the inventory level will be used to determine how often the inventory capacity is exceeded. Moreover, with information about the subdivided inventory, the contribution of each possible cause is measured. This will allow for an analysis of the causes for exceeding the inventory capacity.

4.7. Simulation results

As described earlier, the simulation output is written to excel. For each replication, the inventory capacity performance with inventory capacity X, which is denoted as ICP(X), is calculated by dividing the amount of data points with an inventory level that does not exceed 80 percent of the inventory capacity by the total amount of data points. Thus the ICP(X) is calculated as follows:

\[
ICP(X) = \frac{\text{Count } x_i \text{ with } x_i < (0.8 \times X)}{\text{Count } x_i} \quad \text{for } i = 337 \text{ until } 8760
\]

With \( x_i = \) the inventory level at data point or hour \( i \)
And \( X = \) the physical inventory capacity

The following example illustrates the calculation of the ICP(X) in the first independent replication at the current inventory capacity of 4300.

\[
ICP(4300) = \frac{\text{Count } x_i \text{ with } x_i < (0.8 \times 4300)}{\text{Count } x_i} \quad \text{for } i = 337 \text{ until } 8760
\]

\[
ICP(4300) = \frac{5902}{8424} = 70.02\% 
\]

This calculation is executed for all independent replications, resulting in ten values for the ICP(4300). From these values, a one-sided 97.5% confidence interval for the ICP(X) can be derived.

4.7.1. As-Is analysis

The simulation result of the current situation is a one-sided 97.5% confidence bound of the ICP(4300). The sample mean \( \bar{x} \) of the ten independent replications is 73.4% and the sample standard deviation \( s \) is 5.0%. The one-sided confidence bound, with \( \alpha = 0.025 \) and \( n = 10 \) can now be calculated:
\[
\bar{x} - t_{a,n-1} \sigma / \sqrt{n} \leq \mu
\]

\[
73,4 - 2,262(5,0) / \sqrt{10} \leq \mu
\]

\[
73,4 - 3,6 \leq \mu
\]

\[
69,8 \leq \mu
\]

This result means that the inventory capacity performance in the current situation is 69,8%, with 97,5% certainty when humans would not intervene. This performance in reality is higher due to (preventive) intervention; however, as was described in assumption 3 in chapter 4.2.2, a system without intervention is wanted. The ICP of 69,8% is the new benchmark, which is used during the remainder of this thesis.

From this result, we can continue by calculating how much inventory capacity would lead to an ICP(X) of 100%, meaning that the inventory capacity is never exceeded. This calculation is executed by increasing the inventory capacity X and calculating the corresponding ICP(X). The result is presented in figure 4.5. The previous result of an ICP(X) of 69,8% in the current situation without human intervention can be found on the Y-axis, with the current inventory capacity of 4300 pallets.

![Figure 4.5: ICP(X) in current warehouse](image)

An ICP(X) of 100% requires an extremely high inventory capacity. From a managerial perspective, it is more interesting to gain insight in the tradeoff between the costs and risk of blocking production lines and the inventory capacity costs. Therefore, the values of required inventory capacity for inventory capacity performances close to 100% are included in table 4.1.

<table>
<thead>
<tr>
<th>Inventory capacity X</th>
<th>ICP(X) 97,5% confidence bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>5350</td>
<td>95%</td>
</tr>
<tr>
<td>5800</td>
<td>98%</td>
</tr>
<tr>
<td>6100</td>
<td>99%</td>
</tr>
<tr>
<td>7450</td>
<td>100%</td>
</tr>
</tbody>
</table>
In order to obtain a higher ICP, the warehouse capacity should be increased; however, this is difficult due to physical constraints. Therefore, measures should be undertaken to reduce the inventory level, resulting in a decreased risk of blocking, without increasing the inventory capacity. In order to do so, an analysis about the underlying causes is required. Therefore, we analyze the inventory levels while they exceed the inventory capacity. Information about the subdivision of these high inventory levels will show which causes contribute most to the high inventory levels. We calculate the average subdivision of inventory over data points with an inventory level higher than the maximum value. The result can be found in figure 4.6, which shows the average subdivision of inventory when the maximum capacity is increased. For example, we see that the copack pallets on average constitute 6% of the total inventory, while the inventory exceeds the maximum capacity.

![Figure 4.6: Average subdivision of inventory when capacity is exceeded](image)

The major factors with high inventory levels can be derived from figure 4.5. The most important factor is conventional inventory, which constitutes 62 percent of the total inventory amount. The underlying cause is the process of how these goods are handled. All conventional goods are transferred to stock instead of being directly loaded into a container. Moreover the time spend in inventory is long due to the Heineken drumbeat. Quarantine, blockage and copack inventory are the subsequent factors with 15, 8 and 6 percent respectively. Together, these four underlying major factors account for 91% of the average subdivision of inventory.

For this research it is interesting to examine the contribution of intermodal characteristics in this inventory subdivision. Three factors represent the intermodal characteristics: container unavailability inventory, regular inventory due to delays and mechanical inventory due to delays. These three factors
account for 8% of the inventory subdivision in figure 4.5, which seems relatively low. However, the influence of intermodal characteristics seems significant due to high variability of the absolute value of the corresponding inventory level. The average inventory level caused by intermodal characteristics is 280 pallets with a standard deviation of 181 pallets and a maximum of nearly 1400 pallets. This shows the high variability in inventory caused by intermodal characteristics.

4.7.2. Derived scenarios

Although the intermodal characteristics have a significant effect on the inventory level, structurally decreasing the inventory level can easier be obtained via the presented four major factors; conventional, quarantine, blockage and copack inventory. From these factors, directions for further research can be derived. For each factor, two scenarios will be investigated that are inspired by Little’s law, which states that the long term work in process in the system is the multiplication of the throughput or arrival rate and the cycle time, which is the time spend in the system (Hopp & Spearman, 2008). The same logic can be applied in the case study. The long term expected number of pallets in the warehouse is the multiplication of the arrival rate of pallets and the time they spend in the warehouse. According to Little’s law, the average inventory levels of all four factors might be reduced by decreasing either the arrival rate of pallets or the time spend in the warehouse. Eight scenarios are presented below.

Scenario 1: Conventional throughput time. The throughput time of conventional goods is currently determined by the utilized drumbeat and has an average of 5,5 days. Reducing the throughput time practically means that the planning of conventional transport should be detached from the drumbeat. Transport companies should be informed of the desired transport moment, which can be a few days after production. For this scenario, we assume that the time until transport is normally distributed with a mean that can be varied from 5,5 until 2 days and a standard deviation of 0,3 days.

Scenario 2: Conventional volume/week. The current volume per week of conventional goods is 14.250 hectoliters (hls), which equals 12,3% of the total amount of produced goods. Reducing this amount leads to less conventional goods and thus less inventory due to conventional goods. The percentage of conventional goods will be reduced from 12,3% to 7%, which is 8.100 hls/week. The values will be presented in hls per week, since that is the common unit communicated within the company. Reducing the volume per week might practically be obtained by utilizing the intermodal supply chain for destinations that are currently served by trucks only. The total production amount should be maintained, which implies that reducing the conventional percentage accompanies an increase in the percentage of regular pallets in the system. This shift from conventional to regular pallets is not feasible for all markets that are currently served via the conventional process. However, certain markets, such as the Portuguese market, can be served by an intermodal supply chain and containerized goods. Although this might not be the cheapest option, it will result in other benefits such as a lower inventory level and less risk of blocking.

Scenario 3: Quarantine throughput time. The throughput time of quarantine goods is based on the time needed to perform quality checks, which might be accelerated. The current average throughput time is 11,27 days and will be decreased stepwise to 6 days.

Scenario 4: Quarantine arrivals. The amount of quarantine goods that arrive in the system is based on the time between arrival and the size of a quarantine batch. The latter is based on the size of a production run, which cannot be influenced by the logistics department. The time between arrivals can be changed by utilizing a specific procedure that implies that products can be directly transported to the
customer while a small batch is tested during the transit time. This means that quarantine goods do not require a specific procedure but can be handled as normal products. The current amount of arrivals is on average 100 arrivals per year. This scenario investigates situations with a decreased (50 and 10 per year) and increased (150 and 200 per year) amount of quarantine arrivals.

**Scenario 5: Blockage throughput time.** Blockages need to be examined before they leave the inventory. The current throughput time in the system is 12 days. This scenario will provide insight on whether the ICP(X) is improved by reducing the throughput time from 12 to 6 days.

**Scenario 6: Blockage arrivals.** The average amount of blockage arrivals is equal to the amount of quarantine arrivals: 100 per year. The effect of an increased or decreased amount of blockage goods is examined by changing the amount of arrivals to 10, 50, 150 and 200 arrivals per year. Heineken is continuously involved in decreasing the amount of blockage arrivals by analyzing the errors and improving the production line. When this scenario shows a large correlation between blockage arrivals and the ICP(X), managers might increase the attention and investment for this topic, to reduce the amount of blockage arrivals even more.

**Scenario 7: Copack volume/week.** The effect of copack products on the ICP(X) is relatively large since it exists of 0,6% of the total input flow, but constitutes 6% of the inventory as depicted in figure 4.5. The current copack volume is 840 hls/week, which will be varied to 0, 420, 1260 and 1680 hls/week. This corresponds to 0%, 0,3%, 0,9%, and 1,2% respectively. The planning department might influence this percentage by allocating the production of these goods to different production sites. They might decide to produce copack goods at the brewery in ‘s Hertogenbosch when that brewery has more inventory capacity available for such products.

**Scenario 8: Different copack process.** The contribution of copack goods to the total amount of inventory might also be reduced by decreasing the average time spend in inventory. A practical implementation of such measure is to arrange direct transport from the copack company to the customer or the Alpherium, which is named improvement step 1. A second possibility is to handle copack goods as if they were regular goods, which implies that they are directly transported from the brewery to the copacker and from the copacker to the customer or the Alpherium. This process is named as step 1 + 2. Both cases will be compared with the current situation.
5. Scenario analysis

5.1. Scenario results

For every scenario, the one-sided 97.5% confidence bound is calculated for each parameter value and presented in a single figure, such that conclusions on the improvement of the ICP(X) can be evaluated. The result for each scenario is presented below.

Result 1: Conventional throughput time. The result of varying the throughput time of conventional goods is presented in figure 5.1. This figure depicts the improvements provided by reducing the conventional throughput time. A throughput time decrease of 1.5 days provides an ICP(4300) increase of 19%. Further reduction of the average throughput time provides an even better ICP(X).

Result 2: Conventional volume/week. This scenario examines the effect of the conventional volume on the ICP(X). The results are presented in figure 5.2 and show that reducing the volume of the conventional flow of goods result in a large increase of the ICP(X).

Result 3: Quarantine throughput time. The result of scenario 3 is depicted in figure 5.3. Although the throughput time of quarantine goods has less effect on the ICP(X) than the throughput time of conventional goods, the ICP(X) is still significantly improved by reducing the quarantine throughput time. The main challenge in this scenario is the feasibility of this measure, since this throughput time is based on chemical tests that require some waiting time.
Result 4: Quarantine arrivals. The effect of the amount of quarantine arrivals on the ICP(X) is presented in figure 5.4. A reduced amount of quarantine arrivals provides an improvement of the ICP(X). However, increasing the amount of quarantine arrivals has a relatively large negative effect. This is observed from the relatively low performance of the situation with 200 quarantine arrivals per year.

Result 5: Blockage throughput time. The throughput time of blockages was assumed to have much impact on the ICP(X), however; results in figure 5.5 show that reducing the time required to examine a batch of blockage goods does not result into large improvements of the ICP(X). Improving this throughput time variable might not be interesting at this point. However, when more blockage arrivals occur, the reduction of blockage throughput time will likely have more effect.

Result 6: Blockage arrivals. The effect of varying the amount of blockage arrivals has a weaker effect than the amount of quarantine goods. However, it still shows significant changes of the ICP(X), especially when the amount of blockage arrivals is increased.
**Result 7: Copack volume/week.** The effect of copack volume on the ICP(X) is relatively large, since a small increase from 0.6% to 0.9% reduces the ICP(4300) with 7%. On the other hand, a decrease in copack volume leads to a significantly improved ICP(X). The forecasts for the next three years depict a steady amount of copack goods; however, sudden marketing events might cause an increase of copack demand.

![Figure 5.7: Result scenario 7](image)

**Result 8: Different copack process.** The result of direct export from the copack company (step 1) is depicted in figure 5.8. The result of transporting the pallets directly to the copack company (step 1+2), is shown in figure 5.9. The latter case has more effect on the ICP(X), since copack goods do not spend any time in the inventory. Both ICP(X) improving effects will be larger when the percentage of copack goods in the product mix increases.

![Figure 5.8: Result scenario 8 step 1](image)  
![Figure 5.9: Result scenario 8 step 1 + 2](image)

**5.2. Scenario implications**

Several implications can be derived from the scenario simulation results described in chapter 5.1. As can be seen by comparing the scenario result figures, the largest ICP(X) improvement is gained by reducing the conventional throughput time or the amount of conventional goods that arrive in the system. Further research should be conducted on how these improvements might be realized. The time between production and scheduled transport is equal to the new mean throughput time. The transport time should not be scheduled too soon, since production might be delayed. A tradeoff between the effect of reducing the throughput time and the risk and effect of producing conventional pallets too late should be made in order to determine the desired average throughput time of conventional goods. Reducing the amount of conventional goods might be realized by delivering products to certain countries via barges instead of trucks only. The feasibility of this change should be investigated per country.
The next measurement that significantly improves the ICP(X) is reducing the throughput time of quarantine products. The downside of this measurement is that implementing it might not be possible due to strong quality constraints. Therefore, this measurement should be discussed with the quality department.

Another possible measure is reducing the amount of arrivals or the throughput time of copack goods in the system, which leads to a strong ICP(X) improvement as well. However, the volume of copack goods is more likely to increase in the coming years. This significantly decreases the ICP(X), which underlines the importance of undertaking measures to improve the ICP(X). When the copack volume increases, the relative improvement by changing the copack process increases. Changing the copack process is an important ICP(X) improving measure, especially when the amount of copack arrivals increases.

Although not all scenarios provided opportunities for improvement, some still provide important managerial insights. Scenarios 4 and 7, on the amount of quarantine and copack goods respectively, suggest that an increase in the arrival of these goods negatively effects the ICP(X). This effect should be considered when decisions are made on the planned amount of copack goods or the way in which Heineken deals with quarantine. The importance of improving the ICP(X) with other measures is therefore underlined by the result of scenarios 4 and 7.
6. Conclusions
A simulation model was developed, based on the SMDP of Manuj et al. (2009). The simulation model was used to conduct a case study at the Heineken brewery in Zoeterwoude, Netherlands. From the case study, conclusions can be drawn that apply to the case study context itself. Moreover, general conclusions that might be applied to other ISC’s will be described in this chapter. The conclusions of the research will be presented by following the research questions that were stated in chapter 2.2.

6.1. How much inventory capacity is required to prevent blocking in intermodal supply chains?

6.1.1. Heineken case study
The current situation without human intervention was modeled and simulated in order to calculate the ICP(X) which is defined as the percentage of time that the inventory capacity X is sufficient and not saturated, meaning that no blocking of production lines occur. The result of the current situation without human intervention is a 97.5% confidence bound for the ICP(3000) of 69.8%.

From this result, we increased the inventory capacity while recalculating the corresponding ICP(X). The values of the inventory capacity that provide ICP(X) values that approach 100% are presented in table 6.1. The case study result was that a capacity of 7450 pallets is required to prevent blocking with 97.5% certainty.

6.1.2. General case
Answering the research question for the general case requires that we look at the inventory capacity as a percentage of the average inventory, so that we can apply the outcome to multiple ISC’s. A third column was added in table 6.1, which includes the inventory capacity as a percentage of the average inventory. The simulated average inventory level in the current situation without human intervention is 3063 pallets. An inventory capacity of, for example, 5350 pallets is therefore

\[
\frac{5350}{3063} \times 100\% = 175\%
\]

An interesting observation is the fact that conventional and copack products are not transported via the ISC, but are transported by road transport only, as was described in chapters 3.1.2. and 3.1.3. In order to generalize the case study’s result, we should adjust the case study result to a situation with intermodal transport only, by assuming that these products are transferred to another warehouse after production. This way, the inventory in the case study is solely used by the intermodal supply chain, which makes the case study more representative for general intermodal supply chains. The data was adjusted and the corresponding results are presented in table 6.2. As can be seen in the second column, the absolute values of the required inventory capacity are decreased, compared to table 6.1. However, these results are actually worse, since the average inventory is also decreased to 1053 pallets. Therefore, the third column values are increased, resulting in a required inventory capacity of 3.28 times the average inventory to prevent blocking.

\[\begin{array}{|c|c|c|}
\hline
\text{ICP(X)} & \text{Inventory capacity X} & \% \text{of Avg inventory} \\
\hline
95\% & 5350 & 175\% \\
98\% & 5800 & 189\% \\
99\% & 6100 & 199\% \\
100\% & 7450 & 243\% \\
\hline
\end{array}\]

\[\begin{array}{|c|c|c|}
\hline
\text{ICP(X)} & \text{Inventory capacity X} & \% \text{of Avg inventory} \\
\hline
95\% & 2300 & 219\% \\
98\% & 2600 & 247\% \\
99\% & 2750 & 261\% \\
100\% & 3450 & 328\% \\
\hline
\end{array}\]
Even though we adjusted the results, we still have to discuss how representative the (adjusted) case study is. As was described in chapter 1.1, the case study perfectly fits the definition of an intermodal supply chain, since two modes of transport are utilized in a single transport chain, without change of container for the goods (Macharis & Bontekoning, 2004). Theoretically, the case study seems representative. However, it is difficult to state whether the same holds for specific characteristics of the case study’s supply chain. The Heineken ISC suffers from multiple disruptions that were described in chapter 3.2. These disruptions influence the inventory and might be different from other ISC characteristics. It would require more research on different ISC’s to draw stronger general conclusions.

Although generalizing the result is difficult, we can state that the problem is quite severe. According to the adjusted case study results, an inventory capacity of 328% of the average inventory is required to prevent blocking. Even if we assume that the disruptions in the Heineken case cause twice the amplitude of the general case, an ISC in general would need 2.14 times the average inventory capacity. This addresses the gravity of the problem and demands for further research on intermodal supply chains and on how to improve the inventory capacity performance.

6.2. What are underlying causes for high inventory levels in intermodal supply chains?

6.2.1. Heineken case study

The underlying causes were presented in chapter 4.7.1. and four major causes were derived. They are stated below, including their average percentage of the inventory.

- Conventional goods (62%)
- Quarantines (15%)
- Blockages (8%)
- Copack goods (6%)

The reason that these causes have such a significant influence on the inventory is the fact that these causes all have a long throughput time in inventory, varying from five to twelve days. For Heineken, this result provides good opportunities for improvements which will be discussed in chapter 6.3.1.

6.2.2. General case

According to Little’s law, high inventory levels can be caused by either many arrivals in inventory or a long throughput time. From the case study result, we see that a significant throughput time is the common factor of the four major underlying causes. However, this might be different in other ISC’s that encounter more arrivals in inventory instead of long throughput times.

The case study includes an analysis of the underlying causes; however, a more detailed research on the effect of specific intermodal characteristics on the inventory level is required to further address the underlying causes. Moreover, different ISC’s have different characteristics. In order to conclude on underlying causes for the general case, more ISC’s should be investigated. This will be further discussed in chapter 7 on future research.
6.3. What measures can be applied to reduce the risk of blocking in intermodal supply chains?

6.3.1. Heineken case study
Scenario analyses were conducted to find ICP(X) improving measures. For all four major factors, two scenarios, based on Little’s law, were derived; reducing the amount of arrivals and reducing the time spend in inventory. For each scenario, the corresponding parameters were changed and the effect on the ICP(X) was measured. An ease and effect analysis should be executed more extensively and is not included in the scope of this thesis. After consultation with SME’s, a list of the most promising and feasible improvements is determined, including their figure numbers in chapter 5.1:

1. Decreasing conventional throughput time. This measure provides large improvements on the ICP(X) and seems feasible to implement. (figure 5.1)

2. Changing the copack process. This measure provides some ICP(X) improvement and decreases the effect of an increased copack volume/week. Moreover, the current process requires much pallet handling since they need much transfer to different locations. Changing this process leads to less pallet handling, which relieves the operational workload. (figure 5.8 and 5.9)

3. Decreasing quarantine arrivals. This can be realized by loading and transporting quarantine goods as they are normal goods, while the quality checks are executed. (figure 5.4)

4. Decreasing conventional arrivals. Changing the delivery process to certain countries from transport by truck to transport by barges requires extensive research on the costs and benefits. The ICP(X) improvement is significant, but realizing fewer arrivals seems difficult. (figure 5.2)

The simulation model can be used to determine the effect of combined improvements on the ICP(X). This analysis can even be extended to take future characteristics into account. For the case study, the first two measures are combined. Specifically, the conventional throughput time is decreased from 5.5 to 3 days and the copack process is changed to the situation where the product is exported directly after the copacking process. Moreover, the copack volume/week is doubled as an example future situation. The result shows an ICP(4300) change from 70% to 97%, which means a major improvement of 27%, without investing in an increased inventory capacity. The result of this improvement is depicted in figure 6.1.

6.3.2. General case
As was described in chapter 6.2.2, the throughput time in inventory is a major cause and should therefore be improved to reduce the inventory level and therefore the risk of blocking. Some suggestions that help realizing this are:

![AsIs Vs. Future example](image_url)
- Arranging earlier transport from the warehouse
- Tighter scheduling of production, such that the time until transport is shorter
- Analyzing whether a fixed planning schedule can be adjusted to reduce throughput time. The Heineken case study illustrates that enabling production and transport in the same week would lead to a decrease in throughput time.

Another way of reducing the inventory level is to reduce the errors in ISC’s that cause products to be transferred to inventory. This might lead to promising results and should not be overlooked; however, human mistakes such as communication errors might require much effort to improve. Moreover, several errors in ISC’s actually cannot be reduced, such as bad weather that leads to delays. Therefore, it seems more rewarding to focus on reducing the throughput time in inventory.
7. Future research
From the research described in the previous chapters, multiple topics for further research can be derived. They are divided in topics regarding the Heineken case study context and general topics.

7.1. Heineken case study
The simulation model was developed with the assumption that truck capacity is always correctly planned. In practice however, problems with the truck shuttle capacity are encountered. When there is no slack in the truck shuttle capacity, a small delay can have large effects, since hardly any capacity is available to compensate previous delays. Moreover, delays in the truck shuttle with low capacity disturbs the continuous arrival of individual trucks which causes more waiting time, since places where trucks are handled include limited capacity. Future research on this topic can provide insight in the effect of poor planning of truck capacity on the supply chain performance indicators.

Another topic for future research is the separation between two parts of the inventory at the end of the brewery. The thesis research focusses on one part of the warehouse, however; more warehouse capacity is available, but physically separated by buffer lanes and the ATLS. Combining both parts of the warehouse provides more flexibility since the inventory capacity and loading dock capacity is shared. The downside is that radical rebuilding is necessary to realize the combination of both parts of the warehouse. Research on the tradeoff between rebuilding costs and benefits might be conducted.

The final suggestion for further research within Heineken is to determine whether buffer lanes can be better utilized. Warehouse management employees encounter situations where a buffer lane is saturated, which lead to transferring pallets to stock, while other buffer lanes are idle. Enabling a flexible use of the buffer lanes leads to a better buffer lane utilization and less handling due to transfer to stock. A study on the technical feasibility and software programs required should be conducted to gain insight in the costs and benefits of implementing flexible buffer lane utilization.

7.2. General case
As was described in chapter 6.1.2, more research on the required inventory capacity to prevent blocking in intermodal supply chains is needed. The case study seems quite representative, but more ISC’s should be examined to draw stronger general conclusions.

A more detailed research on the effect of specific intermodal characteristics on the inventory level is required, as was described in chapter 6.2.2. This research might focus on these characteristics only and their (quantitative) influence on the inventory level. Possible factors of importance are communication errors between multiple parties in the supply chain or the unavailability of empty containers.

In the case study’s context, the intermodal characteristics of the case study supply chain had a relatively small effect on the inventory level, compared to the effect of production errors for example. This might be caused by the short distance (14 kilometers) between the brewery and the next decoupling point; inland terminal Alpherium. The Heineken brewery in ’s Hertogenbosch (NL) issues a similar transport process with an even shorter distance (less than 2 kilometers) to an inland terminal that serves as the next decoupling point. Logistic managers encounter even less disturbances from intermodal characteristics of the supply chain starting in ’s Hertogenbosch, compared to the supply chain starting in Zoeterwoude. A short distance includes fewer possibilities for transport delays and enables fast compensation of errors in the transport shuttle operation. Besides, Uncertainty in the part of the supply chain behind the terminal is (partially) compensated by a stack of empty containers and inventory.
capacity. These findings suggest an interaction between the distance from a production site to the next decoupling point in an intermodal supply chain and the magnitude of the effect of disturbances on the inventory level at the production site. This effect might be examined in further research, for example by simulating virtual cases or comparing multiple intermodal supply chains.
8. References


9. Abbreviations

ISC’s  Intermodal Supply Chains
SMDP  Simulation Model Development Process
SME’s  Subject Matter Experts
WMS   Warehouse Management System
10. Appendix A: Conceptual model

10.1. Top level

The conceptual model is presented and described in this appendix. In figure 9.1, the top level of the IDEF0 model is depicted. The input for the system consists of finished products and after the export process, the product is at the inland terminal Alpherium in the right container. The export process is executed by both Heineken and Alpherium personnel and specifications about the product and order are required to correctly execute the export process.

![Diagram of top level IDEF0 model]

10.2. A0 manage export process

The A0 process consists of three separate processes A1, A2 and A3, and is depicted in figure 9.2. The first process is warehouse management on the Heineken site. The input consists of packaged products on pallets that can be directed to two output flows. The conventional and copack goods leave the warehouse in trucks and are of no further interest once they are sent to the customer. The second output flow consists for containerized export products that need to be transported to the Alpherium. The handling process in the warehouse depends on the product type, which is therefore necessary information for the Customer Service and Logistics department that is responsible for executing the warehouse management. Warehouse management is further explained in chapter 9.3.

The second process A2 obtains the output of A1, containers that need to be transported to the Alpherium, as input flow. The A2 process is the truck shuttle between the brewery and the Alpherium. The inland terminal is responsible for the truck shuttle and requires information about the container type that is required at the brewery. This information is provided by Heineken, which means that communication between both parties is important to ensure an efficient operation. The output is equal to the input, although the container is now located at the inland terminal.
Handling at the Alpherium is the third process and is named A3. At the inland terminal site, trucks and barges are handled, which is further explained in chapter 9.7. Specifications on the container type are required and all handling is conducted by the Alpherium. The output is containers that are on a barge, which is another step closer to the harbor.

Figure 10.2: A0 IDEF0

10.3. A1 warehouse management
The A1 process of warehouse management is depicted with more details in figure 9.3. This figure includes A11, A12, A13 and A14, which represent palletizing goods, crossdock process, inventory management and container loading respectively. After the packaging process, the final step of the packaging department is palletizing goods. The palletizing of goods depends on the specific pallet type that is required and is physically executed in the first part of the warehouse. The process uses boxes of goods as input and provides pallets with goods as output.

The crossdock process is an important process for the Customer Service and Logistics department. Pallets are transported on buffer lanes where they await loading; however, when buffer lanes become saturated, the pallets are transferred to the inventory. These two routes are represented by the two output arrows. The route can also be determined by the product mix, since conventional and copack goods are always transferred to inventory. The crossdock process is performed by automated buffer lanes, but can also be performed by forklift trucks in case of failures or the absence of a buffer lane, as was described in chapter 3.1.1. The crossdock process is presented with more detail in figure 9.4.

Inventory management is the third process within warehouse management. Pallets constitute both the input and output flow of this process. The Warehouse Management System (WMS) provides
information on pallet locations and available space in the warehouse. Forklift trucks physically execute the warehouse management, which is further explained in figure 9.5.

The final process of warehouse management is container loading. As can be seen in figure 9.3, container loading obtains two different input flows, which represent pallets that are directed loaded from the crossdock process and pallets that are loaded from inventory. Specifications about the order and pallet are required to ensure that the right pallets are loaded in the right container. The loading itself is executed by either the Automated Truck Loading System (ATLS) or by forklift trucks. The two output flows represent the flow of containers with conventional and copack goods, which is of no further interest once they are sent to the customer, and containers with goods that need to be transported to the Alpherium. The process of container loading will be further discussed in chapter 9.6.

Figure 10.3: A1 IDEF0

10.4. A12 crossdock process

The crossdock process is numbered A12 and is subdivided in A121 up to A124, as can be seen in figure 9.4. The A121 process is call container, which means the required container type is requested from the Alpherium. Pallets are both the input en output flow, because nothing changed about the product. However, the container call is important to ensure that the container is available once the pallets are ready for loading. The container call is executed by the WMS and requires the pallet and order specifications to request the suitable container.

Pallets are transferred towards the end of the warehouse, where the loading is executed. This transfer is executed by automated buffer lanes or forklift trucks, which depends on the production line at which the products are produced. At the end of the warehouse, pallets are transported to two pickup points for pallets that are routed to either the inventory or direct loading, which is depicted by the two output flows of A122.
The pallets are transferred towards the pickup point for either inventory (A123) or direct loading (A124). Both transfers are executed by a transfer car and require the pallet type as information to correctly transfer the pallets.

Figure 10.4: A12 IDEF0

10.5. A13 inventory management

The third process that was described in chapter 9.3. is inventory management (A13). As can be seen in figure 9.5, inventory management consists of three processes; pickup pallets for inventory (A131), (re)allocate pallets (132) and transfer pallets to loading area (A133) and all three are executed by forklift trucks. As soon as pallets are transferred to the pickup point for pallets that are routed to inventory, a light signal is shown, which triggers forklift trucks to pick up the pallets. Pallets are then allocated to a certain position in the warehouse, which is determined by the WMS. While pallets are in inventory, they might need to be reallocated to another position, which means the allocating process is repeated. When all requirements for loading are met, pallets might be picked up from their warehouse position and transferred to the loading area. This is again initiated by the WMS, which provides information to the forklift truck driver about the current pallet location.
10.6. A14 container loading

The final process within warehouse management is container loading and was briefly discussed in chapter 9.3. Three processes constitute container loading and the first is A141: pickup pallets at loading station or area. This process is executed by either a forklift truck or the Automated Truck Loading System (ATLS), depending on the pallet’s origin, which is provided by WMS. The loading stations are used in direct loading and loading areas are used for pallets from inventory.

Pallets are loaded into containers by forklift trucks or the ATLS, which requires information from WMS about the loading pattern. This process is named A142.

The third and final process of container loading is A143: unlock and seal container. The former is executed by the warehouse operator and the latter by the warehouse coordinator, who requires container and order specifications to check whether the container contains the right product. Combined, this is the final step in the container loading process, after which the container transport might commence.
10.7. A3 handling at inland terminal

The final part of the conceptual model is the handling at inland terminal. Three processes occur at the terminal’s site: handling trucks (A31), handling barges (A32) and empty container inventory management (A33).

Trucks with containers arrive at the terminal and need to be unloaded. The containers are picked up by reachstackers and placed within range of large cranes. The reachstackers require a container request, which was originally provided by the WMS (see A121), to load the correct empty container on the truck.

The second process of handling barges (A32) is similar to handling trucks, although empty containers are now unloaded and full containers are loaded on the barge. Handling barges is executed by cranes and by reachstackers and requires the container destination in the harbor as information, since barges travel to a specific harbor terminal.

Empty container inventory management is executed by terminal employees and reachstackers. The former determine the required empty containers from the harbor, based on current inventory position and a request forecast from Heineken. The latter executes the physical empty container management by relocating containers. This might be necessary when a container is located at the area which is restricted during the night.
Figure 10.7: A3 IDEF0