Designing an automated, efficient, flexible, scalable, and future-proof return hall in an automated retail distribution center

A conceptual design for a return hall at Hoogvliet Supermarkets

Beekman, E.W.

Supervisors

Chair of the committee:
Prof. Dr. R.R. Negenborn
TU Delft - Department of Maritime and Transport Technology

Committee members:
Ir. M.W. Ludema
TU Delft - Department of Engineering Systems and Services

Ir. M.B. Duinkerken
TU Delft - Department of Maritime and Transport Technology

J. Berkheij
Hoogvliet B.V. - Operational Manager Hoogvliet

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Preface

Dear reader,

The MSc thesis you are holding is the end product of 7 exciting months of work and the document with which I conclude my master 'Transport, Infrastructure, and Logistics' at the TU Delft.

First of all, I would like to thank Ir. M.W. Ludema and Ir. M.B. Duinkerken for their (personal) guidance and useful feedback. I would like to thank Prof. Dr. R.R. Negenborn for chairing my assessment committee and Patty Bokop-van der Stap for her patience and help in organizing the meetings.

I also want to thank Hoogvliet supermarkets. As a 15-year-old shelf stocker, I got to know Hoogvliet as a progressive supermarket that organizes its processes just a bit smarter than its competitors. I am grateful that I was allowed to contribute to their mission. In particular, I would like to thank Joost Pater and Johan Berkheij for their trust and instructive guidance over the past seven months.

Finally, I would like to thank my family and friends for their support during my graduation, and above all, God for His help.

Elwin Beekman
Delft, March 2022

Abbreviations

- AGV: automated guided vehicle

- Big bag: a transparent big plastic bag for empty bottles

- Breadcrates: crates which are used at the bakery of Hoogvliet to deliver all types of bread to the supermarkets

- DC: distribution center

- Dolly: A small steel loading carrier to store crates on

- DPS crate: dynamic picking system crate

- EPS: Euro pallet system

- EPT: Electric pallet truck

- Flower rack: racks that are used to store flowers boxes

- RC: roll container, used for delivering groceries to supermarkets, used as loading carrier for different types of wastes and crates in the reversed flow

- RIC: roll-in container

- System pallet: pallet in Witron system which functions as universal loading carrier

- Thermo: isocontainer which Hoogvliet uses to trasnsport frozen goods to the supermarkets

- Witron system: reference to the automatic infrastructure of the DC with associated software

Abstract

Background: With around 70 supermarkets, Hoogvliet is one of the smaller supermarkets in the Netherlands. During the past years, more companies have become aware of the importance of efficient reversed logistics (Senthil et al., 2018). By optimizing this return flow, the return hall of supermarkets plays an important role. With the expected increase of supermarkets that the same return hall must serve and the limited capacity of employees in mind, Hoogvliet wants to redesign its return hall. However, based on literature research, research is primarily done on reusable packaging systems instead of processes and the dynamics within a return hall. This article partly closes this knowledge gap with a conceptual design for the return hall of Hoogvliet, which gives insight in the efficient solutions and layouts within a return hall. Based on the brownfield of the return hall of Hoogvliets DC, this article aims to 'design an efficient, flexible, scalable and future-proof return and packaging hall, which solves the capacity issues in employees and workspace and increases the throughput of containers per hour.'

Method: A design method is used, derived from Dym et al. (1999), containing five phases. The first phase is called problem definition. In this section, the current situation is analyzed qualitatively and quantitatively. The qualitative analysis includes the system layout and the description of the processes within the return hall. The quantitative research focuses on the key performance criteria and the current and future volumes entering and going through the return hall. The design constraints and (non-) functional requirements are listed at the end of the first phase. In the second phase of this thesis, a conceptual design is made based on solutions found in literature and submitted by operational experts of Hoogvliet. These solutions are listed per process in a morphological chart and scored based on the predefined requirements. The solutions which obtained the highest scores are primarily used by creating designs. These solutions have resulted in three different designs; all validated based on the constraints. The third phase contains the model and evaluation of the design. With a simulation model, these designs are evaluated based on the performance criteria. The simulation is done in a simulation tool called Simio. Besides the current volumes, three scenarios of future inbound volumes are defined, which refer to the forecasts that Hoogvliet has made for the upcoming years. The fourth phase is called 'Optimize and implement the design.' This chapter evaluates the previous step's results and results in one optimized design. After all, a short implementation plan is made for this design. In the fifth phase, general findings, a recommendation and reflection is given.

Results: Analysing the current situation shows that 23 main processes can be defined. The quantitative analysis shows that the transportation of loading carriers is one of the most labor-intensive jobs. For all of the 23 processes, three designs are made called 'split waste and packaging' (1), 'carousel' (2), and 'completely automated' (3). All these designs are simulated for three future scenarios. The simulation shows that design 2 has the best score for transport and loading. However, design 3 obtains a higher overall score. The disadvantage of design 3 is the long inbound queue. With some improvements, the second design will get the most stable performance in the future and has an inbound line that is acceptable for Hoogvliet.

Implementation: The second design is advised to implement at the return hall of Hoogvliet. This could be done in different phases. First, Hoogvliet needs to make someone responsible for the implementation and coordination. One of his first tasks should be job standardization and allocation per employee, then relocating some sorting stations, and lastly, the different solutions could be implemented step by step. Per scenario, the estimated quantities per solution are given. Based on the developments in terms of growth, a separate floor is needed as a buffer zone for empty loading carriers, which is already part of the optimized second design of this thesis.

Concluding: The (different) conceptual design(s) give insight that closes the knowledge gap: (1) Transportation within return halls with the same processes significantly impacts the workload and should be eliminated as far as possible. (2) In the short term (<3 years), transport solutions could result in significant savings. (3) In the long term (>3 years), advanced automated sorting systems have higher savings than minor improvements.

Summary

Introduction

Since 2020, Hoogvliet supplies its supermarkets from a new automated DC in Bleiswijk. Although this DC uses advanced technology and has automated most of its in- and outbound flows, the return hall was left out of scope until now. Because of the expected growth in the number of supermarkets and the capacity problems in terms of employees and space, Hoogvliet wants to re-design the return hall. This results in the following objective of this thesis: *'Design an efficient, flexible, scalable, and future-proof return and packaging hall of an automated retail distribution center, which solves the capacity issues in employees and workspace and increases the throughput of containers per hour.'* This objective is achieved using the design method, which is derived from the process according to Dym (1999).

Based on a literature review is found that most research is done on return subprocesses or a whole return chain, but that an article which shows the efficiency of all different processes within the return hall and to a certain extent the flexibility and scalability of these different processes, is still missing. This knowledge gap is closed by comparing multiple conceptual designs of a whole return hall from a Dutch retailer and by evaluating the different designs based on how their performance will evolve, facing other throughput volumes.

Problem definition

Qualitative analysis

There are two input sources which are the interchangeable containers carried by trucks that return from the supermarkets. These interchangeable containers contain different types of loading carriers which needs to be sorted within the return hall.

The return hall is part of the automatic DC of Hoogvliet. The return hall is connected to the DC with different infeed points for crates and loading carriers but also with an outfeed for empty pallets and waste boxes from the DC. The second input source is the DC itself which supplies empty pallets that needs to be sorted and waste boxes which must be emptied and returned to the DC.

Based on a qualitative analysis of the return hall is found that 23 different processes take place within the return hall that needs to be designed. These are described based on a Gemba walk and shown in detail in process flows. The following processes are in scope for this design:

- Receiving and unloading container
- Sorting roll containers / thermos / RIC's / bread dolly
- Transport loading carrier
- Process roll container with old bread
- Process roll container with carton
- Process roll container with bio / residual waste
- Process roll container with orange peels
- Process roll container with big bags
- Process roll container with e-commerce bags and crates
- Process roll container with flower racks
- Process roll container with CBL crates
- Process roll container beer crates
- Infeed loading carrier
- Process dairy roll-in container (RIC)
- Infeed (bread) crate
- Process empty pallets
- Process waste bin with seal residuals
- Loading reusable packaging
- Loading big bags
- Change waste container Renewi
- Process non-food returns
- Cross-docking
- Process roll container with trash cans (future process)

There are three outbound flows: waste containers, suppliers that pick up reusable packaging, and the Witron system.

Quantitative analysis

The qualitative analysis consists in the first place on the key performance criteria which Hoogvliet uses. These criteria are the interchangeable containers that arrive per day and the hours used to process these containers. The team leader analyzes how many loading carriers are infeeded and how many interchangeable containers are not unloaded. These performance criteria are transformed into 'required hours per interchangeable container', 'payback period', 'estimated savings', 'queue length on inbound docks', and 'limited space per process' to make the design *efficient, flexible, scalable, and future-proof.* Also part of the quantitative analysis is the forecast Hoogvliet has made regarding the number of supermarkets. These forecasts contain (A) 100 supermarkets and (B) 120 supermarkets. The two forecasts are based on the situation in 2040. Based on the volume with 70 supermarkets in 2019 and the corresponding interchangeable containers, a linear forecast is made for interchangeable containers that arrive each day.

Business problem
The quantitative analysis is done on a more detailed level, the workload analysis, to identify the actual business problem inside the return hall. Based on own and historical measurements, a complete workload analysis is done to see which activity is most time-consuming and the share of productivity loss within the return hall. The 386 hours which are used on average per day can be split into six categories: unloading (9%), transport (27%), processing (29%), loading (6%), management (10%), and productivity loss (19%).

Design constraints, functional and non-functional requirements
Based on this thesis's objective and the problems found in the business problem section, some constraints and (non)-functional requirements are listed in consultation with Hoogvliet. The main general constraints are that the design must fit within the return hall and be possible to implement the solutions within five years. The only functional requirement that summarizes the return hall's performance is 'Throughput as many loading carriers per hour as possible. For some processes unit of 'loading carriers' is varied in a specific unit. There are five non-functional requirements listed: 'Should have as small as possible amount of working hours, 'Should have a short as possible payback period,' 'Should be as flexible as possible to cope with extreme peak hours/days/weeks,' 'Should have a lifetime which is as long as possible' and 'Should have the ability to identify deviant goods between the load.'
Because all proposed solutions are scored based on these (non-)functional requirements, a 5-points scale is made. The best solution is given 5 points and with this solution as reference point, other solutions are given lower points.

Conceptual design

Listing solutions
The relevant solutions for the design of the return hall are based on the current solutions and the solutions found in literature and input from operational experts. All solutions are based on proven technology to satisfy the constraint that the solution could be implemented within five years. The current solutions consist of Employee, Temp worker, Shredder, and Cardboard press. The proposed solution consists of Joloda Moving Floor, Conveyor belt, Scale, EPT, AGV Tugger, Chain track, CBL crates sorter, CBL stacker, Pusher, Beer crates sorter, Tilt table, R-CNN + Conveyor belt.

Scoring solutions
These solutions are connected based on their functionality to the subprocesses defined during the qualitative analysis. The score for the functional requirement is based on the numeric scale in main terms of loading carriers or interchange containers. To score the solutions for the non-functional requirements, in consultation with Hoogvliet, all solutions are scored at once per requirement. An explanation is given why some of the solutions have obtained a higher score.
This scoring results in a total ranking with solutions above and below average. The solutions that score far below average are eliminated to narrow the solution space to concrete designs.

Drawing designs
The proposed solutions result in three designs are shown below (a bigger picture in section 'Drawing preferred designs'). A legend table can be found in Table 4-2: Legend regarding conceptual designs.

Design 1: Split waste and packaging

Design 2: Carousel

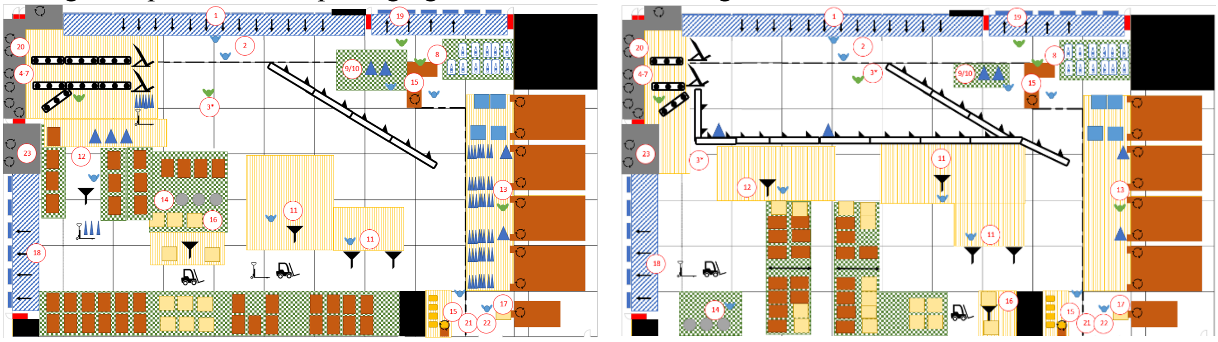

Figure 0-1: Conceptual layout of designs 1 and 2

Design 1 tries to split all waste and packaging as soon as possible from the loading carriers. Also, the beer sorting location is relocated to shorten the distance for beer crates within the return hall. All empty loading carriers at the sorting stations are transported with pallet EPTs to the infeed points, and the loading carriers that arrive empty in the return hall can be transported with the chain track.

Design 2 uses the chain track to deliver the loading carriers to the different sorting locations and transfer the empty loading carriers from these sorting locations to the infeed points. Also, the place for sorting empty pallets is relocated to an area close to the outfeed point of the Witron system to reduce this transport time.

Design 3: Completely automated – Ground floor

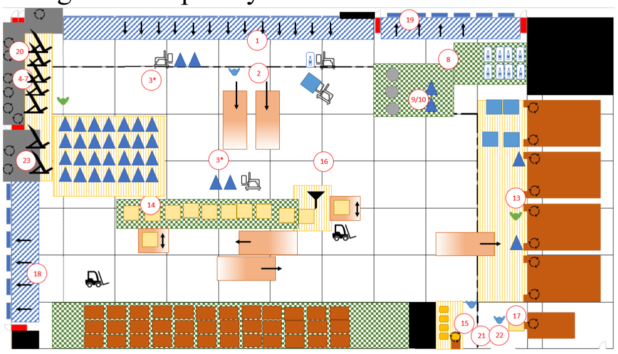

Figure 0-2: Conceptual layout of design 3 - Ground floor

Design 3a: Completely automated - First floor

Design 3b: Completely automated - First floor

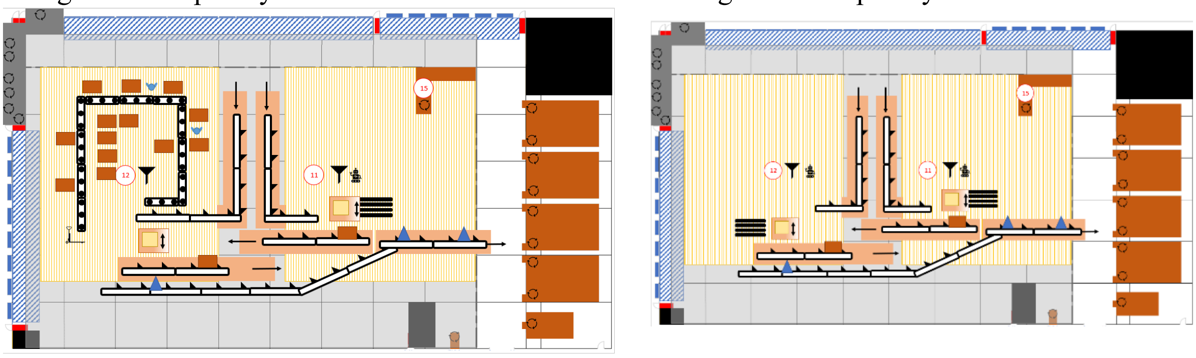

Figure 0-3: Conceptual layout of design 3a and 3b - First floor

Design 3 is the most advanced design, which automates the return hall as far as possible. AGV tuggers transport the loading carriers to the sorting or processing station on the ground floor. Full pallets are still transported with reach EPTs. This design requires a separate floor in the return hall for an automatic beer crate and CBL sorter. However, because automatic beer sorting is quite expensive, a manual alternative for beer sorting is proposed in design 3a. All (empty) loading carriers are transported with a chain track on a slope that connects the ground and first floor in this design.

Model and evaluate design

All layouts are modeled in a simulation model to estimate the required manual labor hours and compare the performance of the throughput of these designs.

Implementation of the simulation model

The designs are transferred per process into a modeling description and modeling objects. A simulation on scale is made in Simio which corresponds with the 22 of the 23 processes which are defined in the first phase (only the change of the Renewi container is not implemented since this process is performed by assistant team leaders which does not count for the required manual labor hours). The input, throughput and output are defined on the workload analysis. However, the input of the interchangeable containers is varied into three different arrivals to create a more realistic performance. The simulation outcome is based on the average of these three arrivals. The verification and validation are done by simulating the current layout for the current situation. Based on the outcome of required hours and the animation of the simulation model, could the model be validated and verified.

Experimental plan and motivation

The forecasts of 100 and 120 supermarkets and the differences in interchangeable containers could result in many scenarios. Therefore, three scenarios in the number of interchangeable containers are defined, which refer to the different inbound flows in the future. Currently, on average, 205 interchangeable containers arrive on an average day. Scenarios 1, 2, and 3 use a factor of 1.5, 2, and 2.5, respectively, which results in 308, 410, and 513 interchangeable containers. Because the layout and capacity per design may slightly change in the future, the modeling improvements are defined for each design. In the end, the current layout (as reference), design 1, design 2, design 3a, and design 3b are simulated for the three scenarios, resulting in 15 simulations.

Results and evaluation

The simulation results are evaluated based on the performance criteria as defined in section 'Key performance criteria'.

<u>Required hours per interchangeable container</u>

The required hours per process are split into unloading hours, transport + loading hours, and processing hours. Design 3 obtains, of course, the lowest score for unloading since this process can be fully automated. The transport and loading hours are most stable and efficient performed by design 2. The required hours for processing activities are the lowest for design 3b.

<u>Payback period</u>

Compared with the current layout and additional investments for future scenarios, the shortest payback period is obtained by design 2, which has an expected payback period of 0,5 years for the current situation. The most extended payback period is the complete automated design 3b with a period of 4 years, which can be reduced to 1.5 years in scenario 3.

<u>Estimated savings</u>

The estimated savings assume that all solutions will last for ten years. For the current situation, design 3a has the highest expected savings of €8.2 million, which is €820.000 per year. The lowest expected savings are obtained by design 1 with €41.000 per year. Increasing the volume as defined for scenario 3, design 3b will have the highest expected savings of €2.6 million per year.

<u>Queue length on inbound docks</u>

The higher the inbound volumes of interchangeable containers, the higher the pressure on the inbound docks. For the current situation (scenario 0), the shortest queue is obtained by design 3; however, for scenarios 2 and 3, the longest queue rises for design 3. The most temporary queue for scenario 3 is obtained by design 1.

Limited space per process

The allocation of the surface for each sorting station is computed whether the amount of loading carriers in the input or output buffer does not exceed the limited space. Especially for scenario 3 is shown that a buffer zone is needed for empty loading carriers since the capacity of infeeding these loading carriers is too low to process the supplied amount of loading carriers.

The results per criteria and design are summarized based on an average of scenario 1-3 in Table 0-1: Average result per performance criteria.

Table 0-1: Average result per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Unloading hours per container	0,14	0,15	0,00	0,00
Transport and loading hours per container	0,56	0,46	0,47	0,46
Processing hours per container	0,61	0,61	0,30	0,26
Required hours per container	1,31	1,22	0,77	0,73
Payback period	185	80	484	849
Estimated savings per day	€ 1.198	€ 2.727	€ 7.672	€ 8.361
Queue length on inbound	647	717	1980	1917
Limited space per process	limited by sc. 3	limited by sc. 3	limited by sc. 3	limited by sc. 3

Results are based on the average of scenario 1-3.

To determine which two designs are the most preferred designs, a ranking score is given per criteria. The two solutions which has overall the best ranking are chosen as the preferred designs.

Table 0-2: Ranking per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Required hours per container	4	3	2	1
Payback period	2	1	3	4
Estimated savings per day	4	3	2	1
Queue length on inbound	1	2	4	3
Limited space per process	1	1	1	1
Total ranking	12	10	12	10

Based on Table 0-2: Ranking per performance criteria is concluded that design 2 and 3b are the preferred designs which will be fine-tuned in the next chapter. This fine-tuning will refer to the problems that are found during simulation and extension or optimization of solutions that are already proposed.

Operational problems that are found by simulation:

- Limited space per process in scenario 3 for both design 2 as design 3b.
    - This applies to the chain track capacity in design 2 and the AGV Tugger capacity in design 3b.
- Long inbound queue's, for design 3b.
- Prevent waiting times for the AGV's at the bread infeed point, for design 3b.
- Prevent long walk trips for employee's with return or cross dock loading carriers, for design 2.
- Infeed points not optimal used, for design 2 and design 3b.

Optimize and implement design

Improvements to design 2 and 3b

Because design 2 and design 3b obtain overall the best performance for the defined criteria, these layouts are improved to get better performance, based on the evaluation per design. For design 2, the chain track is extended to put the loading carriers on this track in front of the inbound docks. Also, a separate floor is proposed, which functions as a buffer zone for empty loading carriers. Design 3b has to improve the inbound performance. However, this unloading should be performed manually because of the limited space at the inbound docks. Also, some minor improvements on job allocation are made for both designs.

Results and second evaluation

The results for per criteria are summarized in the table below.

Table 0-3: Comparison improved design 2 and improved design 3b

Criteria	Improved design 2	Improved design 3b
Unloading hours per container	0.14	0.15
Transport and loading hours per container	0.45	0.62
Processing hours per container	0.61	0.25
Required hours per container	1.19	1.01
Payback period	0.23 year	1.96
Estimated savings	€13.456.848	€ 17.880.002
Queue length on inbound	One small peak of 600 loading carriers waiting	900 loading carriers on average waiting
Limited space per process	Does almost not exceed the capacity	Exceeds capacity

Based on the last two rows of this table, improved design 3b still has no stable inbound flow, exceeding the inside capacity. This is why a layout like design 2 is advised.

Implementation

The first step is making someone responsible for the coordination and implementation of the design. The costs as defined in section 'Proposed solutions' indicate the costs, but these should be evaluated in more detail by requesting a quote from multiple suppliers. Then, job allocation per employee should be introduced as far as possible to streamline the processes and, as a side effect, better evaluate the performance of your employees. The implementation of this design should be done step by step to avoid interrupting the business. This should be possible by first relocating some servers. Then, step by step, the proposed solutions can be implemented using the conceptual drawings and estimated quantities per scenario as defined in section 'E.4 Quantities per solution and investment cost per design' and 'F.5 Quantities per solution and additional investment costs per scenario'.

Closing knowledge gap

Based on these outcomes and the outcomes presented in section 'Results and evaluation,' the following findings refer to the knowledge gap and objective.

- Peak arrival rates result in long queues throughout the whole day;
- Manual inbound processes for small return halls with higher capacity and throughput;
- Transportation within return halls with the same processes has a significant impact on the workload and should be eliminated or automated as far as possible;
- In the short term (<3 years), transport solutions could result in significant savings;
- In the long term (>3 years), more advanced automated sorting systems have a higher savings than minor improvements;
- Work standardization, also for manual transportation, streamlines the whole throughput;
- Enough output capacity (such as infeeding capacity for roll containers), solves many blocking issues in previous processes;
- Enough (buffer) space is essential for an efficient throughput.

Regarding to the efficiency, and to a certain extend, flexibility, scalability and future-proof level of the return hall, it can be concluded that:

- A stable inbound process at the return hall is important for an efficient throughput;
- Automating transport activities will most likely pay for itself;
- Job standardization will increase the efficiency of the return hall;
- Using multiple docks makes the return hall more flexible because of the higher inbound capacity. However, this flexibility is limited as long as the transport, processing and buffer capacity are not as high as the inbound capacity;
- Important to allocate allowable space per process in future scenario's and use buffer zones to ensure the scalability of the return hall.

Academic recommendations

The design proposed in the previous sections aims to be efficient, flexible, scalable, and future-proof. The evaluation of this design has shown that a primary limiting factor is an available space for all processes that need to be performed. Therefore, it is recommended to research the general area or optimal layout for an efficient, flexible, scalable, and future-proof return hall. To see whether a return process is flexible and scalable, it is recommended to investigate the use of multiple return halls and different arrivals.

Besides the available space and layout of the return hall, it is recommended to do further research on the efficiency of the detailed processes within the return hall. Especially the processes of CBL crate sorting and beer crate sorting, which are hard to automate, can be further investigated. Since this automation is not commonly used, there is not much knowledge on the pros and cons of these systems and their performance level.

Thirdly, with the detailed knowledge of these automation systems, extending the simulation model, which is built for the return hall of Hoogvliet. With this information, it is possible to investigate the impact of the reliability and performance of the servers on the throughput of the return hall. In the simulation, which is done, is chosen to model the processing times in a random triangular way with 10% above and below average as a limit. However, since most of these processing times rely on manual activities, this could differ per employee. Scoping to a (couple of) process(es) and fine-tuning parameters could improve the outcome's reliability and give opportunities to enhance the design further. Also, improvements can be made regarding the employees and vehicles that are modeled. The capacity of these employees and cars is now fixed based on an average. Still, in practice, the amount of loading carriers that an employee or EPT can transport depends on the loading carriers' weight and stability. A possible subject for future research is to investigate the impact of more standardized loading carriers (prepared at the supermarket) on the efficiency of the return hall processes.

Practical recommendations

This thesis aims to make a conceptual design for the whole return hall. Because this design is conceptual, it is possible to design 23 processes simultaneously, but on the other hand, some practical details can be overlooked in this thesis. For a detailed implementation plan, doing thorough research per process instead of 23 processes simultaneously would be recommended. Based on the workload analysis, this detailed research can be prioritized regarding potential working hours that can be saved.

Besides optimizing the processes themselves, improving the performance management within the return hall is recommended. Also shown in the workload analysis is that 19% of the hours spent per day are based on productivity loss. It is an illusion to reduce this percentage to 0, but a better task division, job standardization, and logging activities per employee could result in a higher productivity level.

An extra floor is proposed regarding the advised design in the third scenario. This seems possible because of the return hall's height; however, this must be analyzed from an architectural expert and constructors point of view.

The functionality and the efficiency of the proposed solutions are based on the information that suppliers give. However, a pilot setup is advised to evaluate the actual performance or efficiency increase for some answers, such as the tilt table and chain track.

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1 Introduction

1.1 Design context

1.1.1 Background of Hoogvliet supermarkets

In this thesis, a conceptual design is made for a return hall of an automated distribution center of a small retailer in the Netherlands named Hoogvliet B.V. Hoogvliet is one of the smaller supermarkets in the Netherlands. With around 70 supermarkets, it has a market share of 2.1% (Distrifood, 2020). Nevertheless is Hoogvliet an innovative company with its recent build automated warehouse in Bleiswijk near the A12. This distribution center covers almost all supplying activities to the 70 supermarkets. Hoogvliet has the ambition to increase to 100 supermarkets in 2040 which can be delivered from this DC (De Weerd, 2020).

The DC in Bleiswijk contains almost all supplying activities for Hoogvliet with a bakery, butchery and fresh goods in store. Daily fresh articles such as milk and flowers are cross-docked at the DC. The same method applies to the E-commerce goods. The preparation of E-commerce orders is currently done in the old location of Hoogvliet in Alphen aan de Rijn and transported by trailers to the DC of Hoogvliet. At the expedition hall in the DC, all these flows are combined and distributed in interchangeable containers.

An important component of this supply chain is the transport activity. Hoogvliet arranges the transport from the DC to the supermarket with interchangeable containers. These are picked up at the DC and dropped at the supermarket. Another container is picked up from the supermarket and dropped at the distribution center. Besides the transport lane from the DC to the supermarket, the transport from supermarket to consumer (home delivery), is also in scope for some of Hoogvliets supermarkets.

The retail supply chain from supplier to consumer, has also a reversed flow. This flow has multiple starting points, for example, with the consumer who uses recyclable bottles and brings these bottles to the supermarket and receives his deposit. Other flows in the reversed flow start at the supermarket (e.g. empty crates or cartons) or at the distribution center itself (e.g. empty pallets). From the supermarket, this reversed flow continuous with the interchangeable containers to the DC. This reversed transport activity is also done by Hoogvliet itself. By doing so, the general retail supply chain is dominated by two echelons of the same company. This DC is the main echelon in the supply chain which Hoogvliet is part of. The reversed chain can be found in Figure 1-1.

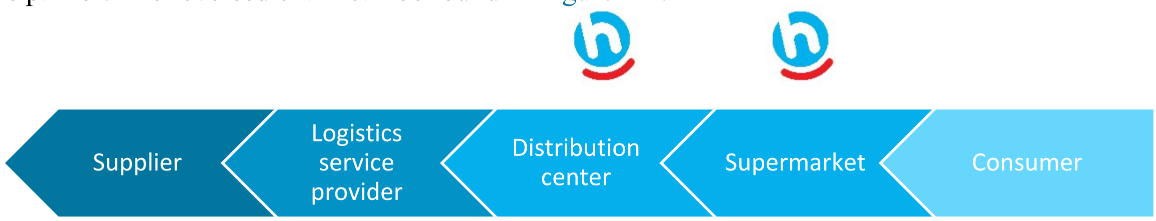


Figure 1-1: Reversed retail supply chain Hoogvliet is part of

The design of the return hall is not a total greenfield but has to do with several restrictions. This is based on the position of the return hall at the DC of Hoogvliet and the arrival of trucks (red arrows) at this DC. This is shown in Figure 1-2: Map of Hoogvliet DC Bleiswijk (Google Maps, 2022)

Figure 1-2: Map of Hoogvliet DC Bleiswijk (Google Maps, 2022)

The receiving and unloading of the interchangeable containers at the DC is defined as the main input of the return hall processes. The second input is the empty pallets and waste boxes that flow out from the DC. The throughput contains primarily sorting processes. These processes are hardly the only processes that are not automated in the DC. During the automatization of the new DC, the return hall has not the focus of the management of Hoogvliet which leads to a practical, manual solution for the return hall. The DC manager of Hoogvliet explained that these manual processes are too costly at the moment. Currently, employees are assigned ad hoc to their task, depending on which subprocess has the highest priority. This makes it hard for the team leaders of Hoogvliet to manage the performance of the employees.

Besides, the limited capacity of enough skilled employees, the limited space within the return hall and the low throughput per hour are problems that are experienced by Hoogvliet. The output of the return hall is the suppliers which pick up reusable packaging, waste in the containers and the loading carriers and crates that are intended for the automated DC. In Figure 1-3: Blackbox representation of the return hall a schematical representation of the system is given.

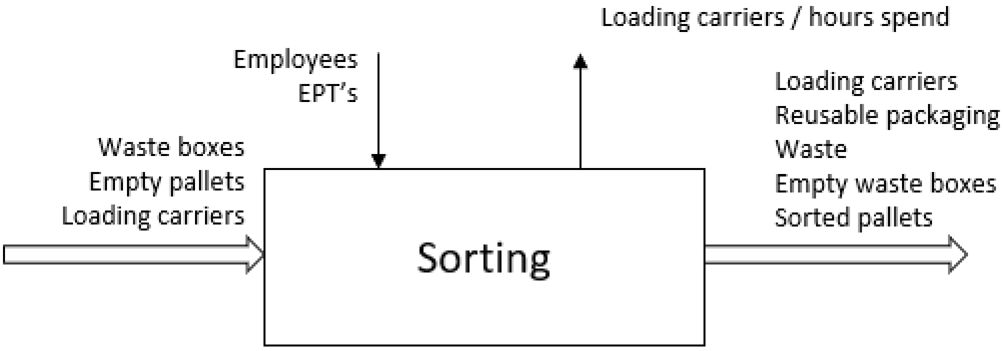


Figure 1-3: Blackbox representation of the return hall

1.1.2 Dutch automated retail DC's

Automated retail DC's are relatively new within the Netherlands. There are currently three conventional supermarkets that has an automated warehouse and one dedicated e-commerce supermarket. Besides, one supermarket is currently building a new automated warehouse which is expected to be operational near the end of 2022. An overview of these supermarket companies, the moment of being operational, the company who automates the supermarket DC and market share (for conventional supermarkets) are given in Table 1-1.

Table 1-1: Automated retail warehouses within the Netherlands (Stad, 2019. Redactie Transport online, 2020. Weerd, 2017, 2020, Redactie BD, 2021 Statista. 2021)

Supermarket	Operational since	Solution	Market share
Albert Heijn	May 2019	Vanderlande	35%
Hoogvliet	January 2020	Witron	2%
Jumbo	August 2020	Witron	21.5%
Picnic	June 2021	TGW	*
Plus	End of 2022 (expected)	Witron	6.7%

*: Picnic is only an e-commerce retailer which is not part of the market share for regular supermarkets.

According to Table 1-1: Automated retail warehouses within the Netherlands (Stad, 2019. Redactie Transport online, 2020. Weerd, 2017, 2020, Redactie BD, 2021 Statista. 2021) Hoogvliet is the smallest company within the Netherlands that fully automates his distribution center. Because of this scale differences, the company has to think smart and a step ahead in comparison with its competitors.

1.1.3 Reversed logistics at (automated) retail DC's

According to Statista (2021), there are many different supermarket companies within the Netherlands, These companies organize their reversed logistics in their own way which could be separated between an outsourced revised flow and an internal reversed flow. Whether is chosen for an outsourced or internal reversed flow, also depends on the transport strategy of these companies. Companies that organize their transport (Jumbo, Hoogvliet, Plus), also organize the returns within their distribution center. According to a former employee of Albert Heijn, J. Medendorp, the transport of Albert Heijn is outsourced by Simon Loos Logistics and the reversed handlings are outsourced to Kuehne+Nagel as so-called 'aftermarket services' Kuehne+Nagel (2021). Although two other retail companies choose the same automated solution, the reversed flow within these companies (Jumbo, Hoogvliet), do slightly differ. Besides the differences in transport and outsourcing, the processes within a return hall are determined by the cash flow within these companies. That is wh some companies like Jumbo and choose to have franchise entrepreneurs who 'own' one or more supermarkets. This means that every crate or reusable packing material is a property of the franchise entrepreneurs. However, Hoogvliet has its own supermarkets which makes it less relevant to trace each crate or waste volume. For all supermarkets applies that this reversed flow is not part of their revenue model and that they want to minimize the number of returns.

These differences in background result in different approaches and processes within the reversed flow of these companies. Tracking and tracing of the reusable packaging is very important for companies like Albert Heijn and Jumbo, but not for Hoogvliet. However, zooming into the basic return processes within the return hall (external or internal), the same processes apply since the same types of waste, reusable packing and crates are used. How each company exactly executes this sorting and processing operation is not known, but in the end, each company tries to have a closed-loop and cash flow and wants to optimize their reversed flow. Also for supermarkets which not already have automated their distribution center, could this design be relevant. This is because of the fact that not all of the processes that take place within the return hall have a connection with an in- our outfeed system of the automated warehouse.

1.1.4 Reversed logistics in literature

As background information, this section focuses on what is described in literature on reversed logistics and the design of return halls.

Topic of growing importance

Based on a literature study, Agrawal et al (2015) claim that reversed logistics has become a more relevant topic in research for companies and according to Senthil et al (2018) is the relevance of reversed logistics strengthened at an increasing rate by the strict environmental regulations. This knowledge field is growing due to the importance of growing environmental concerns and legislation. Besides, there is more focus on sustainability and social responsibility.

According to Rogers and Tibben-Lembke (1998) reverse logistics or reverse supply chain, can be defined as "the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin to recapture value or proper disposal."

The reversed chain is important because the costs depress the profit of the retailers. This is why, according to Badenhorst (2013), the focus on reversed logistics started to increase. Badenhorst suggests that many retailers can not decrease the costs in reverse logistics since they do not actually know where these costs come from. With some guidelines, he tries to create insight for companies in their reverse cost structure.

Returnable packaging

Looking into the echelon of the distribution center within this supply chain, the returns contain mainly the reusable packaging and roll containers. According to Hellström (2007), the packaging is classified into primary, secondary and tertiary packaging. Primary packaging means the package of the product itself, produced by the manufacturer. The secondary packaging means the tray or crate e.g. The tertiary packaging is the pallet on which all trays or crates are stacked. The reverse flow at the distribution center contains secondary and tertiary packaging. Regarding reversed logistics and packaging, a lot of conflicts could arise because many different stakeholders are involved (Demajorovic, 2019). This makes it hard to create an efficient and optimal reversed chain. Contrary to this, Demajorovic suggests that these conflicts enforce a debate and further research on the optimization of this reverse flow for retailers. After all, the optimal reversed chain is determined by how the transport is organized. This is why the transport stakeholders should be involved as well (Hooft, 2017).

Technology and sustainability

Nevertheless, optimization and automatization of the reversed chain is important topic in literature. According to Haddioui et al (2021), the market share of the global warehouse automation market, grew more than 10% since 2015. And also more than 55% of the retailers, manufacturers, and logistics professionals currently investigating warehouse automation, which probably will double the market share of global warehouse automation in 2026.

According to Antonyová et al (2016), many trends in the reversed chain are connected with technology and innovation. According to Ellsworth-Krebs et al (2022), this (advanced) technology such as Digital Passports is needed in the reuse of material and packaging, but also in the interaction and communication within the whole chain. Also, Kokkinaki (2004) already suggested that technology is one of the main factors which is the driving force in innovation.

Moreover, Antonyová (2016), claims new trends such as sustainability (which consists of many topics), the reintervention of decision making within this reversed chain, and the funds for big innovation such as automation. On the other hand, fewer companies have already automated their reversed chain but the first step of awareness and need for change is proven.

Once companies consider automation, research is done on whether this automation suits the business operation and how different scenarios have an impact on their performance. This is why Beiler (2020), tries to understand this impact with simulation. Not only performance but also the level of sustainability

can be simulated. According to Beiler and Stuijt (2021), a closed-loop supply chain is needed to guarantees this level.

1.1.5 Defining Knowledge gap

The previous section shows that a lot of research has been done on reversed logistics and reusable packaging systems. Besides the research which is related to returns and return systems, several actual designs and design tools are made. According to Long et al (2020), these designs are driven by the threat of the sustainability of the environment because much packaging is not re-used and is thrown away. This is why Long proposes a design tool to understand reusable packaging systems which helps reusable packaging experts in creating a design. Regarding concrete designs for reversed logistic processes, only a subprocessor a whole chain is designed, such as by Langevelde (2021), Supriyanto (2021), Stuijt (2021), Hooft (2020). And, as an example, for the process of delivering waste containers to a return hall, a wrapping solution is proposed (Dixon-Hardy et al, 2009). These articles and designs give insight into how processes or a reversed chain should be designed. *However, an article that shows the efficiency of all different processes within the return hall and to a certain extent the flexibility and scalability of these different processes is still missing.* This knowledge gap will be closed with a comparison between multiple conceptual designs of a whole return hall from a Dutch retailer. Besides varying the layout of the return hall, the different designs will be evaluated based on how their performance evolves over time with different throughput volumes. The objective of this thesis is defined in section 'Design problem and objective'.

1.2 Design problem, objective, and questions

1.2.1 Design problem and objective

The knowledge gap which is found in the previous section relates to the business problem of Hoogvliet. Although in literature many design tools are made regarding reversed logistics and reusable packaging, dynamics within a supermarket return hall is not analyzed. The proposed design will give insight in the dynamics by, for example, computing the difference in efficiency per design for the different processes within a return hall and thereby closes the knowledge gap.
In general, this thesis aims to improve the performance of the return hall at Hoogvliet's DC with a conceptual design. Currently, the only layout which is known is the current layout of the return hall, which is based on practical operational knowledge. The proposed design should eliminate the issues which are just listed. This design is based on the current volume but must handle a certain increased volume as well to remain stable. The improvement refers to the objective, which contains several issues: limited space on the floor, limited capacity of working hours (will become probably worse), and throughput of containers per hour which is too low. Lastly, there are peak hours/day's/weeks, which causes problems, moreover because performance management is done on an ad hoc basis by (assistant) team leaders walking around.

The defined knowledge gap and business problem are answered with a design which gives insight in the missing knowledge. The objective is defined as:

Design an efficient, flexible, scalable, and future-proof return and packaging hall of an automated retail distribution center, which solves the capacity issues in employees and workspace and increases the throughput of containers per hour.

The objective will be underpinned in more detail after the current and expected future situation is analyzed in section 'From business problem to objective'.

1.2.2 Design questions

The main objective of the previous section is split into five phases with a general sub question per phase. At the most detailed level, these general sub questions are split into detailed questions which give concrete steps to a conceptual design as a solution to the general question. These steps are based on the engineering design process derived from the design method according to Dym et al (1999). This method will be elaborated on in the next chapter.

Phase 1: Problem definition

1. *What does the return process look like?*
    a. *What does the current return process look like and what are the performance criteria for this process?*
    b. *What will the future scenarios for this return process be?*
    c. *What are the design constraints, requirements and functions for the return process?*

Phase 2: Conceptual design

2. *What are the preferred designs which solve the requirements and functions?*
    a. *What are the possible designs that commit to the requirements?*
    b. *How do these solutions compare per requirement?*
    c. *Which preferred designs can be made from the best-scoring solutions?*

Phase 3: Model and evaluate design

3. *How can the preferred designs be tested or simulated to evaluate the performance criteria?*
    a. *How can the preferred designs be tested?*
    b. *What is the score of the preferred designs on the defined criteria?*
    c. *How can the preferred designs be evaluated based on this score?*

Phase 4: Optimize and implement design

4. *How can the preferred designs be improved based on the evaluation?*
    a. *What modifications can be made to the preferred designs?*
    b. *How affect these modifications the preferred designs?*
5. *How can the preferred designs be implemented?*

Phase 5: Conclusion

1.3 Outline

The structure of this thesis follows the designing steps derived from the design method according to Dym et al (1999). Each phase of this approach is supported by several (sub)questions. The structure of the chapters in this thesis is related to these questions which can be found in Table 1-2: Thesis structure

Table 1-2: Thesis structure

Chapter	Question
2. Methodology	
3. Problem definition	1 - What does the return process look like?
4. Conceptual design	2 - What are the preferred designs which solve the requirements and functions?
5. Model and evaluate design	3 - How can the preferred design be tested or simulated to evaluate the performance criteria?
6. Optimize and implement design	4 - How can the preferred designs be improved based on the evaluation? 5 - How can the preferred designs be implemented?
7. Conclusion	*Design an efficient, flexible, scalable and future-proof return and packaging hall of an automated retail distribution center, which solves the capacity issues in employees and work space and increases the throughput of containers per hour.*

2 Thesis Project Methodology

In this chapter, the design approach with different design phases is explained and it has been argued why the used methods are suitable for this thesis. Furthermore, the scope of the thesis and the data requirements are analyzed.

2.1 Design approach

Each design phase contains several activities and of course uses different methods. In this section, the different design phases will be explained and the proposed methods within these phases are given based on the activities that should take place. The different phases and activities are shown in Figure 2-1: Design method derived from Dym et al (1999).

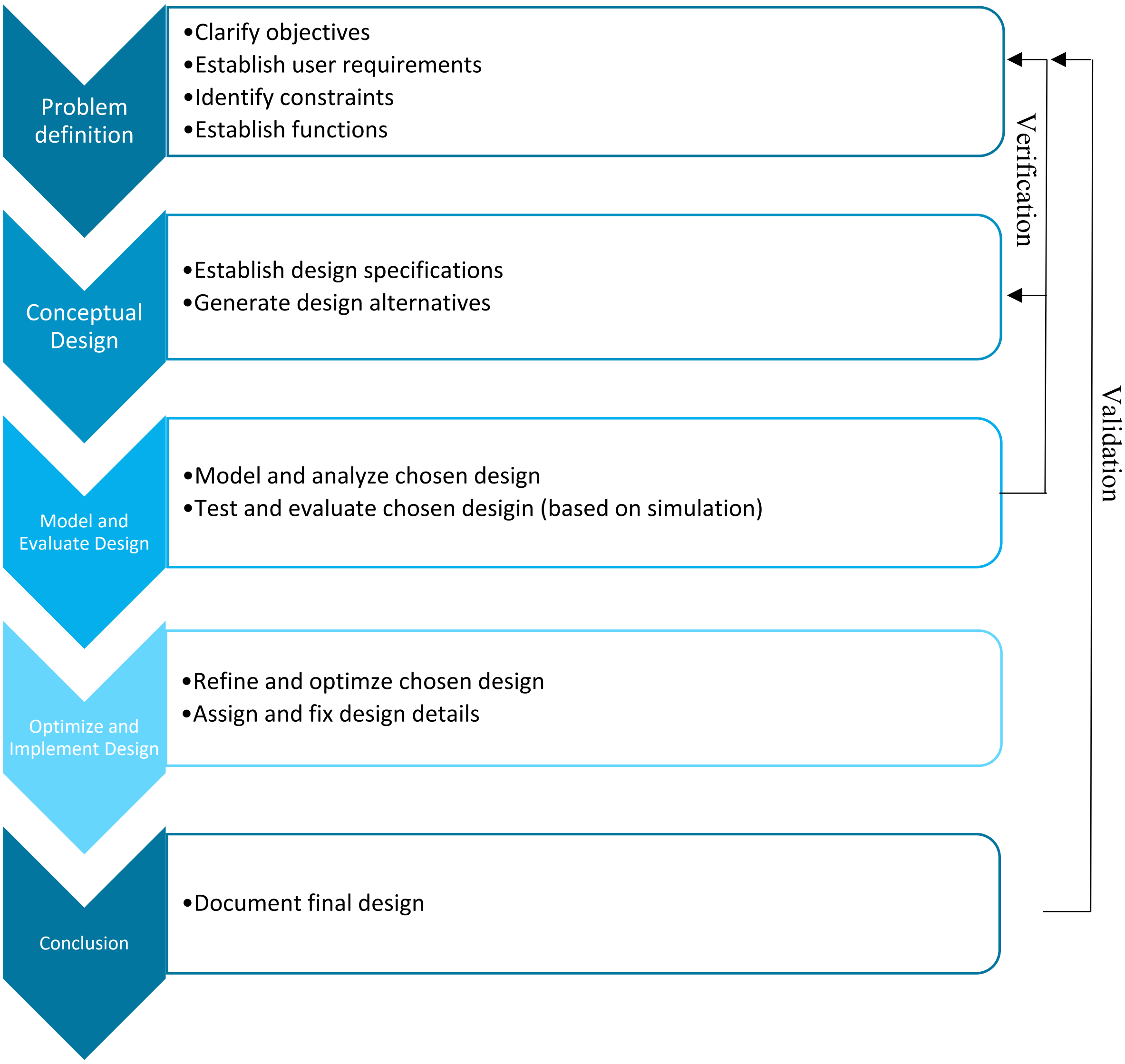


Figure 2-1: Design method derived from Dym et al (1999).

Problem definition

During the problem definition phase, a qualitative and quantitative analysis are made on the current situation, which are the basis for the definition of the business problem and to list the constraints and requirements of the design.

The main purpose of the qualitative analysis is to define the process that take place within the return hall. Because there is no description of the processes available, this analysis takes place on site. A suitable method is the Gemba Walk which is a lean method that is used to understand the day-to-day business on the work floor (Lange, 2019). In practice, the operations can hugely differ or be disrupted in comparison with the general work appointments. To visualize the physical flow and dependency of the different processes per loading carrier, a swim lane diagram is made. A swim lane indicates what a certain loading carrier has to 'do' in the return hall (Janse, 2020). Furthermore, to categorize activities and to connect the functionality of different process to solutions, a functional flow block diagram is made. A functional flow block diagram shows the different actions that take place and whether these activities are performed in series or parallel (Blanchard et al. 1990).

This qualitative analysis should be supported with quantitative data as well. This data could be provided partly by Hoogvliet and will also be collected by field measurements.

The next step, is a more in-depth workload analysis to identify the business problem. Based on this business problem, the constraints and requirements for the design can be listed. These are gathered with expert's interviews and could also be obtained by some literature research.

Conceptual design
With the input of the objectives, constraints, requirements, and functions, the conceptual design phase can start. This phase contains a morphological chart and a multi-criteria analysis. The possible designs are generated with a morphological chart. This chart contains the different subprocesses on the y-axis and the methods how to perform each subprocess on the x-axis. Based on constraints and (non-) functional requirements a combination of these subprocesses is made as a possible design. Which solutions are most suitable for the conceptual design, is defined with a multi-criteria analysis with the use of the functional and non-functional requirements. The weight and score per requirement and solution are given by the supervisors from Hoogvliet.

Model and evaluate design
After the design choice, this phase contains a first test set-up which will be made in a simulation model. This model will estimate the performance in terms of the defined KPIs by Hoogvliet. With this simulation could also be tested whether the process is future-proof. This is analyzed based on the performance criteria and by manipulating the volume in peak hours. By doing so, the simulation shows whether the process remain efficient by an increase of a certain amount of loading carriers per hour.

Optimize and implement design
After the evaluation of the previous phase, the components which has the lowest score in their criteria are reviewed. This will result in two designs which are improvement further and finally, one optimal design is chosen, which has a higher score on the performance criteria.

Conclusion
As a result of this thesis, a final proposal for a design will be given. This proposal summarizes the results of the preferred designs, closes the knowledge gap and gives recommendations for future research.

2.2 Scope of the thesis, data requirements and deliverable

The supply chain as discussed in the first section has several stations and flows. This thesis will focus on the retail DC of Hoogvliet with respect to the return flow from the supermarkets to the DC as well the return flow within the DC. This covers the receiving and unloading of the interchangeable containers and the sorting of the different types of waste, packaging and roll containers.

Investigating this part of the supply chain, the interaction with the supermarkets, the reversed flow with suppliers and the regular flow at the DC (to the Bakery, Butchery, infeed for regular outbound) are also involved. This is shown in Figure 2-3.

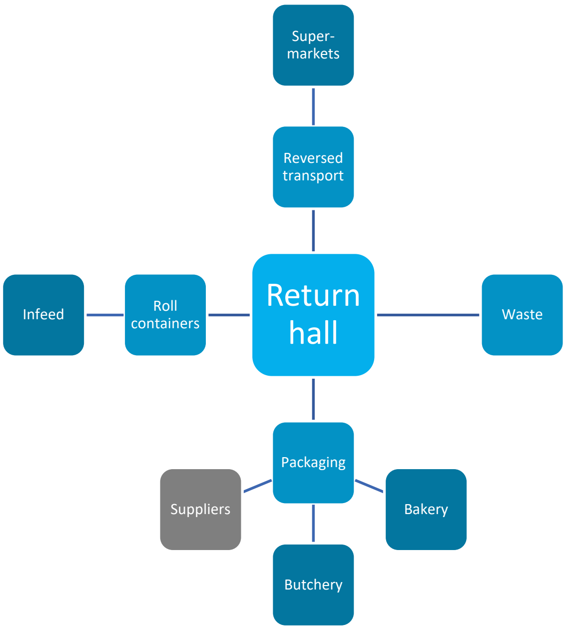


Figure 2-2: Scope of thesis with adjacent components

With these components in mind, this investigation will search for mechanization and automatization within the return hall. Many handlings within this return hall are performed manually. Also for mainly automated warehouses such as Hoogvliet, this process is still performed manually. For the conceptual design is tried to find the opportunities to mechanize and automatize the whole return hall. The goal period for implementing such solution will be around five years.

Although this design contains a whole new layout for the return hall, many values and parameters should be kept. These will be covered during this thesis. Also the future effects and goals of Hoogvliet should be integrated. The prognosis for 2040 is taken as a reference point.

2.2.1 Data requirements

There is almost no other data available within the return hall which controls the process than the actuals of hours spend, containers in, and pallets/waste/containers out. Data which is retrieved from the floor gives insight in the waste and actual performance.

The data which will be provided by data engineers of Hoogvliet, has an important role in making the design work. Especially the data which will be used to simulate the performance of the chosen design has to be significant Although this data is speculative because this involves future (uncertain) scenarios, the lower and upper bound will give insight in the performance level which will be obtained.

2.2.2 Deliverable

The deliverable of this thesis is a conceptual design for the return hall of Hoogvliet. This design contains conceptual drawings regarding the layout and chosen solutions. The solution which is used in these drawings covers the different processes of the return hall at this moment, but is also prepared for future processes and volumes.
Besides the conceptual drawings, the return hall is analyzed and evaluated in a quantitative way. This is done with a simulation model on scale. This simulation gives insight into the established performance criteria, even for future volumes. Based on the quantitative outcome, two designs are improved to a more optimal performance and again simulated. This results in one final design which is advised. After all, several recommendations are made and some implementation steps are proposed. With this information, Hoogvliet has all knowledge en insight at hand to start with the detailed design and implementation of the new solution for the return hall.

Things which are not part of this design are proformas and technical specifications of the solutions.

3 Problem definition

In this chapter, an answer is given to the following question:

1. *What does the return process look like?*

This question is split into four sub questions:

a. *What does the current return process look like and what are the performance criteria for this process?*
b. *What will the future scenarios for this return process be?*
c. *What are the design requirements and functions for the return process?*

The first two sub questions will zoom into the current process and the different types of waste within this process. For the current situation, a process flow is made and based on a Gemba walk, processes are described in more detail.

Besides the qualitative current situation, a quantitative analysis is done. The historical data is combined with some future scenarios which are made based on the expectations of Hoogvliet. Since Hoogvliet wants to implement a new design within five years and this design should satisfy the demand for the upcoming 20 years, the future scenarios will be compared in terms of volumes. Besides, the future situation within the return hall is relevant as well. These processes are therefore also taken into account.

The business problem contains an overview of the workload division per sub process which has to be decreased. In the last phase of this chapter, the design constraints, requirements and functions are specified and how the requirements can be measured (per subprocess).

3.1 Qualitative analysis of the current process

To understand the business of the return hall and the interaction with the other processes at the DC of Hoogvliet, an overview is given of the inbound and outbound flow of the return hall. This is obtained by interviewing the assistant team leaders of the return hall. Than, the current process in the return hall is schematically explained with a swim lane diagram. This diagram describes the different handlings that take place Thereafter, a more in-depth description is given based on a Gemba walk..

3.1.1 System analysis of return hall

In general, the return hall process can be defined as the unloading and processing of the interchangeable containers which are returned by the different supermarkets of Hoogvliet. This processing starts with the unloading of the container and ends if all sorting have taken place and the goods have left the return hall by infeed point, waste container or a supplier who picks up reusable packaging, crates, or waste. Besides this general process, there is a small return flow with waste (seal) and empty pallets from the expedition which are also sorted and returned to a supplier. So, in general, there are two input activities: the arrival of the trucks with interchangeable containers and the empty pallets and waste from the expedition as shown in Figure 3-1. The output of this system contains multiple infeed systems, waste containers and trucks from external suppliers. Within the return hall, the main resource which is used are human operators. For some type of processes such as loading a truck from a supplier, a reach truck or EPT is used.

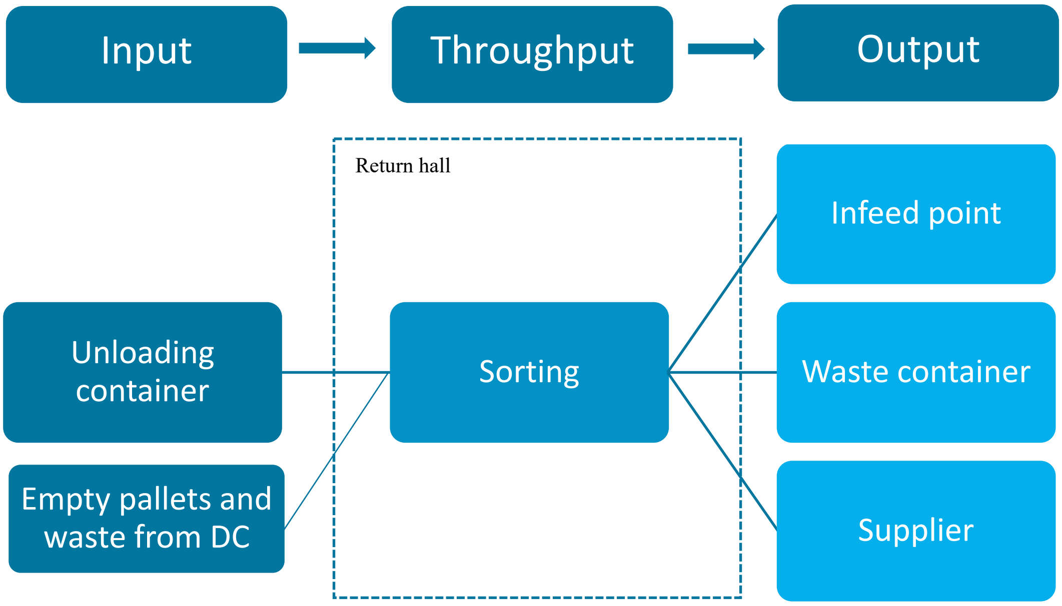


Figure 3-1: System definition

3.1.2 Brownfield layout

Regarding the return hall itself there are several restrictions at the border and inside this hall. This is shown in the figure and legend table below.

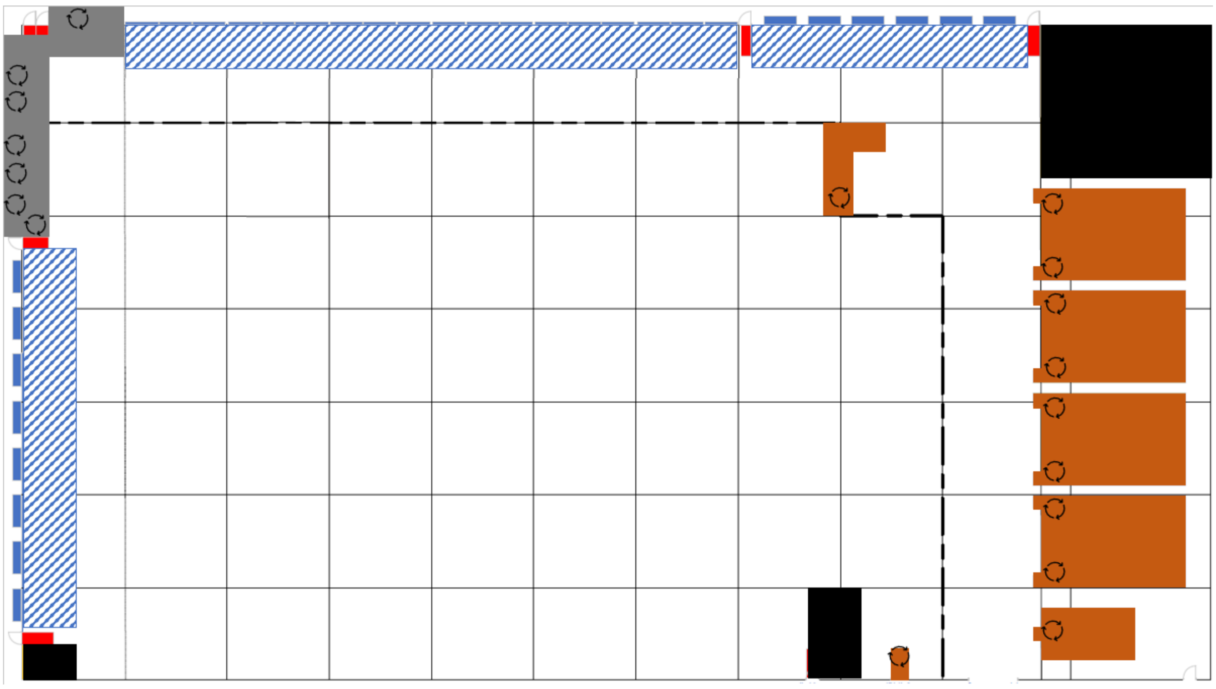


Figure 3-2: Brownfield layout of the return hall at Hoogvliet

The colours and shapes are explained in the legend below.

Table 3-1: Legend of brownfield layout

Shape	Definition
	Processing station: at this location, goods are processed and leave the return hall.
	'Dead' objects which cannot be removed.
	Emergency door, must be accessible

(blue)		Docks
(grey)		Shredder / cardboard press
(orange)		Infeed system, used for crates and loading carriers
(blue hatched)		(Un)loading space

This shows that the focus of the conceptual design is the layout of different working stations and the different interfaces between these processes.

3.1.3 Functional flow block diagram and swim lane diagram

As explained in section 'Design approach', the processes within the return hall are translated in a functional flow block diagram (FFBD) to see all functions within the return hall and in which order these functions take place. Both the general and detailed functions are given general names and thus cover multiple processes. The detailed function flow block diagrams can be found in appendix B – Process flows, section B.1 Functional flow block diagram – detailed functions. These detailed activities will be related to the morphological chart which is composed in the next chapter. Some different processes that will be named in the morphological chart contain the same FFBD number and therefore the same solutions are applied.

Below, the order of general functions is shown in Figure 3-3: Functional flow block diagram - Main processes - Current situation. This figure shows the input activities which are unloading an interchangeable container or the outfeed of the Witron system with empty pallets and waste boxes. These goods are transferred to either a sorting location, storing location, waste processing station, or infeed location. At the infeed point, loading carriers or crates leave the return hall. A second possibility to leave the return hall is when an external supplier picks up for example reusable packaging. These goods are picked up from storage and transferred to the truck. It is also possible that processed or stored goods are transported to an infeed point. This is shown with the arrow from the output OR or activity 2b to the output OR of an external supplier picks up for example reusable packaging. These goods are picked up in activity 2a.

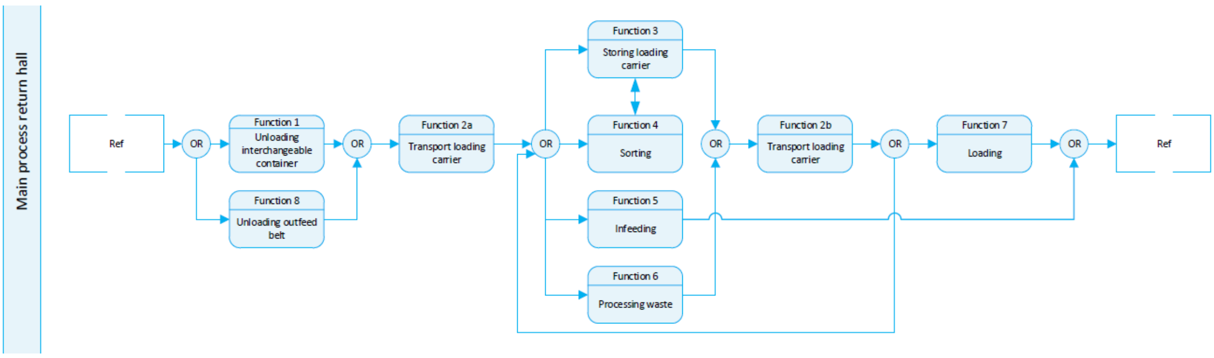


Figure 3-3: Functional flow block diagram - Main processes - Current situation

To understand the movements on the floor, a swim lane diagram is made based on the different type of loading carrier which is currently used. This gives insight from a physical point of view for all different types of loading carriers and the processes in which they are involved. Furthermore, it shows the decisions which the employee currently has to make and what the consequences of these decisions are. The swim lane diagrams can be found in Figure 3-4: Swimlane diagram - Physical flow per loading carrier. In general is shown that all loading carrier lead go to some storage positions and that the main activities are processing and sorting of different load types. Especially for the loading carrier type roll container (RC), many different types of load have their specific sorting process which is also shown per color in ‘appendix B – Process flows’ section ‘B.2 Swimlane diagram - Goods and packaging’. In the end, this load ends in either a waste container or on a pallet for (temporary) storage.

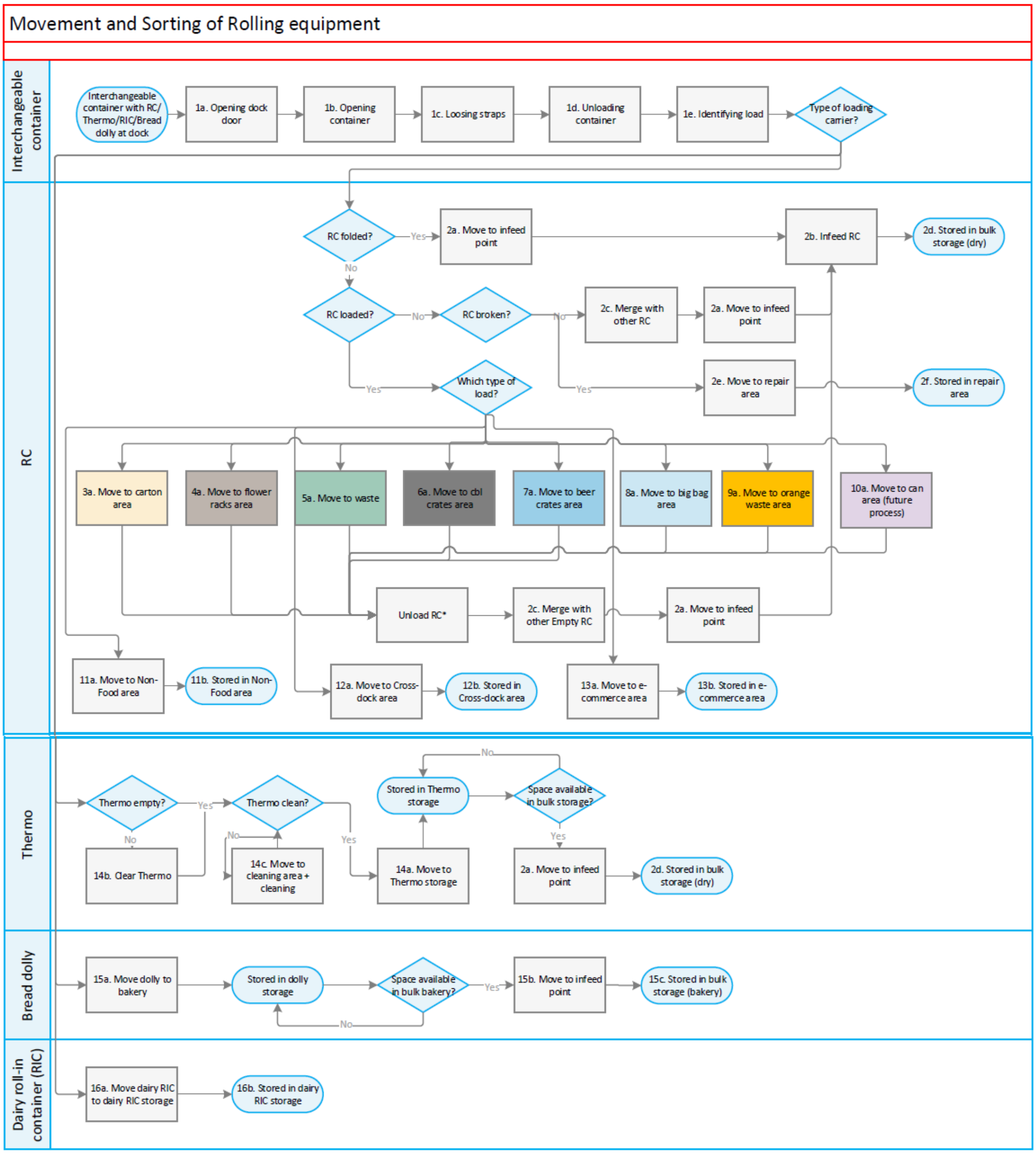


Figure 3-4: Swimlane diagram - Physical flow per loading carrier

Besides the unloading of the loading carriers, a second input flow comes from the automated warehouse which is operated by the Witron system. This flow contains waste boxes with foil and a pile with empty pallets. In Figure 3-5: Swimlane diagram - Physical flow of waste boxes and empty pallets within the return hall. Even as for the loading carriers from the interchangeable container, some sorting and processing handlings take place. The end point of the empty waste boxes is the Witron system of the DC. The empty pallets are stored in the return hall until they are picked up by a supplier.

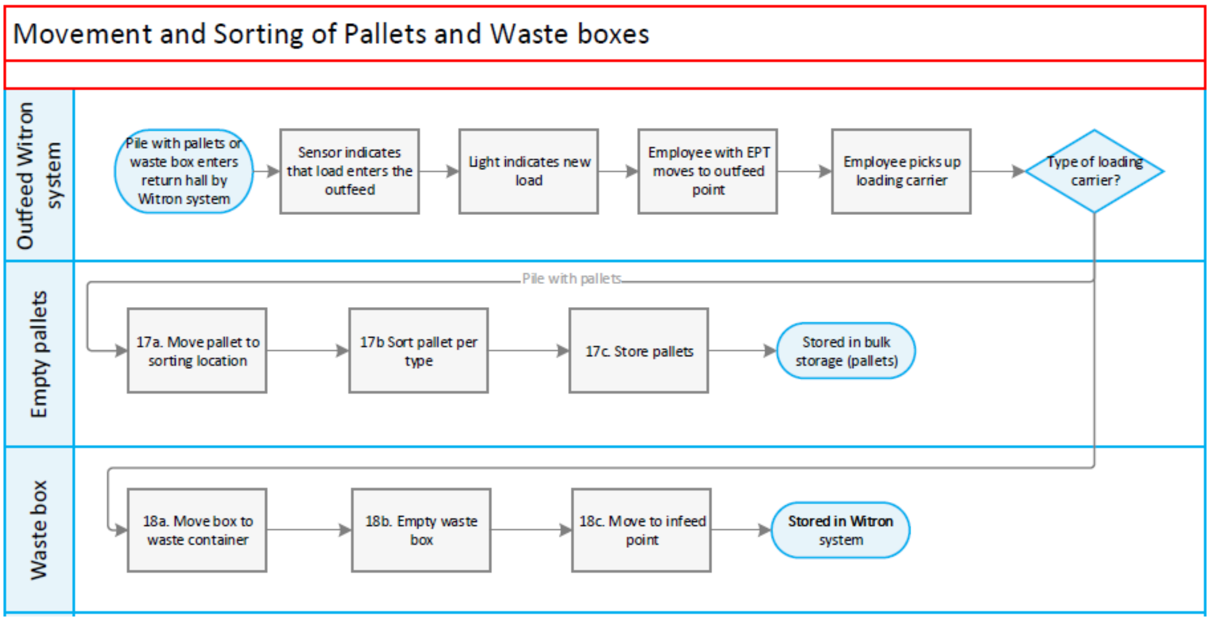


Figure 3-5: Swimlane diagram - Physical flow of waste boxes and empty pallets

Lastly, a separate swim lane diagram is made to show the physical flow of the loading processes. These are shown in Figure 3-6: Swimlane diagram - Physical flow of loading trucks with big bags and reusable packaging. For Big bags, this loading process is done manually. For the other reusable packaging, reach and pallet EPT's are used. All goods end in a truck of an external supplier.

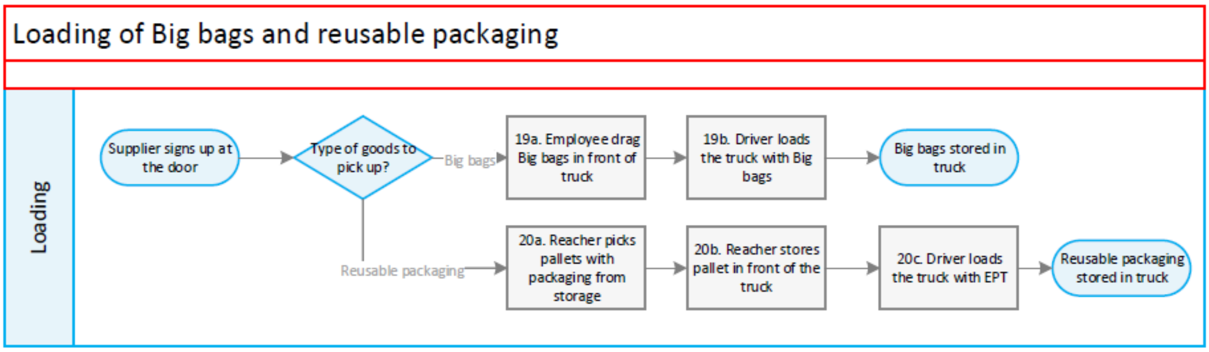


Figure 3-6: Swimlane diagram - Physical flow of loading trucks

3.1.4 Gemba walk – process description

On 23-9-2021, a Gemba walk is done with Maurits de Jong (assistant team leader) through the return hall to understand the different handlings in practice, but also to understand the day-to-day disruptions and work behavior of the employees.

1. **Receiving and unloading container**

The process of unloading of a interchangeable container starts with a green light near the dock door. This light indicates that there is a full container outside which is dropped by a truck. There is a rule, set by the team leader, during the unloading process, that not more than three containers at the same time are open for unloading. In total there are eighteen docks for unloading containers. A load of each container is unique. Since all waste, reusable packaging and empty roll containers are returned by the same container, the load contains a very varied mix of roll containers. The full load of the container is secured with two straps. During unloading, one person is responsible for releasing the strap and driving out the roll containers.

2. **Sorting roll containers / thermos / RIC's / bread dolly**

Outside the container, many employees picks up containers and moves these containers, depending on their load, to the area which is assigned for the sorting process which applies to the load of the container. If a container has a mixed load, the employee tries to sort ad hoc with other nearby roll containers. Otherwise, he moves the container to the area with the dominant load. If a container is broken, the employee brings this carrier to the repair area.

3. **Transport loading carrier**

All different types of loading carriers needs to be transported within the return hall. This is done manually by employees of the return hall. Not every roll container contains a load of waste or reusable packaging. Some roll containers are folded to save space within the interchangeable container. Once a queue of these folded containers is unloaded, this queue is moved to the roll container infeed area. Besides the buffer area for the infeed of roll containers, a separate buffer zone for folded roll container is made in the middle of the hall. These roll containers are intended to send to suppliers.

4. **Process roll container with old bread**

Roll containers with old bread packed in clear plastic are moved to the bread shredder. Roll containers are positioned in a queue. If an employee starts sorting this bread he determines whether the plastic bag contains only bread with a certain fat percentage (no cake or sausage roll). If this is the case, this bag is thrown in the shredder, otherwise, this bag is thrown in the residual container. The empty roll container is folded and combined with other roll containers.

5. **Process roll container with carton**

Roll containers with cartons are moved to the cardboard press. Roll containers are positioned in a queue. If an employee starts throwing away the cardboard, he positions the roll container before the cardboard press and throws all carton forward in the conveyor belt of the cardboard press. The empty roll container is folded and combined with other folded roll containers.

6. **Process roll container with bio / residual waste**

Roll containers with bio or residual waste, packed in clear plastic are moved to the bio/residual container. The plastic bag is thrown in the bio/residual container. The empty container is folded and combined with other folded roll containers.

7. **Process roll container with orange peels**

Roll containers with orange peels, packed in clear plastic is moved to the orange peel boxes. The plastic bag is thrown in the orange peel box. The empty container is folded and combined with other folded roll containers.

8. Process roll container with big bags

Roll containers with big bags (filled with plastic bottles) are moved to the empty trailer (from Hoogvliet) with big bags. The big bags are thrown off the container and piled up. If the trailer is full, the bags are stored on the floor nearby the dock for final loading. If a supplier arrives to pick up these big bags, the bags are loaded from the floor and the empty trailer into the trailer from the supplier. The empty container is folded and combined with other folded roll containers.

9. Process roll container with e-commerce bags and crates

Roll containers with e-commerce freeze bags and folding crates are moved to the e-commerce area. The roll containers with e-commerce packaging are stored till a transport to the e-commerce DC picks up the roll containers.

10. Process roll container with flower racks

Roll containers with flower racks bags and folding crates are moved to the area with flower racks. These racks are sorted based on their color. The empty container is folded and combined with other folded roll containers.

11. Process roll container with CBL crates*

**CBL crates: CBL/EPS/DPS crates*

Roll containers with CBL crates are moved to the area where CBL crates are sorted. First, the roll containers are positioned in a queue. On the front side of this queue, multiple employees are sorting the different types of CBL crates per pallet. Once a pallet is full with the same type of CBL crates, a rope with label is attached around the pallet. The pallet is stored in the CBL crates area with a reach truck.

The same process applies to the EPS and DPS crates. The full pallets with EPS crates are stored in the bulk area of the return hall and the DPS crates are infeeded in the Witron system.

12. Process roll container beer crates

Roll containers with beer crates are moved to the beer crates area. In this area, a couple of employees are sorting the different bottles in crates and the different crates on pallets. Once a pallet is full, the beer pallets are moved to the bulk beer crate storage till a supplier will pick up these pallets.

13. Infeed loading carriers

Two types of loading carriers are infeeded in the warehouse bulk storage: Thermo or isotainers and roll containers.

Thermos are first checked whether they are empty and clean. If there is some waste or crates within the thermo, the employee removes the waste or crates and brings this to the assigned area. If the thermo is dirty, he is moved to the wash cabin in the return hall. All clean thermos are moved to the infeed point for thermos. If this area is full, there is another storage space for this thermos. Thermos at the infeed point are stored, with the door open, on a system pallet. A single thermo is infeeded by an employee pressing the button at the infeed point.

Roll containers are infeeded in six different lanes. First, a roll container is unfolded and straps are positioned in the right place. Then, the employee stores two roll containers on a system pallet and presses the start button for the specific lane. Multiple sensors identify whether the infeed conditions of the roll container are right: roll container fully unfolded? Straps are positioned right? Two roll containers are on a system pallet? If the infeed is denied, the system pallet returns immediately back to the infeed point and the employee has to adjust the roll container according to the notification on the screen.

14. Process dairy roll-in container (RIC)

A dairy RIC is folded and moved as a queue to the storage space for the dairy RIC. Once a supplier picks up these containers the dairy RIC's are loaded.

15. Infeed (bread) crates

The infeed of crates takes place on two different locations, at the butchery, and at bakery infeed point. At the butchery, CBL 7 or CBL 11 crates are needed. An employee lifts a pile of crates with that specific type of CBL crates on the conveyor belt and folds the roll container. The sensor at the conveyor belt detects whether this pile is of the good height and an elevator brings the pile up to the crates laundry of the butchery.

At the bakery, bread crates are infeeded which are loaded on a bread dolly. A bread dolly or multiple dollies are moved to the infeed point for bread crates which are on this. The dollies are positioned on the infeed lane. The employee lifts the crates and puts these on the infeed lane. If this lane is full the dollies with crates are stored nearby this lane till enough infeed space is available. After the bread crates are separated from the dolly, the empty dollies are brought to the outbound side of the bakery. These dollies are now available to pile up the full bread crates.

16. Process empty pallets

Besides the infeed point for roll containers, there is an outfeed of stacks with empty pallets. These are the remainder of the picking process and are stacked by the system up to ten pallets. When the tenth pallet is stacked, the pallets are transported to the return hall. At the return hall, this pile is picked up by the reach truck and moved to the sorting area. Empty pallets are sorted by color and format. Thereafter the stack of empty pallets is stored in the bulk storage for empty pallets.

17. Process waste bin with seal residuals

At different locations of the warehouse, waste bins are stored. These waste bins contains residuals of a pallets which are depalletized for example. The seal which is originally around the pallet is removed and stored in a waste bin. If the machine operator sees that the waste bin is full, he pulls the button near this bin and the bin is transported to the return hall. At the same outfeed point as the empty pallet pile, the waste bin is dropped. A reach truck driver brings the waste bin to the seal container and brings the waste bin back to the infeed point (besides the outfeed point).

18. Loading reusable packaging

Depending on what type of load needs to be exchanged with the supplier, a reach truck driver or employee loads the external truck.

19. Loading big bags

Big bags are cross docked from the empty trailer or the bulk storage for big bags to the truck of the supplier by several employees of the return hall.

20. Change waste container Renewi

Renewi has different types of waste containers around the return hall. These are the container for bread, carton, bio, and residuals. Besides the containers, Renewi picks up the boxes with orange peels.

21. Process non-food returns

The non-food goods are also stored on roll containers and are part of the load of the interchangeable containers. Non-food means promotion articles or other goods which are not part of the regular product range of Hoogvliet. These goods are stored at the return hall until these are picked up by a supplier or an internal transport to Hoogvliet's DC in Alphen. This process will maybe be skipped in the future by direct transportation from the supermarkets to the DC in Alphen or supplier.

22. Cross-docking regular goods

It happens sometimes that goods are loaded at the wrong interchangeable container or that a supermarket has ordered a different product or too many products from the same article. These goods need to be re-allocated to another supermarket. These goods are unloaded at the return hall and directly transported to the cross-dock hall.

23. Process roll container with trash cans (future process)

However this process takes not currently place, it can be described because similar processes 4 till 7 take place. The assumption is made that this process initially will be performed in the same manual way: Roll containers with trash cans are moved to the shredder. Roll containers are positioned in a queue. If an employee starts throwing away the bags with trash cans, he positions the roll container before the shredders press and throws all bags with trash cans forward in the conveyor belt of the shredder. The empty roll container is folded and combined with other folded roll containers.

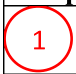
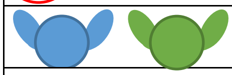
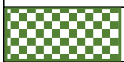
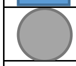
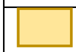
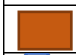
3.1.5 Coding of return hall processes

The functional flow block diagram, swim lane diagram as shown in the section 'Process flows' and processes as described in section 'Gemba walk' are combined in a table which can be found in section 'B.3 Coding of return hall processes'. This table shows that the processes which are described are consistent with the process flows and activities that take place within the return hall.

3.1.6 Layout of current situation

All processes which are described in the previous sections, are schematically drawn on the brownfield layout in Figure 3-2: Brownfield layout of the return at Hoogvliet. The legend table as given in Table 3-1: Legend of brownfield layout, is extended with the following rows:

Table 3-2: Legend of current situation layout

Shape	Definition
	Process indication with a number that refers to a specific process as defined in section Gemba walk.
	Employee and temp worker
	Sorting station: at this location, goods are sorted such as CBL crates, beer crates and empty pallets.
	The flow of goods: for example the incoming or outgoing flow by (un)loading of trailers.
	Temporary storage location for loading carriers, big bags, or pallets
	Roll container unfolded and roll container folded
	Thermo
	RIC
	Bread dolly
	Empty pallet
	Full pallet (with reusable packaging)
	Big bag
	EPT, different types shown in Figure 25: Different types of EPT (Crown, 2021)
	Manual sorting

In Figure 3-7: Current situation layout the current situation is shown schematically. This means that for example the number of roll containers and employees not corresponds with the reality but that gives only insight in the position and movements that take place within this return hall. Also, the incoming and outgoing flows are given.

Process 3 is indicated with a * because the transport activities take place all over the return hall and can be found in Figure 3-3: Functional flow block diagram - Main processes - Current situation and Figure 3-4: Swimlane diagram - Physical flow per loading carrier.

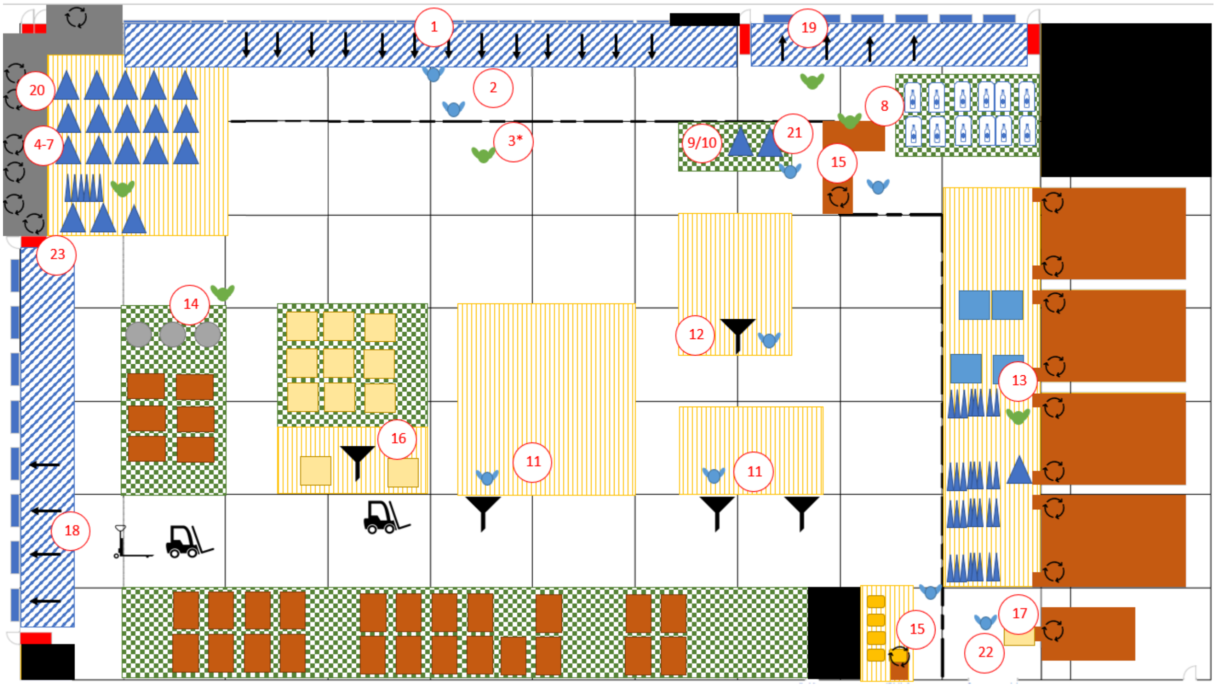


Figure 3-7: Current situation layout

3.2 Quantitative analysis and future scenarios

3.2.1 Key performance criteria

The management of the return hall has a small amount of key performance criteria to mange the performance. Basically, these are only general criteria:

- Hours spend in total per day
- Interchangeable containers processed per day
- Amount of roll containers that left the system (to the buffer location of the automated warehouse)

There are no performance criteria per activity or employee. This makes it hard for the (assistant) team leader to control the performance per employee or station. Currently, the performance is managed by (assistant) team leaders, walking around and assigning tasks to the employees. Which task is assigned is based on the urgency of these tasks. The urgency of a task is determined by the length of the queue and buffer possibilities. That is why the unloading of trucks has a high priority because the buffer in amount of docks is very small. Besides the unloading of containers, the urgency is determined by the length of the queue of, for example, roll containers with carton. An employee is assigned to this task which will make the queue shorter. However, how fast an employee is processing these containers is not very clear for the (assistant) team leader because he is observing twenty simultaneous processes as well. In line with the objective of this thesis, (*Design a efficient, flexible, scalable and future-proof return and packaging hall of an automated retail distribution center, which solves the capacity issues in employees and workspace and increases the throughput of containers per hour),* the following key performance criteria are relevant:

(1) Hours spend per interchangeable container or productivity (operational - efficiency)
(2) Payback period and estimated savings (cost – efficiency)
(3) Queue length - especially during peak hours - on the inbound docks (flexibility)*
(4) Limit space per process (scalability)*
    Evaluating each design on upper criteria, validating that all processes are in scope and able to process future volumes make that the design is future-proof.*

*: to define a design as flexible, scalable, and future-proof, more criteria are needed. However, this thesis aims to create a design which is to a certain extend flexible, scalable, and future-proof.

3.2.2 Throughput volumes and future scenarios

According to the DC manager of Hoogvliet, J. Pater, Hoogvliet has the ambition to increase its amount of supermarkets from 70 to 100-120 supermarkets in ten years. This increase should be obtained by takeovers of other supermarkets but also by opening new supermarkets as well. According to Retail Insiders (2021), the amount of physical outlets is still increasing as shown in Figure 3-8: Physical supermarket outlets Netherlands (Retail Insiders, 2019).

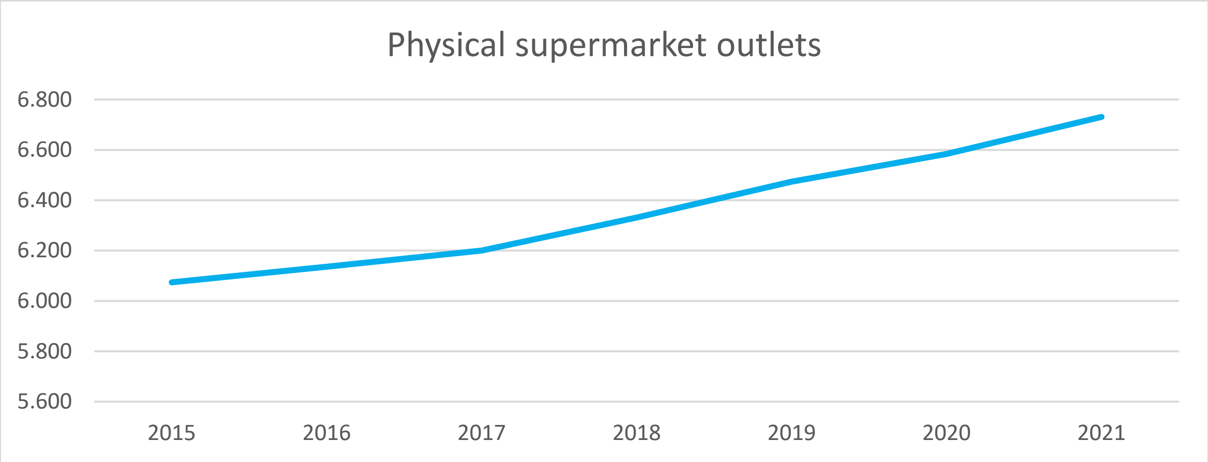


Figure 3-8: Physical supermarket outlets Netherlands (Retail Insiders, 2019)

The 70 supermarkets that Hoogvliet currently has, must be increased to stay competitive. The increase with an amount of 30 supermarkets is defined as scenario A and the increase with 50 supermarkets is defined as scenario B. These are shown in the graph below.

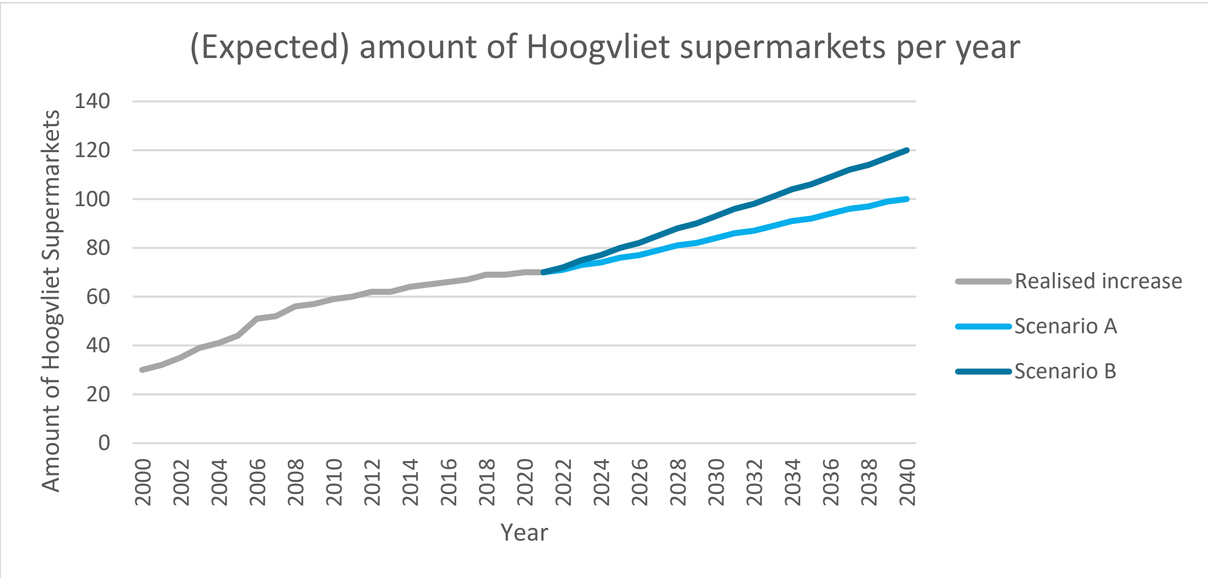


Figure 3-9: Expected amount of Hoogvliet supermarkets per year (Hoogvliet internal source, 2021)

At this moment, around 1450 interchangeable containers arrive at the return hall per week. With an increase from 70 to 100-120 supermarkets (40-70%), this amount of containers will increase to 2000-2500 containers per week. However, besides the average flow, there are peak weeks which can be related to public holidays, such as the week before Christmas. The yearly volume of containers with the different scenarios are plotted in the figure below.

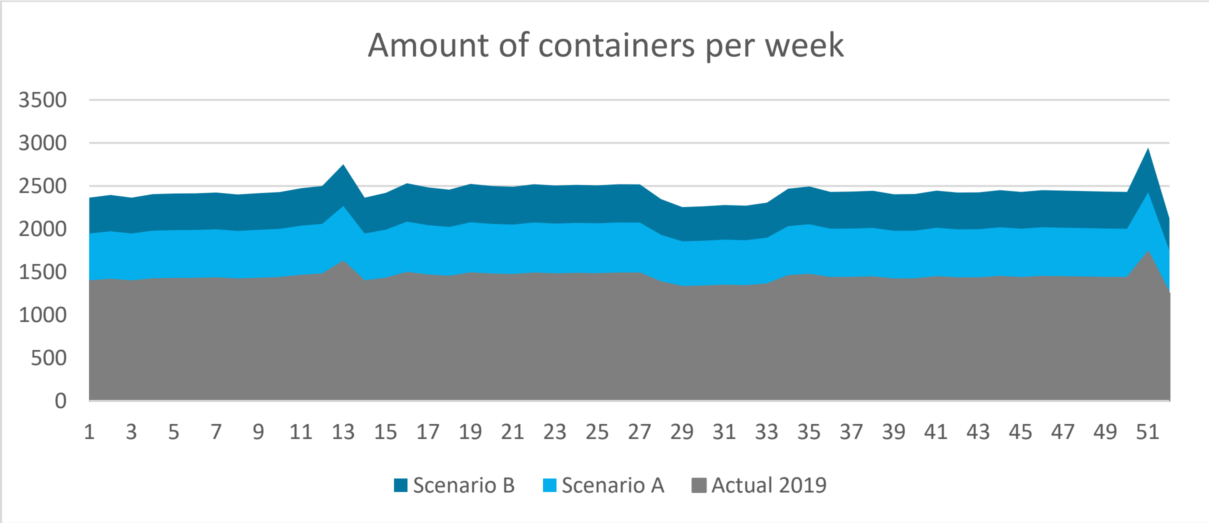


Figure 3-10: Containers per week, comparison 2019 with future scenario's (Hoogvliet internal source, 2021)

This results in peak weeks with 2750 containers in week 13 (Easter), till 2940 containers in week 51 (Christmas). The lowest supply of containers can be found during the summer period (week 29-33). The number of containers will reach a maximum of 2280 containers in Scenario B which is 60% higher than the current average amount of containers.

Regarding the return hall, not only the total amount of interchangeable containers per week is relevant, but the day and hour supply as well. Below, an overview is given of the demand per day, currently on average, but also in the context of the future scenarios.

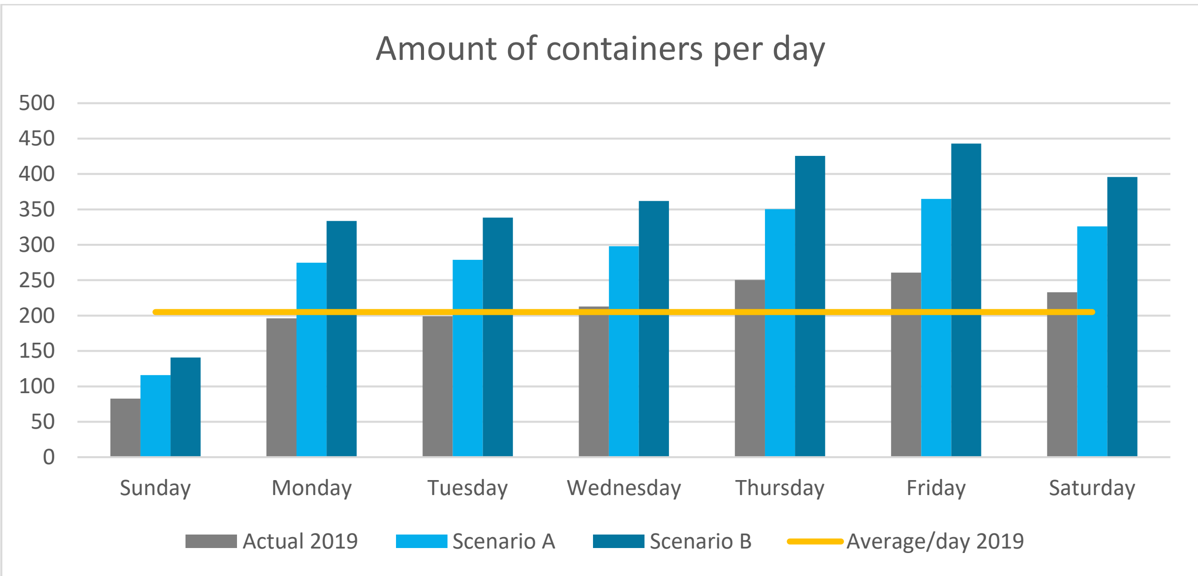


Figure 3-11: Containers per day on average, comparison 2019 with future scenario's (Hoogvliet internal source, 2021)

Figure 3-11: Containers per day on average, comparison 2019 with future scenario's (Hoogvliet internal source, 2021) shows that there is a weekly trend in the amount of containers. The lowest amount of containers arrive on Sunday and the highest amount of containers arrive on Friday. This trend is also visible in the amount of hours used to process these containers.

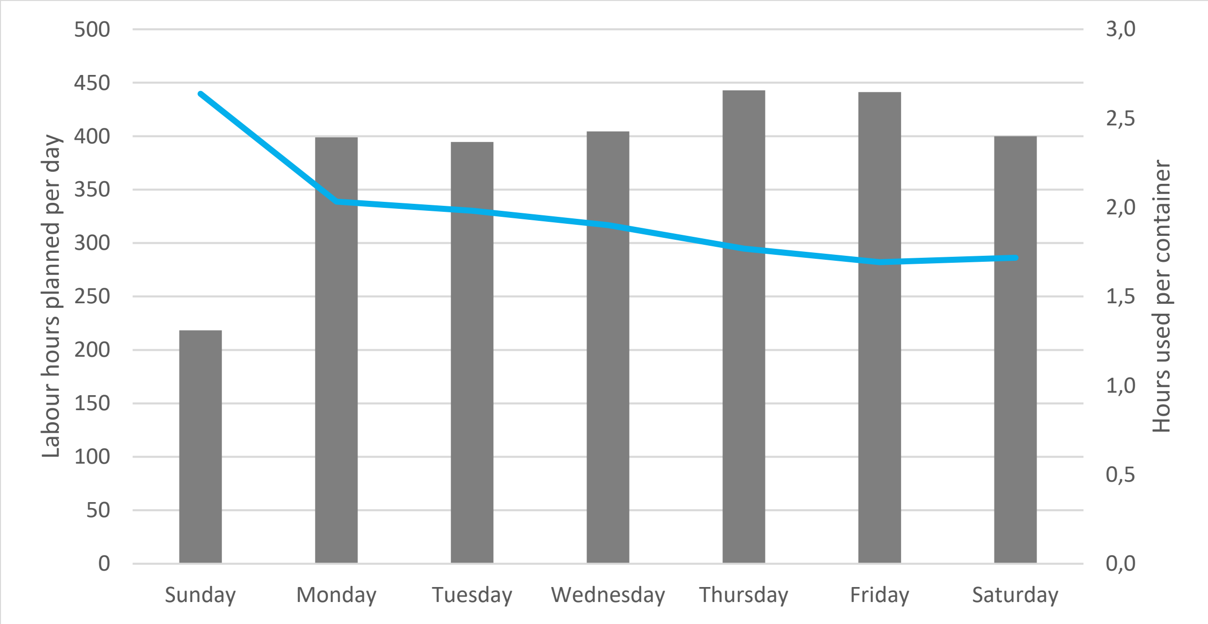


Figure 3-12: Labour hours planned per day versus hours used per container (Hoogvliet internal source, 2021)

From Figure 3-12: Labour hours planned per day versus hours used per container (Hoogvliet internal source, 2021) can be concluded that there is a negative correlation between the amount of containers per day and the hours used per container, which means that the efficiency increases. This should be taken into account by forecasting the amount of hours needed in future scenarios A and B.

To see the impact from the arrivals on the workload within the return hall, an overview is given of the current and expected peak and quiet hours what can be traced to the moment of arrival of the interchangeable containers. This arrival is the result of the optimal planning of the transport department, the delay's during the delivery to the supermarkets and the speed of dropping and picking up the container at the supermarket. The following figure gives an overview of these trucks on average per quarter based on internal data from 2019.

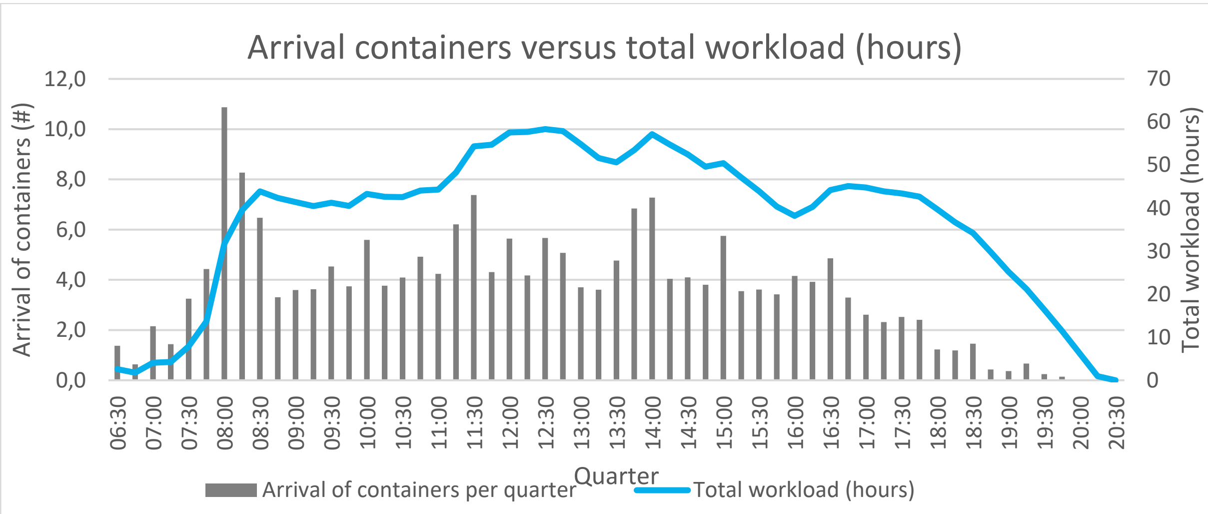


Figure 3-13: Amount of container arrivals per quarter versus workload per hour (Hoogvliet internal source, 2021)

The amount of containers per quarter contains a workload of 1.88 hours on average. Based on the current planning (week 42, 2021), the blue line indicates the remaining workload for processing the incoming containers. This line shows that there is enough work during the whole day. The capacity of the employees will elaborated in more depth in section 'business problem'.

Besides the total workload, the capacity on the docks or dock occupation can also be a (future) bottleneck. The return hall has 18 docks available for unloading containers. In reality, 15-16 docks are actually available because the carton waste process occupies 2-3 docks. Based on field research is known that it takes approximately 8-10 minutes to unload a container and that there are 3 containers unloaded at the same time. This gives a capacity of unlading 5.6 containers each quarter, 320 containers from 6:30-20:30. In the next figure, the dock occupation based on the current arrivals is shown. Besides, the future dock occupation (assuming that the share of arrivals per quarter remains the same), is given.

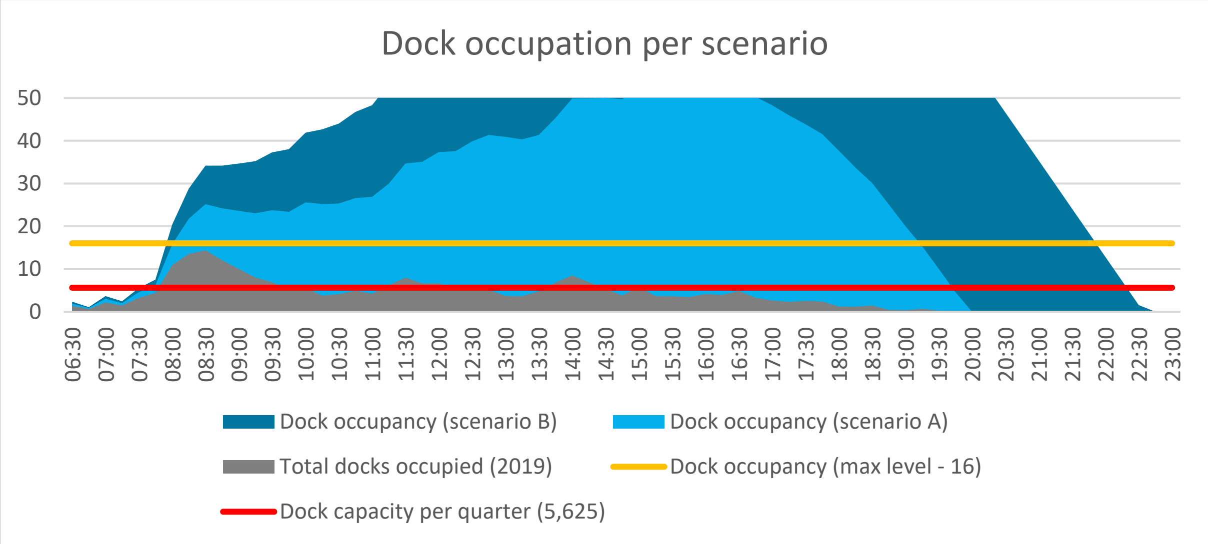


Figure 3-14: Dock occupation (and queue) per scenario (Hoogvliet, internal source, 2021)

Because of the peak around 8:15, a queue is forming which increases further around the peak of 11:30. To prevent such a queue, the incoming flow should be spread more equal and more containers should be unloaded at the same time (four instead of three). The next figure shows the capacity and queue if the containers are spread equally between 8 and 12 o'clock and between 12 and 20 o'clock. This gives the result that only during the morning hours this queue increases for scenario B.

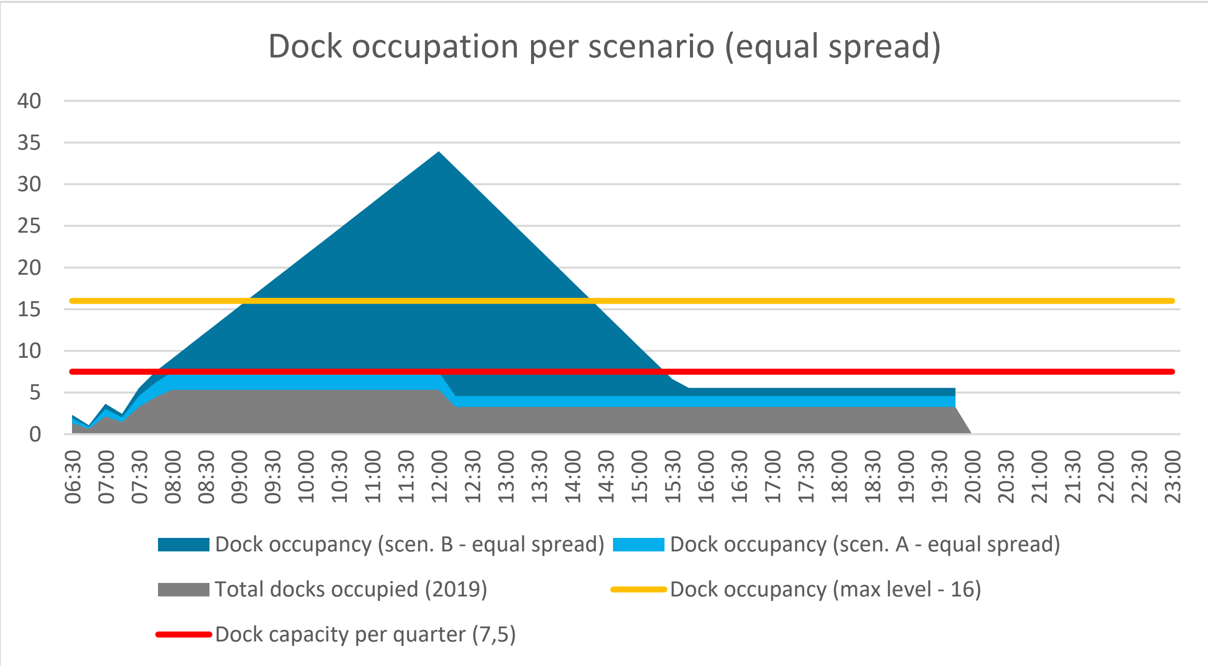


Figure 3-15: Dock occupation (and queue) with equal arrival spread per scenario (Hoogvliet, internal source, 2021)

3.2.3 Future processes

The processes within Hoogvliet's return rely hugely on the Dutch legislation. According to Ministerie van Infrastructuur en Waterstaat (2020), no longer only big (>1 liter) pet bottles contains deposit. Also small pet bottles contain a deposit per July 2021. However, because these bottles are gathered in the same big bags as the big pet bottles, no new process is needed within the return hall, but the amount of big bags processed per week is expected to increase.

A really new process is introduced by Ministerie van Infrastructuur en Waterstaat (2021a), with a deposit on cans from the start of 2022. This means that the consumer probably will bring these cans to the supermarket and that these cans will be processed by the return hall at the DC as well. These cans will be picked up by a supplier as the big bags are now picked up by suppliers. Another possibility is that Hooglvliet starts with the recycling of pet bottles and cans on his own, but for now, recycling is not in scope.

The third legislation from Ministerie van Infrastructuur en Waterstaat (2021b), contains the ban on disposable cups for all companies. This also applies to the cups in the supermarket at the coffee bar. If disposable cups are still used, these cups must be recycled. If Hoogvliet chooses to keep using this cups, a separated flow is the consequence. Hoogvliet shall also have to decide whether to do the recycling of these cups by themselves or to cross-dock these cups to an external party. Each choice will probably interact with the processes that take place within the return hall and should therefore be in scope.

3.3 Business problem

3.3.1 Workload analysis of return hall processes

As shown in the Gemba walk section, almost all activities take place within the return hall. During all these (sub)processes, many different types of waste can be identified. This waste increases by the amount of hours and containers that are needed for, or are going through a specific process. The following table and pie shows the division in loading carriers per flow based on some earlier internal measurements of Hoogvliet.

Table 3-3: Average loading carriers per container

Load	Current amount	Current share	Future amount	Future share	Difference in share
DPS	24	2,2%	24	2,2%	0,0%
EPS	35	3,2%	0	0,0%	-3,2%
Beer	37	3,4%	37	3,4%	0,0%
CBL	144	13,3%	160	14,8%	1,5%
Returns	3	0,3%	2	0,2%	-0,1%
(Bread) dolly	60	5,6%	60	5,6%	0,0%
Flower racks	10	0,9%	10	0,9%	0,0%
E-commerce	15	1,4%	35	3,2%	1,8%
RIC's	21	1,9%	21	1,9%	0,0%
Big bags	45	4,2%	60	5,6%	1,4%
Thermo	105	9,7%	105	9,7%	0,0%
Folded RC	240	22,2%	240	22,2%	0,0%
Foil	12	1,1%	15	1,4%	0,3%
Orange peels	20	1,9%	25	2,3%	0,4%
Biowaste	28	2,6%	30	2,8%	0,2%
Old bread	60	5,6%	45	4,2%	-1,4%
Residual waste	65	6,0%	25	2,3%	-3,7%
Carton	155	14,4%	155	14,4%	0,0%
Cans	0	0,0%	30	2,8%	2,8%

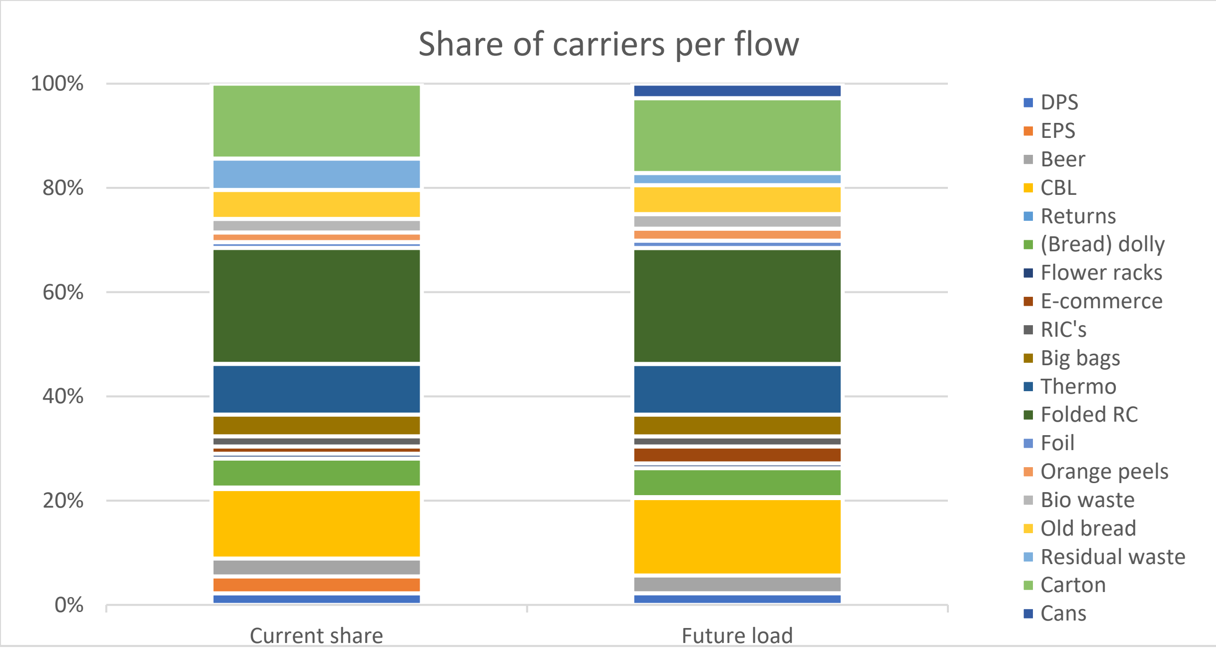


Figure 3-16: Bar chart of average share loading carriers per container

In general is stated by Hoogvliet that too many hours are used to process the interchangeable container. This inefficiency can be specified per subprocess to have a full insight into the spread of workload. This information is also relevant to create a business case for the proposed design at Hoogvliet.

Based on measurements at the return hall in terms of time and quantities, the following workload deviation is found. The timestamps and measurements can be found in appendix C. Besides, the total amount of hours spend is known, which gives a bruto/netto productivity rate of 80%. This is also shown in Figure 3-18: Workload division - current situation and sums up to 386 working hours on average spend.

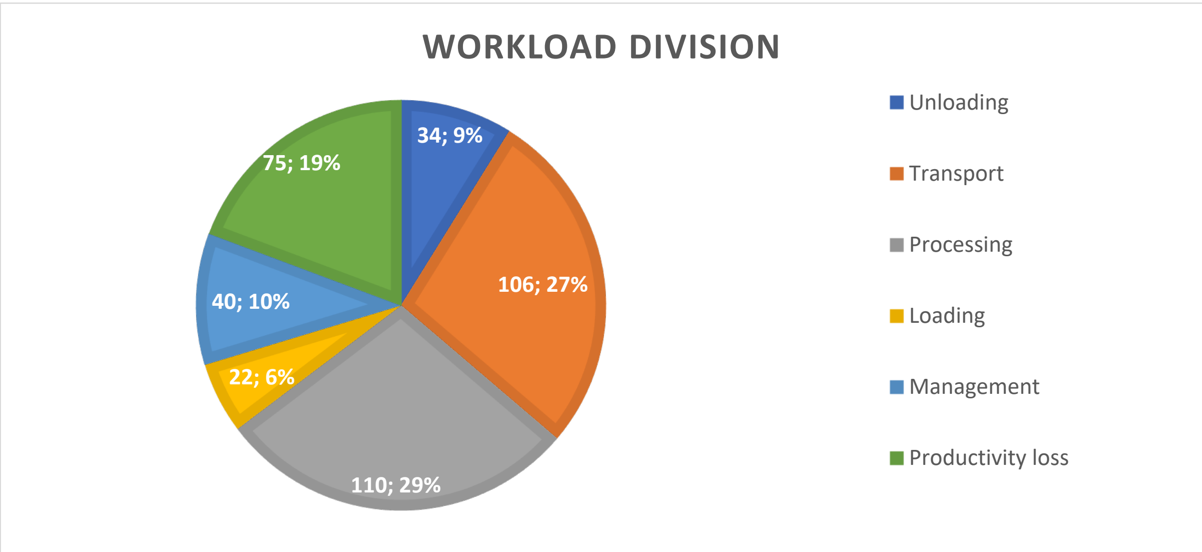


Figure 3-17: Workload division - current situation

This workload should be taken into account in the simulation, at the moment that some alternatives will be compared in terms of throughput and amount of working hours reduction.

For now is assumed that the future scenarios has an equal share in workload per subprocess. Therefore, the share per process will be the same too. The total amount of hours spend will increase linearly with the amount of interchangeable containers of scenario A. This gets even worse when the expected future scenario B of Hoogvliet becomes true. Currently there is almost no space available within the return hall to perform more or additional handlings and the dock occupation could block the whole operation. This needs to be taken into account, considering the whole throughput of the return hall as a main important performance criteria.

3.3.2 Connection objective and business problem

The business problem which is explained in the previous section is translated in the design objective:

Design a efficient, flexible, scalable and future-proof return and packaging hall of an automated retail distribution center, which solves the capacity issues in employees and work space and increases the throughput of containers per hour.

This design must be *efficient* because the processes in the return hall do only cost money. This efficiency could be obtained by reducing the required hours, as shown in Figure 3-18: Workload division - current situation. This contains the unloading, transport, processing and loading hours. The management and productivity loss hours are out of scope for this design. Besides the operational efficiency, the design should be cost efficient as well. This will be elaborated in section 'Quantitative validation' and Results per performance criteria'. The *flexibility* of the design is needed since the return hall contains a lot of different processes and the arrival of the interchangeable containers varies through the day (see Figure 3-14: Amount of container arrivals per quarter versus workload per hour (Hoogvliet internal source, 2021). Besides, the current volume, this design should also be prepared for future volumes. Therefore, the aim of this design is to use flexible solutions or have a basic throughput capacity that is high enough for future volumes as shown in Figure 3-11: Containers per day on average, comparison 2019 with future scenario's (Hoogvliet internal source, 2021). By increasing the throughput and size of the workstations, the floor availability becomes more relevant. This is why the solution should be *scalable* in terms of available space (for both loading carriers as processing stations. The design must be not only be *future-proof* in terms of volumes, but in processes as well. Evaluating each design on upper criteria, validating that all processes are in scope and able to process future volumes make that the design is future-proof.

3.4 Design constraints, functional and non-functional requirements

Based on the objective and the actual processes in the return hall, several constraints and requirements are listed for the design. These constraints and requirements limit the possible design to fit within a realistic and allowable situation for Hoogvliet. The design constraints, requirements, and functions can be split in general constraints, requirements and functions and specific subprocess constraints, requirements and functions. These are observed at the return hall of Hoogvliet and are validated with the staff of Hoogvliet. In the section 'From objective to requirements' is shown how these requirements are based on the objective and the current processes.

To validate how different designs compare to each other, it is important that the functional and non-functional requirements are measurable. This will be done in section 'Measurement of functional and non-functional requirements' Regarding the constraints applies that these will be checked with a 'yes' or 'no' and that no in between score can be given.

3.4.1 Set general constraints, functional and non-functional requirements

The general constraints, functional and non-functional requirements apply to all different subprocesses which will described after the general constraints and requirements.

General constraints (GC) regarding the full design:

- GC1 - Fit within the return hall
- GC2 - Be compliant with safety regulations
- GC3 - Be compatible with the existing infeeding and waste processes
- GC4 - Implementable in 5 years
- GC5 - Accessible for employees

GC1 and GC3 refer to the system as defined in section 'System layout'. Hoogvliet wants only to redesign the return hall itself on the same location for practical reasons (like the connection with the existing infeed points). GC2 and GC5 are added to cover the safety and troubleshooting of the system. GC4 is also based on the input from the logistic manager of Hoogvliet.

Requirements can be split into functional (FR) and non-functional requirements (NR). Both functional and non-functional designed are connected to the objective of the design in section 'From objective to requirements'. First, the functional requirement regarding the full design is given. This requirement tells what the system should 'Do'. The 'system' is defined as the return hall itself.

- FR1 – Throughput as many loading carriers per hour as possible;
    - *efficiently processing goods and packaging is the main function of the return hall. This is generalized in FR1*.

The non-functional requirements can be defined as the requirements what the system (return hall), should 'have'.

- NR1 - Should have a small as possible amount of working hours;
    - *Labour costs are the highest expenditure of the return hall.*
- NR2 - Should have a short as possible payback period;
    - *The payback period must be short because the market changes quickly.*
- NR3 - Should be as flexible as possible to cope with extreme peak hours / days / weeks;
    - *The return hall has to deal with peak amounts of interchangeable containers (*section 'Volumes and future scenarios').
- NR4 - Should have a lifetime which is as long as possible;
    - *The requirements aims to score solutions which are not fragile solutions higher.*
- NR5 - Should have the ability to identify deviant goods between the load;
    - *As explained in section 'Gemba walk', loading carriers could contain deviant goods which must be identified during the sorting processes.*

3.4.2 Process specific constraints

The process-specific constraints can be found in section 'C.2 Process constraints and requirements'.

3.4.3 From objective to requirements

In Table 3-5: Connection between objective and requirements the connection between the objective and the requirements is shown. For each part of the objective, one or more requirements are connected which shows that the solutions that will be proposed in next chapter, are scored based on their connection with the objective. All functional and non-functional requirements are scored on a 5-point scale. This makes it possible to score the different alternatives for one single subprocess, which passes the constraints, among each other. The scale for these functional and non-functional requirements are given in the table below.

Table 3-4: Connection between objective and requirements

Objective	Requirements		Unit of measure
Efficient	FR1	Throughput as many xxxx per hour as possible*	interchangeable containers/hour*
	NR1	Should have a small as possible amount of working hours	working hours (% decrease)
	NR2	Should have a short as possible payback period	packback period (years)
Flexible	NR3	Should be as flexible as possible to cope with extreme peak hours / day's / weeks	stretchability (% increase)
	NR5	Should have the ability to identify deviant goods between the load	Probability that you will trace
Scalable	FR1	Throughput as many xxxx per hour as possible	interchangeable containers/hour*
	NR1	Should have a small as possible amount of working hours	working hours (% decrease)
Future-proof	NR4	Should have a lifetime which is as long as possible	lifetime (years)
*: definition of xxxx per process can be found in appendix table Table C- 2: Functional requirments with unit of measure and scale definition.			

As said, a 5-point scale is used to make a distinction between the different solutions at some subprocess. This will be done on a relative nominal scale with five different signs:

1. - -; 2. –; 3. 0; 4. +; 5. ++;

Only the functional requirement has a scale which is connected to realistic numbers for each process. A full overview of this scale can be found in 'C.2 Process constraints and requirements'.

3.5 Conclusion of the problem description

This chapter has answered the following question with a qualitative and quantitative analysis of the current process. In more depth, a workload analysis is done to identify the business problem and the design requirements are listed per process.

1. What does the return process look like?

This question is split into four sub question which will be answered below.

a. What does the current return process look like and what are the performance criteria for this process?

The problem definition is first analyzed qualitatively with some functional process flows and with a swim lane diagrams which represents the physical flows of the loading carriers. In more detail, during the Gemba walk, 23 different processes are identified which can be generalized to 8 general functions and 4 types of loading carriers.

b. What will the future scenarios for this return process be?

Besides the qualitative analysis, a quantitative analysis is made based on the volumes as registered in 2019, supplemented and validated with recent measurements. These volumes show the current workload and bottlenecks in the return hall, but also gives insight in the productivity, based on a comparison between the amount of arrivals and hours spend per day.

c. What are the design requirements and functions for the return process?

The design requirements for the conceptual design are split in functional and non-functional requirements. Because the main function of the return hall is a high throughput, this functional requirement is set as 'Throughput as many xxxx per hour as possible'. Xxxx is defined per subprocess with a numeric scale which is in proportion with the throughput level per unit of measure. Besides this functional requirements, in consultation with Hoogvliet, the following non-functional requirements are defined: 'Should have a small as possible amount of working hours', 'Should have a short as possible payback period', 'Should be as flexible as possible to cope with extreme peak hours / day's / weeks', 'Should have a small as possible amount of working hours' and 'Should have the ability to identify deviant goods between the load'.

4 Conceptual design

In the previous chapter, all processes are listed and the business problem is explained. This resulted in constraints and requirements for the return hall. This chapter answers the following main question:

2. *What are the preferred designs which solves the requirements and functions?*

A conceptual design contains a set of possible solutions, one solution for each subprocess. Because multiple solutions per subprocess will be scored, different combinations can be made which make different conceptual designs. Using the following sub questions, a systematic approach will sort and rank these solutions to a limited set of conceptual preferred designs.

a. *What are the possible solutions that commits to the requirements?*

This question will give the solution space for each subprocess based on literature and field research. These solutions will be scored based on the requirements and constraints which are given in the previous chapter, which answers the following question:

b. *How do these solutions compare per requirement?*

From this solutions, some designs will be drawn, which answers the third sub question:

c. *Which preferred designs can be made from the best scoring solutions?*

4.1 Generating solutions per process

In this section, an overview is given of the possibilities which probably may be useful within a full solution of the return hall. This information is gathered both form literature and different suppliers which have solutions for automatization and mechanization. These solutions may be useful for different processes within the return hall and are therefore analyzed from different perspectives. An example of all solutions can be found in appendix D – Solutions.

4.1.1 Current solutions

a.b. Employees and temp workers

Hoogvliet is using two types of workers at the return hall: employee's who have a contract with Hoogvliet and temp workers, provided by Axell which is an employment agency. All these workers are divided in three shifts (small night shift, and two main daily shifts). The workers are not dedicated to one single task but perform manually almost all processes within the return hall. Only the shredders, cardboard presses and infeed systems are automated. The national background of these employees hugely differ, but in general descent from East-European countries such as Polen, Romania and Bulgaria.
Costs are confidential

c/d. Shredders and cardboard press

Before the load of the waste type loading carriers enters the specific container, the load is pressed or shredded to decrease the volume of this load. The shredders and press are assembled on the container itself and are out of the scope of this thesis. Each shredder and press is extended with a small conveyor belt to thrown the load on. This is applicable for processes 4 till 7, 17 and 23 (see section Gemba walk). *No additional investment costs*

e. Infeed system

There are four infeed points already defined which are part of the current solutions that are out of scope for the conceptual design. These infeed points are part of processes 13 (loading carriers) and 15 (CBL and bread crates). Also the position of these infeed points is fixed.
No additional investment costs

4.1.2 Proposed solutions

This section proposes solutions based on literature research and input from Hoogvliet operational experts. The input from operational experts is received during October 2021 and January 2022 by interviewing the warehouse manager, logistics manager, and (assistant) team leaders. Also, a short interview is done with a former employee of Albert Heijn, J. Medendorp. Based on their ideas and suggestions, more research is done on the functionality and costs of these solutions. The sources which are found are listed below per solution. The solutions which are proposed could be applicable for multiple processes. Therefore, a Morphological chart is made with all processes on the y-axis and the solutions on the x-axis. If the solution's functionality corresponds with a subprocess, this solution is listed. An attempt has been made to propose at least three solutions for each process.
The solutions that are listed below are all proven technologies which satisfy the constraints that are defined in section 'General constraints, functional and non-functional requirements' such as the solution could be implemented within five years.

i. Joloda Moving Floor
The Joloda is a loading or unloading solution and is a common solution for logistics companies (Industry Sectors, 2021). Joloda is not a single solution but has different applications. However, there are almost no Joloda solutions that are suitable for roll containers. According to Bart den Hartogh, sales manager of Joloda, is the 'moving floor system' of Joloda. This solution pushes the full loading at once out of the container. Outside the container is a moving floor as well which is connected with the moving floor in the container.
Estimated investment costs: €25.000 per moving floor system (Bas World, 2022)

ii. Conveyor belt
Conveyor belts are available in many different types. But for conveyor belts applies the same problem as for Joloda systems, most of the conveyor belts are not suitable for roll containers because of the (rotating) wheels of the roll container. An solution is found by the conveyor belts of Gebhardt. These conveyor belts only carries the roll container in the middle and ensures that the wheels do not touch the ground (Gebhardt, 2021). An alternative solution is provided by Moderniek (2014), which has the drivers on both sides of the roll container.
Estimated investment costs: €140 per meter (Rollenbaanspecialist, 2022)

iii. Scale
A rough way to identify the load of a carrier is with a roll-through scale (Bosche, 2021). The heaviest roll containers can be identified as a roll container with beer crates. The most light weighted carriers are the RIC's and dolly's. Also thermos could be checked whether these are empty or not.
Estimated investment costs: €909 (Manutan, 2021)

iv. EPT
Currently different types of EPT's are used within the return hall. However, these are only used for loading of pallets en moving (empty) pallets. Sometimes, EPT's are used to move empty roll containers but this is only possible if there are not too many employees walking around on the floor. With the different EPT's which are (for example) are available by Crown (Crown, 2021), many processes can be supported.
Estimated investment costs pallet EPT: €4.400 (Still, 2022); Estimated investment costs reach EPT: €14.400 (Esra, 2022)

v. AGV Tugger
An automated guided vehicle (AGV), is used in many different areas where basic transportation of short distances is a main component of the activities that had to be performed. AGV's are mostly electrical driven and were designed to transport 20 or 40 ft containers at the seaport. Later on, Light weighted AGV's are designed to transport boxes at automated distribution centres. In between, the AGV Tugger's

are designed to have the capacity to pull multiple loading carriers (Ellis Systems, 2019). These AGV Tugger's could be used to transport loading carriers such as roll containers as well.
Estimated investment costs: €30.000 (AGV Network, 2022)

vi. Chain Track
The chain track in the floor is a solution which was used at the former distribution centre of Hoogvliet. Roll containers were pinned down to his track which goes around the hall. A roll container was unpinned by an employee at the destination of the roll container. Nowadays, more advanced chain tracks are developed such as the chain tracks of Vorning (2016). Roll containers are positioned on the track and transferred with some small hooks inside the track.
Estimated investment costs: €790 per meter (Manutan, 2022)

vii. CBL crates sorter
The sorting of crates can be done with a sorter from Elten (2021). This company has a lot of experiences around the world with sorting systems. The crate sorter of Elten can be extended with a washing lane to clean the crates that are sorted.
Estimated investment costs: €1.500.000 (Holste, 2017)

viii. CBL stacker
A CBL stacker could be used in combination with a CBL sorter. According to Ridder (2020), the CBL stacker could handle different sizes of crates. Besides stacking the crates itself, the crates can directly be stacked on a certain type of pallet.
Estimated investment costs: €80.000 (Book, 2022)

ix. Pusher
Sorting of crates or loading carriers can also be done with pushers. Pushers are available in many different shapes and purposes such as the pusher from MAAS IL (2020), which is suitable to push crates based on a camera which detects a different type of crate. Another solution to push crates is the solution from Elten (2020). This solution can push multiple crates at once and could push crates which are loaded on roll containers.
Estimated investment costs: €2.400 (Robotshop, 2022)

x. Beer crate sorter
Sorting of beer crates is not an easy job. There are currently more than 20 types of crates which can divided in slow movers and fastmovers. However, the load of the roll containers with beer crates contains many different crates. A solution is provided by Sidel (2020). This company has a lot of experience with the beer industry and the sorting of crates.
Estimated investment costs: €2.000.000 (VisionTec, 2022; Holste, 2017)

xi. Tilt tables (upside down)
Emptying the roll container could make use of gravity. That is why a solution with tilt tables is proposed to empty the roll container. Different tilt tables are provided by Taylor (2020). This solution can be used to unload different types of waste but also big bags or empty crates.
Estimated investment costs: €8.800 (Vink Lisse, 2022)

xii. R-CNN recognition
According to Sousa et all (2019), manual sorting could be replaced with computer vision techniques in combination with deep learning. This deep learning approach can be used to identify whether a loading carrier contains cartons, crates, etc. Based on this recognition, a transport solution could be directed to choose a certain lane with is assigned for this specific type of loading carrier (Arghadeep, 2020).
Estimated investment costs are unknown

(xiii. Additional floor)

To increase the storage or working space of the return hall. An additional floor could be proposed for future volumes. This floor could be used to store empty loading carriers or for automated beer or CBL sorting. This solution is proposed between brackets because it only extends the working/storing space.
Estimated investment costs: €132 per square meter (Strong building systems, 2021)

4.1.3 Connect solutions to processes

All processes which are described in section 'Process flows' and 'Gemba walk' are listed on the vertical axis of the morphological chart which is explained in section 'Design approach'. This is done on the detail activity level of the functional flow block diagram to connect a specific action to a solution.

In section 'E.1 Solutions per process' all solutions which are applicable for a specific process are listed. In Table E- 2: Solutions per activity in section 'E.2 Solutions per activity', an overview is given from all detail activities per process and their solutions. These solution are chosen based on the research in the previous section.

4.2 Scoring solutions

As described in previous chapters' section 'Measurement of functional and non-functional requirements', there are multiple (non)-functional requirements which measure the expected fitness of a certain solution. This is why each solution, connected to a certain activity is measured based on the (non)-functional requirements described in Table 3-6: (Non)functional requirments and unit of measure. Each requirement has a 5-point scale which is used per activity. This means that the scores which are given are relative among each other. Only the functional requirement is specified per process and can be scored in a quantitative way. The score of the current solution for the functional requirement indicates the current performance and will also be used to compute the throughput of the whole system.
To compute a total score, the score of the 5-point scale is multiplied with the weight for this criteria. This method gives a sum product as a total score. The weights are determined with Hoogvliet and are listed below:

- Functional requirement: weight 5
- Non functional requirement 1-3: weight 3
- Non functional requirement 4-5: weight 2

The minimum total score that could be obtained (1 point for each criteria) = $5*1 + 3*1 + 3*1 + 3*1 + 2*1 + 2*1 = 18$

The maximum total score that could be obtained (5 points for each criteria) = $5*5 + 3*5 + 3*5 + 3*5 + 2*5 + 2*5 = 90$

Because the scale per non-functional requirement is used in a relative way, the score of all solutions must be in line with each other. Especially because the score of each solution is assumed to be the same for each subprocess, this score must be consistent with the different solutions per subprocess. For each requirement, the scores for all solutions are given and explained. How these scores are given is explained in the next section. First, an overview is given of the given score per solution for each requirement in Table 4-1: Total score per solution and requirement.

Table 4-1: Score per solution and requirement

FR1.X		NR1		NR2		NR3		NR4		NR5	
Conveyor belt	5	Conveyor belt	5	Employee	5	Temp worker	5	Employee	5	Employee	5
EPT	5	CBL crates sorter	5	Temp worker	5	CBL crates sorter	4	CBL crates sorter	4	CBL stacker	4
CBL crates sorter	5	Beer crates sorter	5	Shredder	4	Employee	3	Temp worker	4	R-CNN + Conveyor belt	4
Beer crates sorter	5	Tilt table	5	Carboard press	4	Shredder	3	Shredder	4	Temp worker	3
Tilt table	5	Joloda Moving Floor	5	Scale	4	Carboard press	3	Carboard press	4	CBL crates sorter	3
Chain track	5	AGV Tugger	5	EPT	4	Scale	3	Scale	4	EPT	3
Shredder	4	CBL stacker	5	Tilt table	3	EPT	3	EPT	4	Beer crates sorter	3
Carboard press	4	R-CNN + Conveyor belt	5	AGV Tugger	3	Tilt table	3	CBL stacker	4	Shredder	2
Joloda Moving Floor	4	Chain track	5	CBL stacker	3	AGV Tugger	3	Chain track	4	Carboard press	2
AGV Tugger	4	Carboard press	4	Chain track	3	CBL stacker	3	Conveyor belt	4	Scale	2
Employee	4	Shredder	4	Pusher	3	Chain track	3	Joloda Moving Floor	4	Chain track	2
Temp worker	3	Scale	4	Conveyor belt	2	Conveyor belt	3	Tilt table	3	Conveyor belt	2
Scale	3	Pusher	4	Joloda Moving Floor	2	Joloda Moving Floor	3	AGV Tugger	3	Joloda Moving Floor	2
CBL stacker	3	EPT	3	R-CNN + Conveyor belt	2	R-CNN + Conveyor belt	3	R-CNN + Conveyor belt	3	Tilt table	2
Pusher	3	Employee	2	CBL crates sorter	1	Beer crates sorter	3	Beer crates sorter	3	AGV Tugger	2
R-CNN + Conveyor belt	3	Temp worker	1	Beer crates sorter	1	Pusher	3	Pusher	3	Pusher	2

4.2.1 Explanation per requirement

Based on the ranking as shown in Table 4-1: Score per solution and requirement, for each (non-)functional requirement, an explanation is given for the relative score. These scores are given based on both supplier information and operational knowledge from Hoogvliet. For the functional requirement, a numeric scale is used. If solutions applies to multiple processes with multiple scales, an average score is given. However, because the scales in Table C- 2: Functional requirments with unit of measure and scale definition are defined relative to each other, these scores will almost not differ. For the non-functional requirements a score is proposed based on the reasons that are given below. This results in 5 points for the best solution according to the explanation. Solution which will have a lower performance are given relatively lower scores. In a work session with the logistic manager of Hoogvliet these scores are fine-tuned and established. Based on the weights as defined in the previous section, a total score is given which gives an indication of the fitness of the solutions for the return hall.

Functional requirement: Throughput as many ‘xxxx’ per hour as possible
The score for the functional requirement is based on the scale as defined in section ‘Measurement of functional and non-functional requirements’. This scale divides the solutions into three groups. A group of solutions which scored 5 points: Conveyor belt, Chain track, EPT, CBL crates sorter, Beer crates sorter, Tilt table; a group of solutions which scored 4 points: Employee, Shredder, Cardboard press, Joloda Moving Floor, AGV Tugger; and the last group which scored 3 points: Temp worker, Scale, CBL stacker, Pusher, R-CNN + Conveyor belt. These scores are given based on a comparison with the throughput estimation of the solution provider and the scale definition in Table C- 2: Functional requirments with unit of measure and scale definition.

Non-Functional requirement 1: Should have a small as possible amount of working hours
This requirement is measured in increase/decrease of working hours. This is why the employee and temp worker (with a lower productivity than regular employees), obtain the lowest score. On the other hand, all full automated solutions obtain the highest score. Solutions which are operated and controlled by employees obtain a score in between.

Non-Functional requirement 2: Should have a short as possible payback period
The payback period for a solution is based on the (estimated) invest costs and the (expected) efficiency. Because the employees and temp worker are paid per hour, their ‘payback’ period is very short. This is why they have obtained the highest score. Solutions which are relatively expensive and are known as robust and efficient solutions obtained a slightly lower score. The lowest scores are obtained by the most expensive solutions. Although they have an high-efficiency rate, the expected payback period will take a several years.

Non-Functional requirement 3: Should be as flexible as possible to cope with extreme peak hours / day’s / weeks
The flexibility of the solutions refers to the flexibility during peak hours, day’s and weeks. The most flexible work force is the temp worker. The CBL crate sorter has also obtained an high score because this machine should sort a lot of different crates with an high starting capacity. Based on the current situation could be stated that this machine has an over capacity and is in that context flexible to cope with peaks in supply. Because it is hard to distinguish the flexibility of the other solutions, these are all given an average score.

Non-Functional requirement 4: Should have a lifetime which is as long as possible
Also, the expected lifetime of a solution is hard to estimate. Based on operational knowledge is known that own employees can work here for a long time (until their retirement). That is why ‘employee’ gets the highest score for this requirement. Besides, the solutions are divided into a group which is more advanced and laborious and a group which is expected (based on operational knowledge of Hoogvliet) to be more robust and stable. The solution group which is expected to be more stable receives 4 points and the last group receives 3 points.

Non-Functional requirement 5: Should have the ability to identify deviant goods between the load
The probability level of indication of deviant goods between the load is based on human insight and sensors. However, in practice are human eyes and work experience more likely to detect deviant goods. Therefore ‘employee’ gets the highest score here. Than the more advanced technologies gets the best score. Lastly, the solutions with almost no sensors obtain a lower score.

In Table 4-2: Total score per solution the total score per solution is shown, based on the weights as given in section 'Scoring solutions'.

Table 4-2: Total score per solution

Solution	Total score
Employee	70
Chain track	70
CBL crates sorter	69
EPT	69
Tilt table	68
Conveyor belt	67
Shredder	65
Carboard press	65
CBL stacker	64
Beer crates sorter	64
AGV Tugger	63
Joloda Moving Floor	62
Temp worker	62
Scale	60
R-CNN + Conveyor belt	59
Pusher	52

This table shows that solutions like a pusher, scale and the R-CNN technology are not likely to succeed within a return hall. On the other hand, the allround capacity of own employees is still a suitable solution for return halls. The same yields for the transportation solution of chain tracks and EPT's.

By drawing designs in the next section, an attempt will be made to use solutions that score higher more often in the conceptual designs.

4.3 Drawing conceptual designs

To translate the scored solutions into concrete possible designs, the logical connection between the best solutions must be checked. Also is important that the designs comply with the constraints as stated in section 'General constraints, functional and non-functional requirements'. The individual solutions are already checked on the general and process specific constraints but the design as a whole should satisfy the constraints too. One important constraint is that the possible design should fit within the return hall. This is why, for the set of possible preferred designs, an example sketch is made of a possible layout. These layouts can also be used to estimate the new travel time between activities for both employees as automated solutions. Also, the relation between different processes becomes more visible. This relation is based on the process flows as shown in Figure 3-4: Swimlane diagram - Physical flow per loading carrier. If processes are changed due to the setup of the design a short remark will be added.

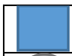
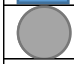
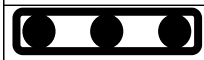
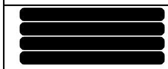
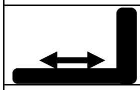
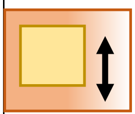
Besides, some solutions could eliminate some activities. For example, a chain track who is able to transport unfolded roll containers, eliminates the activity of folding roll containers at, for example, the old bread process which is shown in the figure above, and the unfolding activity at the infeed loading carrier process. This is why not always the best scoring solution should be chosen as the smartest one because there is interaction with other activities at different processes.

4.3.1 Legend and connection between processes and designs

The processes that take place within the return hall are explained in section 'Qualitative analysis of the current process'. The numbers of each process will also be used in the design to indicate where each process take place. Besides, all different solutions and loading carriers are expressed with a certain shape. A full legend (combining Table 3-1: Legend of brownfield layout, Table 3-2: Legend of current situation layout and the new solutions) is given below:

Table 4-3: Legend regarding conceptual designs

Shape	Definition
1	Process indication with a number that refers to a specific process as defined in section Gemba walk.
	Employee and temp worker
	Processing station: at this location, goods are processed and leave the return hall. For example: waste processing of old bread or infeeding roll containers.
	Sorting station: at this location, goods are sorted such as CBL crates, beer crates and empty pallets.
	Flow of goods: for example the incoming or outgoing flow by (un)loading of trailers.
	'Dead' objects which cannot be removed.
	Emergency door must be accessible
	Docks
	Shredder / cardboard press
	Infeed system, used for crates and loading carriers
	Temporary storage location for loading carriers, big bags or pallets
	(Un)loading space
	Queue area
	Roll container unfolded and roll container folded

	Thermo
	RIC
	Bread dolly
	Empty pallet
	Full pallet (with reusable packaging)
	Big bag
	EPT, different types, also shown in Figure D- 4: Different types of EPT (Crown, 2021)
	AGV tugger, also shown in Figure D- 5: AGV Tugger (Ellis systems, 2019)
	Tilt table, also shown in Figure D- 10: Tilt tables (Taylor 2020)
	Conveyor belt, also shown Figure D- 2: Conveyor belts for roll containers (Gebhardt, 2021)
	Chain track, also shown in Figure D- 6: Chain tracks (Vorning, 2016)
	CBL stacker, also shown in Figure D- 7: CBL stacker (Ridder, 2020)
	Sorting machine such as cbl or beer crate sorter
	Manual sorting
	Joloda Moving Floor system, also shown in Figure D- 1: Joloda Moving Floor solution (Sales Joloda, 2021)
	Empty pallet elevator

4.3.2 Drawing preferred designs

Based on the scores which are given in section 'Scoring solutions' three different conceptual designs are made. These designs vary in level of automatization and locations that the processes should took place. This will have an on the expected travel time between the sorting/infeeding processes, which will be elaborated in more depth in the next chapter.

To refer and compare the three different designs, each design is given a name which is derived from the shape of the design. For each design a short explanation is given to understand the full processes and also the improvements that are made in comparison with the current situation as shown in Figure 3-7: Current situation layout. Based on each design, a hypothesis is made about the time spend per part, which will be elaborated in the simulation evaluation section.

Design 1: Split waste and packaging

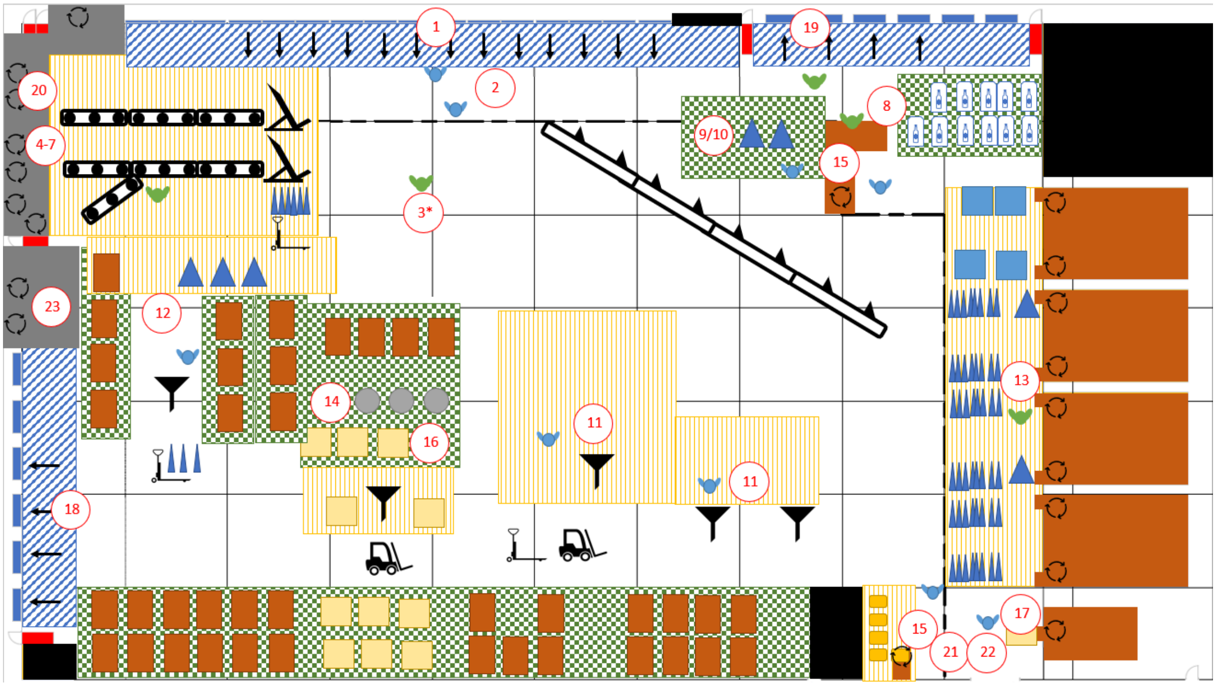


Figure 4-1: Design 1 - Split waste and packaging layout

In this design, the inbound and load identification is performed manually. From then, all loading carriers that contain waste are emptied with the use of a tilt table. Then the waste is moved by conveyor belts to the 'waste corner.' There is a separate lane for carton; all other waste have to be sorted by an employee to the proper waste container. All empty loading carriers are folded and transported by an EPT to the infeed points.

All reusable crates are sorted; all beer crates are sorted in a 'u-shape'. All pallets with reusable crates are stored along the wall.

A significant change is the chain track from the inbound docks to the infeed points. This eliminates a lot of transport activities. Loading carriers are placed upon the chain track, and at the end of this track, employees pick up the loading carriers (folded or unfolded) and divide these loading carriers across the infeed points. Loading is performed manually, but different outbound docks are used on the left side.

A disadvantage of this design is the limited amount of inbound docks available. On the other hand, the trucks can be unloaded faster because they can be sorted and transported directly to the right corner.

Design 2: Carousel

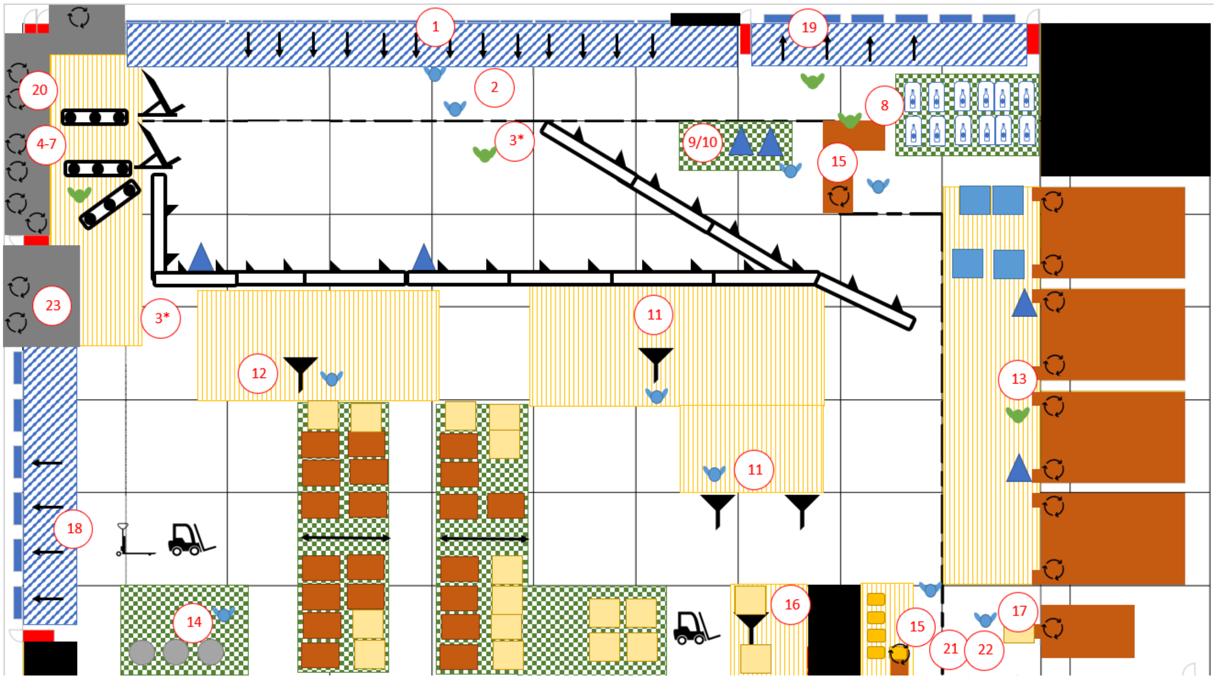


Figure 4-2: Design 2 - Carousel layout

The inbound and identification of the load are performed manually. All loading carriers that contain waste are transported by employees or EPT to the waste corner and are directly emptied with tilt tables. Sorting this waste takes place by placing waste bags on the right conveyor belt. The empty loading carrier (roll container) is placed on the chain track and will be a shunt to the infeed points.

The sorting of crates and beer is performed amid the return hall. Empty roll containers are placed on the same chain track; full pallets are stored in the storage location by reach trucks. The sorting of empty pallets takes place near the outfeed point of empty pallets to reduce the travel time. The sorted empty pallets are stored in the storage location as well. Loading of trucks will be performed manually at the nearest dock.

RICs are positioned in a more optimal way to decrease the loading time of the loading carriers. A disadvantage of this position is that the chain track probably has to stand still when RICs across this chain. On the other hand, RICs are supplied mainly by one or two and can therefore pass over this chain.

The same holds for the separate location for sorting of crates. The DPS en EPS crates is sorted in different areas in the current layout. Roll containers with this type of load must also cross the chain track.

Design 3: Completely automated

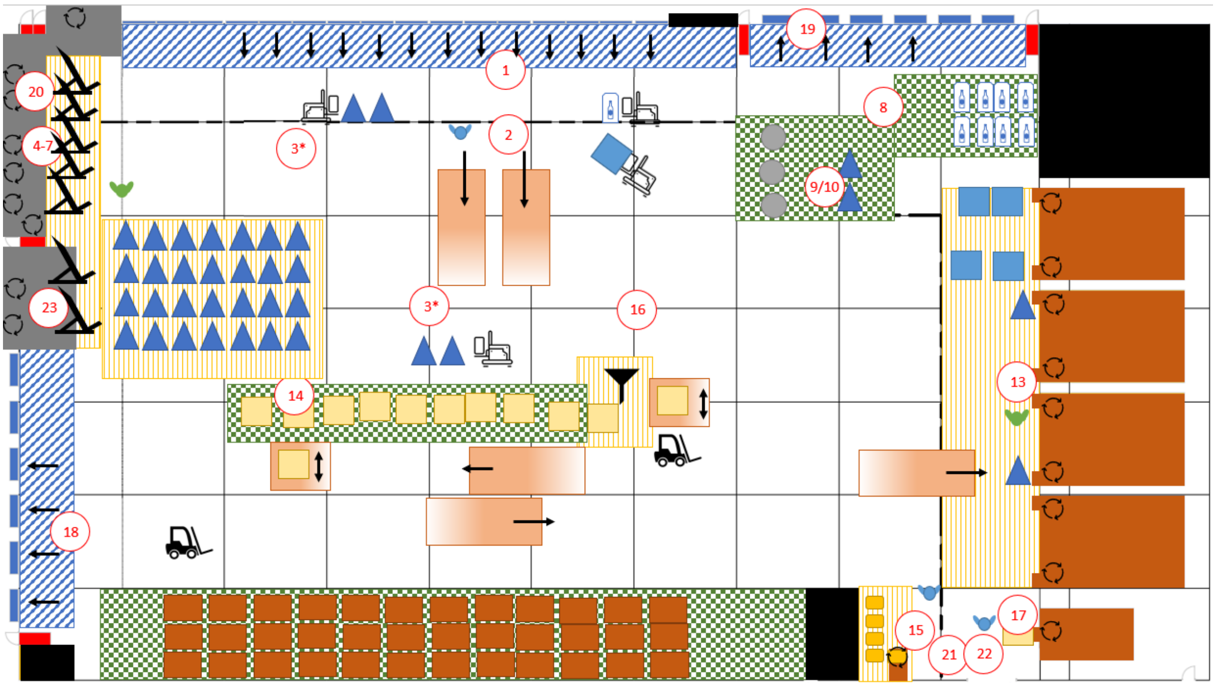


Figure 4-3: Design 3 – Ground floor - Completely automated layout

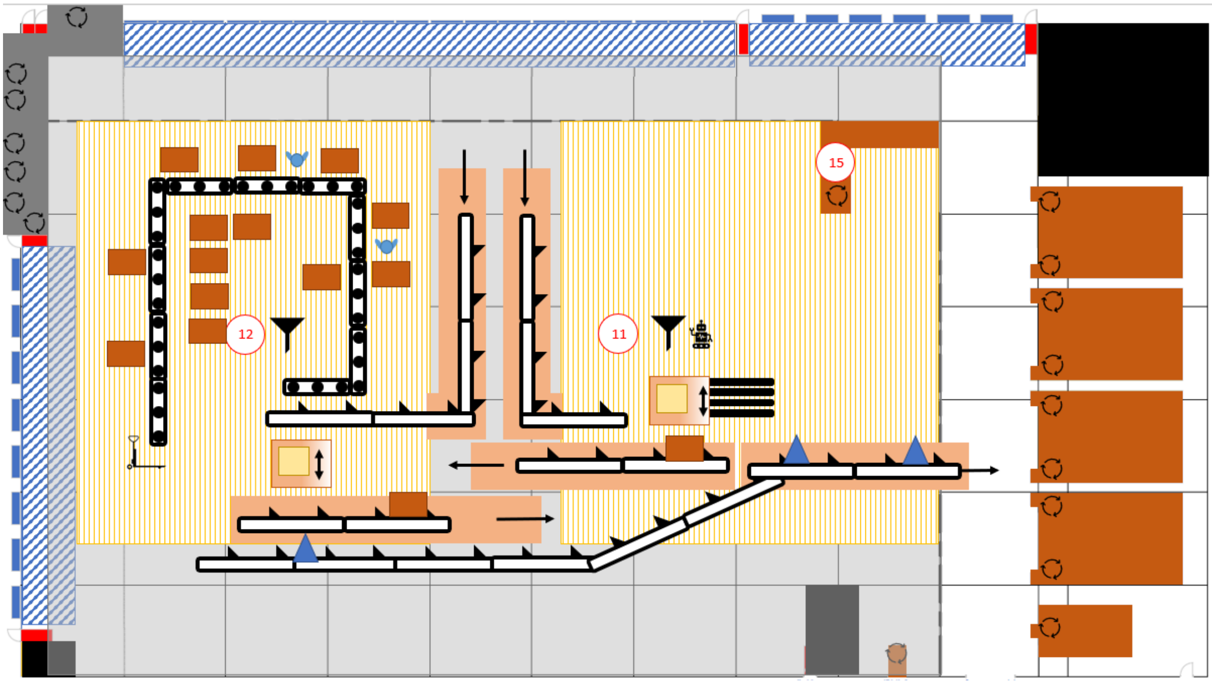


Figure 4-4: Design 3a - First floor - Completely automated layout (manual beer sorting)

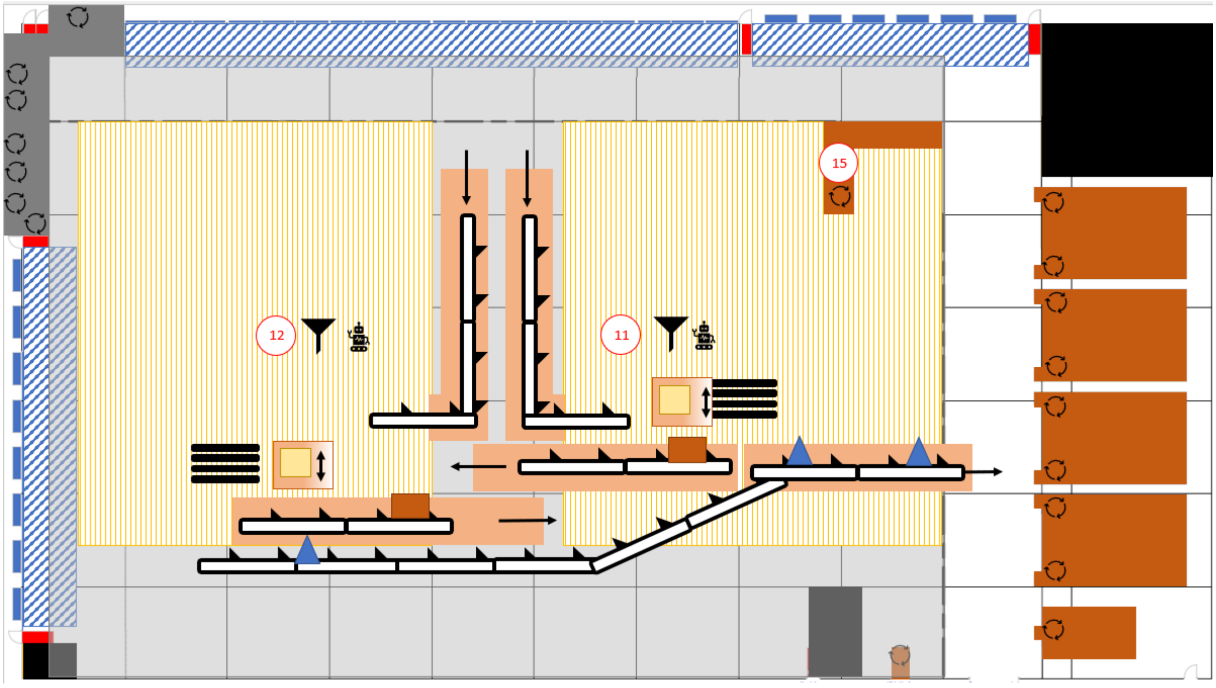


Figure 4-5: Design 3b - First floor - Completely automated layout

The inbound load is performed with a Joloda Moving Floor system. The primary transportation of waste, big bags, thermos, or roll containers is performed with AGV tuggers. Each type of waste has its tilt table at the waste corner. The AGV tugger positions the roll container for the right tilt table and waits till the roll container is emptied. Then the empty roll container is transported to the infeed point by the same AGV tugger. The roll containers with crates and beer are positioned at the chain track on a slope to the (newly built) first floor, which uses the (currently empty) height.

Two areas are equipped with an (automated) sorting system on the first floor. Because an automated beer sorting system is quite expensive, a manual sorting carrousel is shown as well in Figure 4-6: Design 3a - First floor - Completely automated layout (manual beer sorting). Once the (beer)crates are sorted, the crates are piled up on empty pallets supplied by the empty pallet elevator. The full pallets are positioned on the chain tracks on the downwards slope. The empty roll containers are placed on a separate chain track, ending at the infeed point on the ground floor. Once the full pallets are on the ground floor, reach trucks position the pallets in the storage area. Empty pallets also have storage but are also placed in the elevator to supply enough pallets for the automated sorted on the first floor.

One significant change is the infeed of CBL crates. This will no longer occur on the ground floor (and with an elevator to the butchery) but is done on the first floor in combination with the automated sorter and piler.

4.3.3 Validating designs

In section ‘C.2 Process constraints and requirements’, different constraints are given which are related to the design as a whole or a specific process. These constraints are validated per design in section ‘E.3 Validating designs’. In consultation with Hoogvliet has been agreed that there are no insurmountable objections to left out a certain design in this phase, but that all designs can be seen as valid and optional designs.

4.3.4 Investment costs per design

Based on the estimated costs in section ‘Proposed solutions’, the investment costs per design are computed and given in section ‘E.4 Quantities per solution and investment cost per design’.

4.4 Conclusions of the conceptual design

2. What are the preferred designs which solve the requirements and functions?

a. What are the possible designs that commit to the requirements?

To create some conceptual designs, different solutions are proposed in this chapter. These solutions consist of current solutions and new proposed solutions, which are all based on approved technology. These existing solutions consist of Employee, Temp worker, Shredder, and cardboard press. The proposed solutions are Joloda Moving Floor, Conveyor belt, Scale, EPT, AGV Tugger, Chain track, CBL crates sorter, CBL stacker, Pusher, Beer crates sorter, Tilt table, R-CNN + Conveyor belt.

These solutions are then connected to the relevant activities per process, as found in section 'E.1 Solutions per activity'. Whether a solution is suitable for a particular activity is based on the similarities between the explanation and the action that has to be done.

b. How do these solutions compare per requirement?

Per requirement, all relations between a solution and activity are scored based on a multiple criteria analysis with different requirements and weights given in the previous chapter. This is done in consultation with Hoogvliet, and it is assumed that the score per requirement does not differ between the activity to which the solution is connected. This can be done because the activity type is almost identical or the key is multi-functional (an employee or temp worker).

Based on the total score per solution, solutions like a pusher, scale and the R-CNN technology are not likely to succeed within a return hall. On the other hand, the allround capacity of own employees is still a suitable solution for return halls. The same yields for the transportation solution of chain tracks and EPT's. By drawing designs, an attempt is made to use solutions that score higher more often in the conceptual designs.

c. Which preferred designs can be made from the best-scoring solutions?

Three different designs are proposed based on these solutions, which vary the scored solutions into concrete use and position. These solutions have obtained a name that can be derived from the name of the solution: (1) Split waste and packaging, (2) Carousel, and (3) Completely automated.

- The first solution separates the loading carrier directly from the bags with waste at the inbound docks. The crates and other reusable packaging are moved to the return hall's right side.
- The second design has a general flow around the return hall with a chain track. The movements of the (empty) roll container are more streamlined with this.
- The third design contains a completely automated setup. For this layout, a floor is built inside the return hall to use the full height. The automated sorting of the (beer) crates takes place on the first floor. All movements are done with AGV tuggers and reach trucks.

The different designs are compared with the constraints to validate the designs. None of the designs fall off based on these constraints.

5 Model and evaluate design

Different designs are made in the previous chapter which are based on the business problem and processes as described in chapter 3. In this chapter, the preferred designs will be modeled and evaluated on the basis of the following questions:

a. *How can the preferred designs be tested?*
b. *What is the score of the preferred designs on the defined criteria?*
c. *How can the preferred designs be evaluated based on this score?*

This will answer the third main question:

3. *How can the preferred designs be tested or simulated to evaluate the performance criteria?*

To answer these questions, a simulation model is made to analyze quantitatively the preferred designs. Especially the improvements based on the performance criteria as given in section 'Key performance criteria' and the contribution to the objective play a key role.

5.1 Define simulation model

In section 'System analysis' is shown that the return hall functions as the whole system. This system has two input flows and three output flows or categories. Again, the system definition as given in Figure 3-1: System definition is shown in Figure 5-1: System definition. Although the throughput of the system contains mainly sorting processes, some activities like processing, infeeding and transporting are applicable as well which are shown in the functional flow block diagrams.

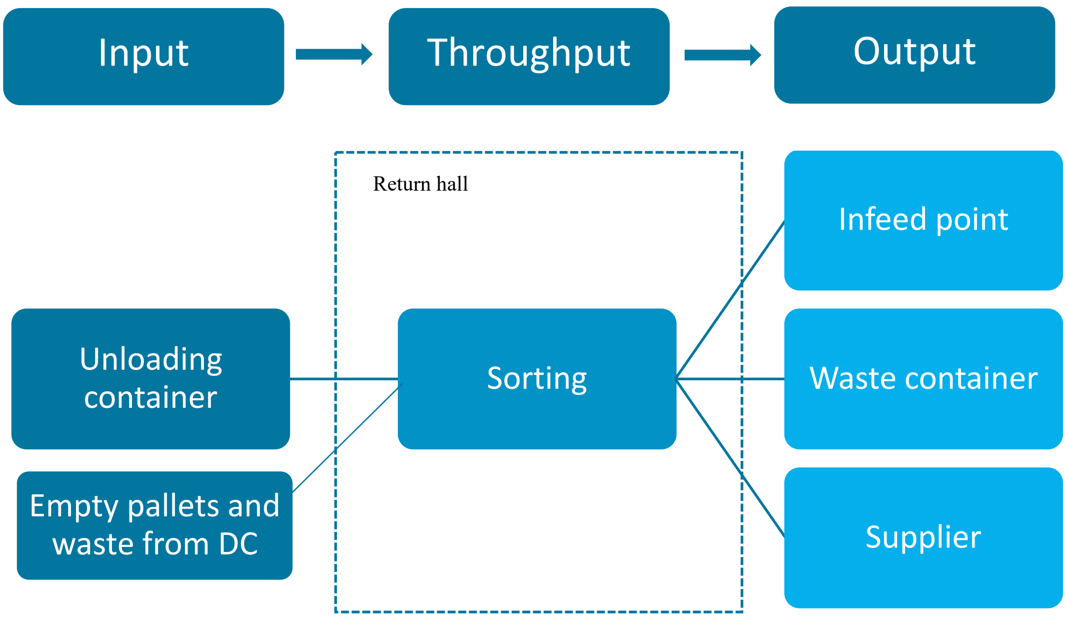


Figure 5-1: System definition

5.1.1 Input of simulation model

The main input source is the amount of interchangeable containers that arrive each quarter. The amount per quarter is determined based on internal measurements in 2019 as shown in section 'Volumes and future scenarios'. According to the logistic manager of Hoogvliet, this arrival process can be assumed to be the same for the current scenario. The type of load per entity is modeled random but in a certain ratio as given in Table 3-4: Average loading carriers per container. However, some of the types are combined into one cluster to make the simulation manageable. In Table 5-1: Share of entities per cluster the share per cluster is defined, the full computation per cluster can be found in 'F.1 Input computations'.

Table 5-1: Share of entities per cluster

Type	Entity	Cluster Share
Foil, Orange peels, Biowaste, Old bread, Residual waste, Carton	A	36%
(Bread) dolly	B	7%
Flower racks, E-commerce, Big bags	C	7%
Thermo	D	11%
Folded RC	E	25%
DPS, EPS, CBL	F	7%
Returns	G	1%
RIC's	H	2%
Beer	I	4%

As also shown in Figure 3-17: Bar chart of average share loading carriers per container, the mix of loading carriers for the future scenarios will slightly differ, but is so small that it is not relevant to take this change into account.. This is based on the expectation (according to Hoogvliet), that the amount of e-commerce roll containers will grow, and that the new waste type 'cans' is implemented.

The location of this input is divided over three or four docks on the upper side of the return hall (see Figure 5-4: Input locations). Because the arrival pattern could vary due to traffic jams or other disruptions, three arrivals are generated based on the average pattern as provided in Figure 3-14: Amount of container arrivals per quarter versus workload per hour (Hoogvliet internal source, 2021). In consultation with Hoogvliet is assumed that the arrival per quarter could vary between 30% below or above the average arrival rate and that the total arrival amount of interchangeable containers could vary 1% below or above the average arrival (for each volume scenario).

For the current situation, the three different arrivals are generated in Excel and are shown in Figure 5-2: Arrivals per hour for interchangeable containers - 3 runs - Current situation. A numeric overview can be found in section 'F.1 Input computations'.

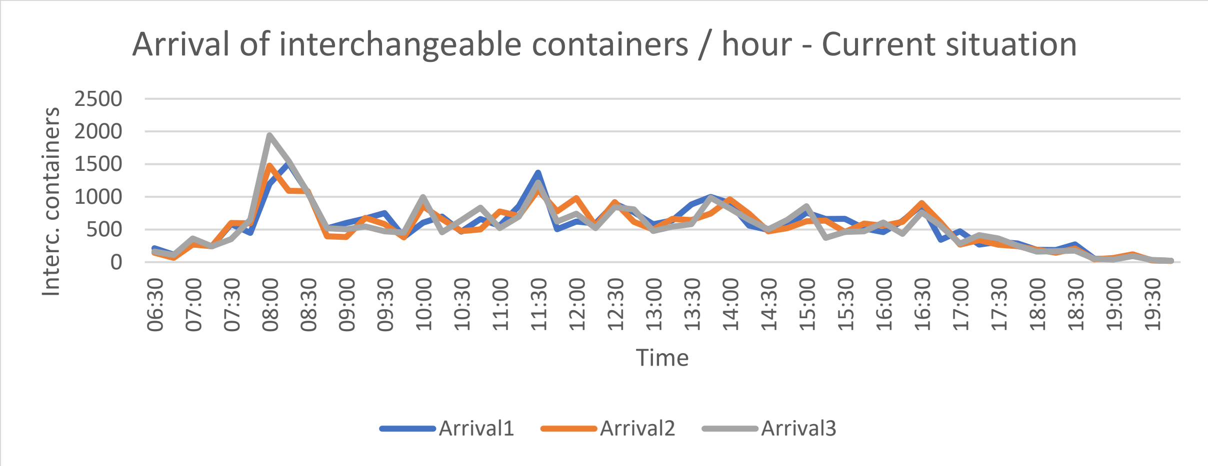


Figure 5-2: Arrivals per hour for interchangeable containers - 3 runs - Current situation

A second input flow are the empty pallets and waste boxes which are the residuals of the depalletizing at the automated warehouse of Hoogvliet. The average amount of empty pallets and waste boxes per hour is given in Figure 5-3: Arrivals per hour for empty pallets and waste boxes (Witron system 2022). Because of the limited volumes of the empty pallets and especially waste boxes, there is chosen for one arrival. A full numeric overview can be found in section 'F.1 Input computations'.

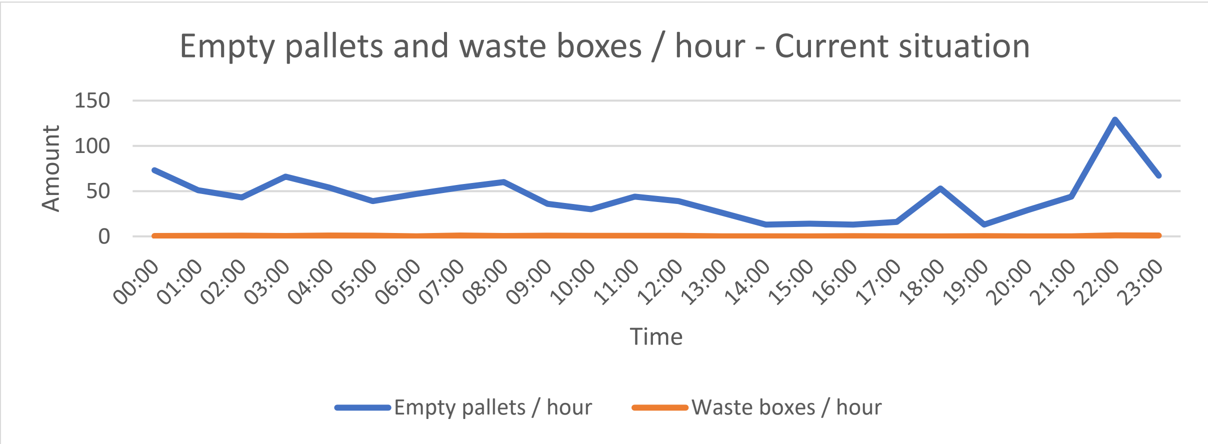


Figure 5-3: Arrivals per hour for empty pallets and waste boxes (Witron system 2022)

The ratio between pallets and waste boxes is also used by generating randomly waste boxes and pallets in a certain amount as defined in the table above. The location of this input is fixed at the lower right corner of the return hall as shown in Figure 5-4: Input locations.

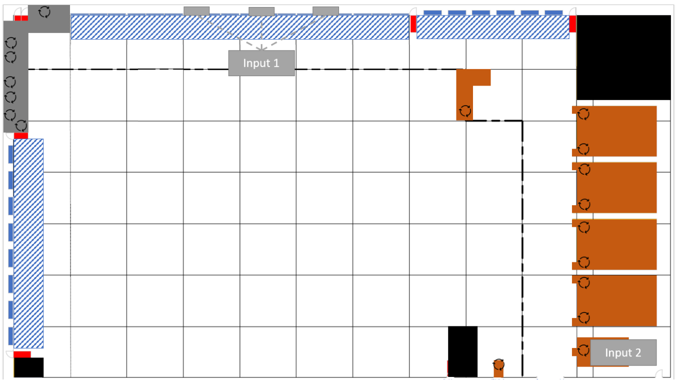


Figure 5-4: Input locations

5.1.2 Modeling throughput simulation model

The structure of the throughput is already visualized in section 'Process flows'. The physical flow and the categories of activities are connected to the processes of the flow chart in Table B- 1: Coding of return hall processes, but also the different solutions in the morphological chart. An insight of the average amount of loading carriers and time currently spend per flow, can be found in the section 'Workload analysis'. The throughput of the model will be validated with the measurements from the workload analysis in section 'Validation of simulation model'.

As stated in section 'Gemba walk', 23 different processes define the whole throughput within the return hall. The throughput consists primarily movements and sorting handlings. In Table 5-2: Translating processes into simulation objects, the 23 processes are mentioned and translated into a simulation object. The throughput of the workers, vehicles and servers that are used are defined in Table 5-3: Transport types and characteristics and Table F- 4: Server names, process times and amount of servers - Current situation. The simulation objects will be explained in section 'Implementation'.

Table 5-2: Translating processes into simulation objects

	Process description	Translation	Simulation object
1	Receiving and unloading container	The arrival of the interchangeable container with loading carriers is done with a Source object. How this arrival is defined can be found in section 'Input'. Currently, only 3 docks are used to unload at the time. This is done by one or two (during peak hours) employees. This will be modeled as three different servers to vary the distance to the other servers within the return hall, which is more reliable than one fixed server.	Source: 'InboundDocks' Server: 'Dock1', 'Dock2', 'Dock3'
2	Sorting roll containers / thermos / RIC's / bread dolly	The sorting of entities is done by the sequence logic of each entity. Besides, all empty roll containers are prepared in rows in front of the inbound docks, before they are moved by an employee or EPT to the infeed points. This entity (E) is therefore combined at a certain server with a zero process time, to create this logic.	Server: 'EntityE'
3	Transport loading carrier	The transportation of the loading carriers is done by a group of employees which are modeled as 'workers'. Besides the walking workers, some employees are equipped with an EPT to transfer more entities at the same time. The capacity for all transporting objects can be found in Table 5-3: Transport types and characteristics.	Table 5-3: Transport types and characteristics
4	Process roll container with old bread	Processes 4-7 are combined into one server because these processes are comparable. The processing time of this server will be a weighted average of all processing times found during the workload analysis.	Server: 'Waste_Processing'
5	Process roll container with carton		

6	Process roll container with bio / residual waste	*Also process 17 and 23 will be modelled with this server.*	
7	Process roll container with orange peels		
8	Process roll container with big bags	Processes 8-10 are combined because their storage space is almost the same (for the current situation). As explained before, this 'process' only contains the storage of these goods. Therefore, these goods are modeled with a sink object.	Sink: 'BBFLEC_Storage_In' (BBFLEC: Big bags, Flower racks and E-commerce loading carriers)
9	Process roll container with e-commerce bags and crates		
10	Process roll container with flower racks		
11	Process roll container with CBL crates	The sorting of CBL (or EPS and DPS crates as explained in section 'Gemba walk'), is modeled with a server.	Server: 'Sorting_CBL'
12	Process roll container beer crates	The sorting of beer crates is modeled with a multiple servers to distinguish slow and fastmovers. The process time for slow movers is significantly higher. Therefore, the flow of beer crates is split with a server with zero processing time. Then two servers are used to model the processing of both fast and slow movers.	Server: 'SplitBeer' Sorting_Beer_FM', 'Sorting_Beer_SM'
13	Infeed loading carrier	All empty loading carriers (from process 1, 4-7, 11, 12, and 15) are transported to the infeed point. In the current situation, there are two infeed points for thermos (which are infeed one by one) and are therefore modeled with two servers. The infeed of roll containers is divided over four stations (which infeed two roll containers at a time). The roll containers are being divided over these four infeed points which are modeled as servers. The thermos and roll containers leave the system by a sink which represents the bulk storage of the warehouse.	Server: 'InfeedT1', 'InfeedT2', 'InfeedRC1', 'InfeedRC2', 'InfeedRC3', 'InfeedRC4', Sink: 'InfeedThermo', 'InfeedRC'
14	Process dairy roll-in container (RIC)	RIC's are stored at a certain location and are therefore modeled with a sink.	Sink: 'RIC_Storage_In'
15	Infeed (bread) crate	The bread crates leave the system by a sink with a certain transfer-in-time which represents the infeed process. A certain share of roll containers form the sorting CBL server are infeeded. The CBL crates are infeeded by different employee and are modeled as a server.	Sink: 'Infeed_breadcrates', Server: 'InfeedCBL'
16	Process empty pallets	Empty pallets and waste bins from the Witron system enters the system with a source object.	Source: 'Witron', Server 'Outfeed',

17	Process waste bin with seal residuals	The share and time varying rate is defined in section 'Input'. They are stored on an outfeed conveyor which is modeled as a server. The empty pallets are sorted and stored in the return hall which is modeled with a server and a sink object. Waste boxes are emptied at server 'Waste_Processing' which is already defined (see process 4-7), and then infeeded next to the outfeed point, which is modeled as a sink.	'PalletSort', Sink: 'Pallet_Storage_In', 'InfeedWB'
18	Loading reusable packaging	Empty pallets, CBL crates, Beer crates, and RIC's are modeled as a source which generates enties at a certain event: This is based on the assumption that what enters the return hall, should also leave the return hall. If e.g. 50 RIC's are stored, a supplier picks up 50 RIC's as well. The reusable packaging is both loaded by reach and pallet EPT's. To create a reliable loading time, this is modeled with time paths that represents the loading activity. These four types of reusable packaging leave the system by a sink which represents the truck of the supplier.	Source: 'Pallet_Storage_Out', 'RIC_Storage_Out', 'Beer_Storage', 'CBL_Storage', Sink: 'Outbound_Supplier'
19	Loading big bags	Because processes 8-10 are combined in the current situation, the same happens for the outbound flow of these goods. Also the same principle as for 'loading reusable packaging' is used. Based on an event count of entities entering the source of process 8-10, the entities for the outbound flow are generated at once. The loading of these goods is done by employees which following a specific time path. The entities leave the system by the truck of the supplier (on a different side of the return hall as explained above), which is modeled with a sink.	Source: 'BBFLEC_Storage_Out', Sink: 'Outbound_Supplier2'
20	Change waste container Renewi	This activity is performed by one of the (assistant) team leaders which will not be simulated.	
21	Process non-food returns	Process 21 and 22 are combined into one entitie and leave the system with a sink at the opposite side of the return hall. The transit-in-time of this sink represents the time of travelling to the expedition hall.	Sink: 'Returns_cross dock'
22	Cross-docking		
23	Process roll container with trash cans (future process)	This process will be combined in process 4-7. Also the processing time will be based on the weighted average of loading carriers per waste type that enters this server.	Server: 'Waste_Processing'

All transportation is performed by four transport types. Each type has it's own speed and capacity in amount of entities. This information is specified in the table below:

Table 5-3: Transport types and characteristics

Type	Description	Processing time (m/s)	Capacity (#)	Type of entity	Initial amount
Worker	Own employees and temp workers	1,3	2	Loading carriers	7
Pallet_EPT	Small EPT for horizontal transportation	1,2	10	Loading carriers (folded)	3
Reach_EPT	EPT for full pallets, horizontal and vertical transportation	1,5	1	Full pallets	2

The throughput per sorting or processing station is based on the amount of servers and the processing time. These are based on the measurements as given in appendix section C – Measurements workload. Because the processing time fluctuates in reality, a deviation of -/+ 10% is applied. The average processing time is chosen as mode. The simulation model should model this process as a random triangular value. In section 'F.2 – Throughput computations' an overview of the servers and throughput times are given for the current situation. This is based on the amount of solutions that are ordered per design. Servers with a zero processing time are left out. The different designs contains sometimes other servers or process times. The deviation in time and additional servers will be given for each design in section Experiments per design. The duration of the simulation is 24 hours to simulate a whole working day. A simulation is done for each preferred design and scenario.

5.1.3 Output of simulation model

The output of the simulation contains lot of information such as occupancy per server or worker, throughput times and waiting times, etc. The output which is relevant for this thesis is already specified in section 'Key performance criteria' and the objective of this thesis:

- (1) Hours spend per loading carrier (efficiency)
    - To compute the hours spend per loading carrier in a realistic way, first the productive hours are computed based on the simulation run and validated in the next section. The efficiency ratio is determined by the amount of loading carriers that are received per day, divided by the amount of total hours (for unloading, processing, transporting and loading) used to process these loading carriers.
- (2) Payback period and estimated savings (cost – efficiency)
    - Comparing the expected cost per design (which can be found in section 'E.4 Quantities per solution and investment cost per design') with the previous criteria required hours and the original required hours, gives the ability to compute the payback period and estimated savings.
- (3) Queue length - especially during peak hours - on the inbound docks (flexibility)
    - The amount of loading carriers that are waiting at the inbound dock is known from the simulation and also validated according to Figure 3-15: Dock occupation (and queue) per scenario (Hoogvliet, internal source, 2021).
- (4) Limited capacity per process (scalable)
    - Although the capacity of the servers and workers will be increased with the same ratio as the future volumes, there could be a limitation because of the space that is assigned according to the sketch of the design as shown in Figure 3-7: Current situation layout. How big that area (or amount of servers) should be is also determined based the occupancy rate per server.

5.1.4 Implementation and verification of simulation model

To simulate the preferred designs for the return hall of Hoogvliet, some research is done to find a tool who could take into account the input, throughput and output criteria as explained above. The choice is made to use the simulation model of Simio which is intended for this type of simulation (Simio, 2021). Simio is an object based simulation tool which can simulated on a real time basis and on scale. The main objects that are used are:

- Entity: these objects represents different type of loading carriers, waste boxes and empty pallets in the simulation tool;
- Source: object which generate entities;
- Server: at this object, entities are processed with a certain processing time by one or multiple 'servers' which represents employees most of the time;
- Sink: object where entities leave the system;
- Worker: represent an employee who transports loading carriers through the return hall;
- Vehicle: represents Pallet and Reach EPT's, as well as AGV's. These are modeled with a different capacity and speed;
- Conveyor: an object which is used to model chain tracks and actual conveyor belts. Entities are transported on this line without carried by workers or vehicles;
- Time path: path with a specific duration for workers or vehicles to travel on. Used to model loading activities.

The original map of the return hall is implemented in Simio to use the real distances between working stations. Also for future designs, this map will be used. As an example, Figure 5-5: Snapshot of current situation in Simio shows a snapshot of the current situation.

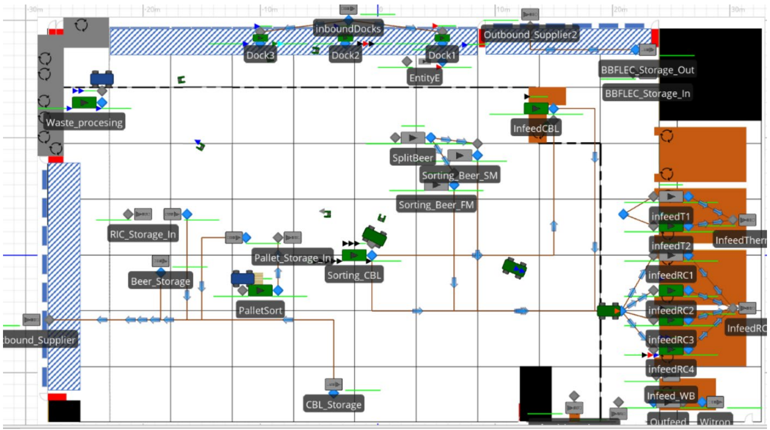


Figure 5-5: Snapshot of current situation in Simio

The simulation tool can be verified based on the following aspects:

- As shown in Table 5-2: Translating processes into simulation objects, all processes are covered in the simulation model.
- To see whether all entities that are generated and enter the system, also leave the system, the amount of entities is plotted in Figure 5-6: Loading carriers in the system - Current layout.

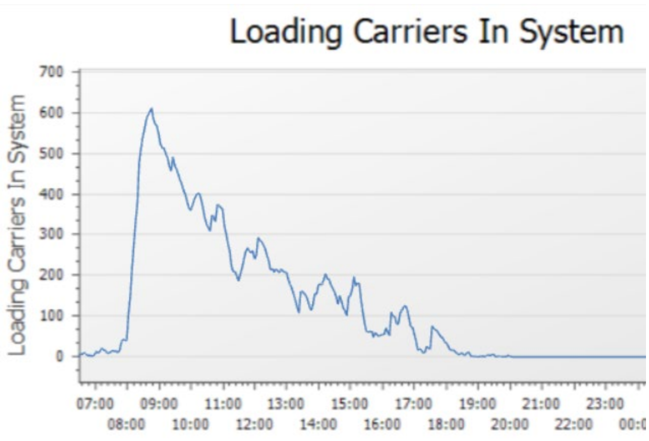


Figure 5-6: Loading carriers in the system - Current layout

5.2 Validation of simulation model

5.2.1 Qualitative validation

Based on the animation of the simulation tool can be found whether the movements and processes that take place at different locations are valid with the real situation. This can be validated by comparing a conceptual drawing on scale of the current situation with a snapshot of the simulation model which is also on scale. This comparison can be found in Figure 5-7: Comparison conceptual drawing of current situation and simulation model. Besides the position of the different servers is shown that the movements take place between the different servers corresponds with the process flows.

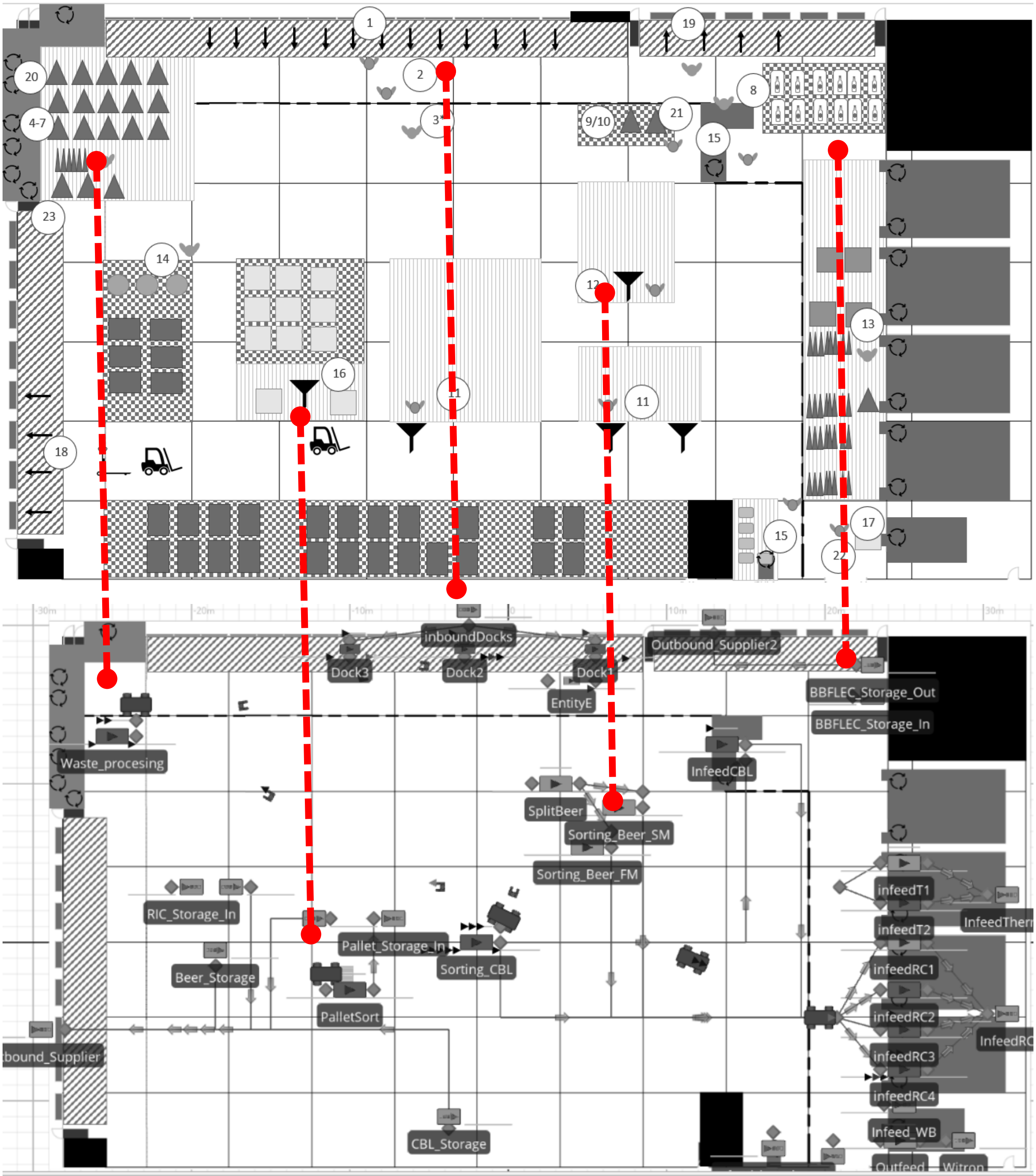


Figure 5-7: Comparison conceptual drawing of current situation and simulation model

5.2.2 Quantitative validation

Based on Table 5-2: Translating processes into simulation objects, could be stated that all relevant processes are in the simulation set up. The outcome performance criteria are validated based on the current layout.

(1) Hours spend per interchangeable container

To validate the required hours of the processes, first, the current situation is reconstructed in Simio. The outcomes in required hours are compared with the workload as analyzed in section 'Workload analysis'. Because the amount of interchangeable containers is (on average) the same as in the current situation, the amount of required hours is relevant on its own to validate the efficiency of the simulation. The model is validated if the total hours do not deviate more than 5%. With an average of 386 working hours per day, this results in an interval between 366.7 and 405.3 hours.

Because the management hours are not simulated, these are assumed to be 40 hours. The share of productivity loss is 19% based on the computations in section 'Workload analysis'. Because this amount will not differ, only the unloading, transport + loading, and processing activities are considered by comparing the different designs. The outcome of the current situation can be found in section 'F.3 Output validation – Required hours' are summarized in Table 5-4: Comparison of hours used. The minimum and maximum hours are given for the simulated categories based on arrival 1, 2, and 3. The difference in time occurs because the arrival process contains a higher peak with more waiting time or contains a slightly different load that needs more processing time. However, this difference is not more than 1 or 2 %. The management hours are not simulated and therefore determined on 40 hours. The productivity ratio is based on the fixed share of 19%.

Table 5-4: Comparison of hours between simulation and workload analysis – current situations

	Simulation				Realization	
	Min. (h)	Max. (h)	Avg. Hours	%	Hours	%
Unloading	27,3	27,6	27,4	7%	34,0	9%
Transport + loading	122,1	124,6	123,0	32%	127,0	33%
Processing	116,6	119,2	118,0	31%	110,0	28%
Management	40,0	40,0	40,0	10%	40,0	10%
Productivity loss	73,6	75,0	74,2	19%	74,9	19%
			382,6		**385,9**	

Because 382.6 hours is within the interval of 366.7 and 405.3 hours, the simulation model is validated.

(2) Payback period and estimated savings (cost – efficiency)

No investment costs or savings can be analyzed for the current layout in the current situation.

(3) Queue length on the inbound docks

The arrival of interchangeable containers contains a big and some small peaks. This could lead to a high dock occupation as shown in Figure 3-15: Dock occupation (and queue) per scenario (Hoogvliet, internal source, 2021) and even a queue that arise. The buffer of the inbound docks is fixed on 36 loading carriers (which does an interchangeable container contain on average). From practice and based on Figure 3-15: Dock occupation (and queue) per scenario (Hoogvliet, internal source, 2021) is known that one or more queue's arise. The model is validated if one or more queue's arise based on the current arrival process and unloading capacity.

The queue of the inbound source 'inbound docks' is plotted based on the three different arrivals as defined in section 'Input'. All plots can be found in section 'F.4 Output validation – Max queue length inbound' This results are summarized in Table 5-5: Max queue length per arrival

Table 5-5: Max queue length per arrival

	Arrival 1	Arrival 2	Arrival 3
Max queue length (loading carriers)	150	62	320
Max queue length (interchangeable containers)	4	2	9

This shows that the queue has not an extreme outcome and that this corresponds with the values which are shown in Figure 3-15: Dock occupation (and queue) per scenario (Hoogvliet, internal source, 2021). This implies that the simulation is also validated based on the second performance criteria.

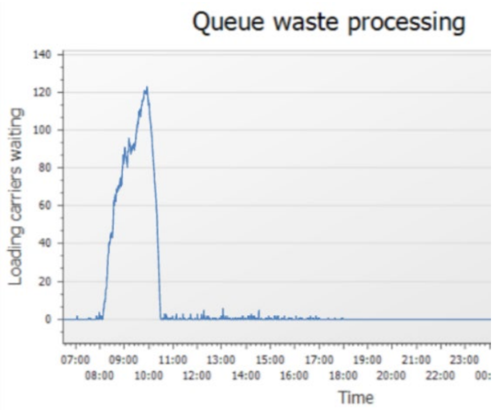
(4) Limited space per process
Besides the total capacity, which is already validated based on the first performance criteria, the limited space per process is also relevant. Because this space is based on the number of resources and the number of resources is determined by the number of employees and working space, the length of a process is determined by the number of employees that are available per hour and the amount of space that is needed for them to perform their job. This is why Table 5-3: Transport types and characteristics contain the number of workers that are used in reality and Table F- 4: Server names, process times, and amount of servers - Current situation also has the number of servers that are also used in reality. There is a switch in occupation between 8 and 10 AM from the waste processing and CBL sorting to the inbound docks because of the limited available docks. This is why the queue of loading carriers at the waste processing and CBL sorting servers increases.

Based on Figure 3-7: Current situation layout, the following computations are made:

- The surface of the Waste processing queue is around 10x10 meter = 100m2
- The surface of the CBL sorting queue is around 15x8 meter = 120m^2
- A roll container has a surface of 0.8 x 0.7 meter = 0.56m^2

This means that almost 100/0,56 = 178 loading carriers can be stored at the waste processing station and 120/0.56 = 214 loading carriers can be stored at the sorting CBL server.

This capacity is compared with the outcomes of the simulation. The results are shown in Figure 5-8: Queue for waste processing and CBL sorting - Current situation. This shows that the peak amount of loading carriers waiting for these servers does not exceed the limited floor space.



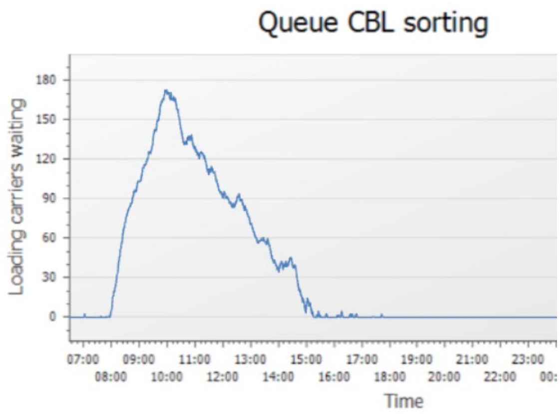


Figure 5-8: Queue for waste processing and CBL sorting - Current situation

5.3 Experimental plan and motivation

The preferred designs will be compared with the current situation of previous section.

5.3.1 Modeling improvements per design

Each design has some variations in the number of servers, processing times, job assigning, and transport types. This will give a different outcome per design for the performance criteria. For each design, all modeling improvements compared to the current situation are listed.

Design 1: Split waste and packaging

Based on Figure 4-3: Design 1 - Split waste and packaging layout, four improvements are made in comparison with the current situation:

- Improvement 1 - Waste processing:
  - The server for waste processing is re-allocated, reducing the approaching time for the workers. With tilt tables, the time to empty a roll container will be reduced. Conveyor belts will transport the waste bags and cartons for the last 10 meters. The waste bags need to be sorted on the right conveyor belt during this transportation. This will be modeled with the server 'waste processing'. The assumption is made that this setup will reduce the processing time by 10%. This changes the processing time from Random. Triangular(.25,.28,.31) to Random.Triangular(.23,.252,.28).
- Improvement 2 - Combined removal of roll containers:
  - All roll containers emptied at the tilt tables are transported with an EPT to the infeed point. Currently, this is done by both workers and EPTs, but this task is performed only by EPTs for this design. This takes place for empty roll containers at the waste processing, beer sorting, and CBL sorting server.
- Improvement 3 - Chain tracks for empty roll containers and thermos:
  - In front of the dock, two chain tracks are modeled for roll containers and thermos. To put these roll containers and thermos on the line, two servers are modeled: 'EnterRollcontainer' (with a transfer-in-time of 5 seconds) and 'EnterThermo' (with a transfer-in-time of 7 seconds). These times are based on the assumption that placing an empty roll container on the chain track takes seconds and the space between these tracks. The speed of these chain tracks is 0,25 m/s (Vorning, 2016).
- Improvement 4 - Different locations for beer crates, RIC, and empty pallets:
  - The different areas for sorting beer crates, RIC, and empty pallets have almost no effect on the simulation. Only the distance from beer crates to the outbound docks is relatively shorter, reducing the loading time.

Design 2: Carousel

Based on Figure 4-4: Design 2 - Carousel layout, four improvements are made in comparison with the current situation:

- Improvement 1 - Waste processing:
  - With tilt tables, the time to empty a roll container will be reduced. This will be modeled with the server 'waste processing'. The assumption is made that this setup will reduce the processing time by 10%. This changes the processing time from Random. Triangular(.25,.28,.31) to Random.Triangular(.23,.252,.28).
- Improvement 2 – Chain track for removal of roll containers:
  - A chain track is modeled from the server waste processing to the infeed points of empty roll containers. Also, at the location for the sorting of beer crates and CBL crates, there is an entrance point to place empty roll containers on the chain track. A server for this entrance is modeled with a processing time of 5 seconds.
- Improvement 3 - Chain tracks for empty roll containers and thermos:
  - In front of the dock, two chain tracks are modeled for roll containers and thermos. To put these roll containers and thermos on the line, two servers are modeled:

‘EnterRollcontainer’ (with a transfer-in-time of 5 seconds) and ‘EnterThermo’ (with a transfer-in-time of 7 seconds). These times are based on the assumption that placing an empty roll container on the chain track takes seconds and the space between the tracks.

- Improvement 4 - Different locations for beer crates, RICs, and empty pallets:
    - The different areas for sorting beer crates, Beer crates, and empty pallets have almost no effect on the simulation. Only the distance for RICs to the outbound docks is relatively shorter, which reduces the loading time (see also Table 5-6: Time paths for loading activities per design in minutes).

Design 3: Completely automated

Based on Figure 4-5: Design 3 – Ground floor - Completely automated layout, Figure 4-6: Design 3a - First floor - Completely automated layout (manual beer sorting), and Figure 4-7: Design 3b - First floor - Completely automated layout, multiple improvements are made.

- Improvement 1 – Unloading with a Joloda Moving Floor:
    - The servers at the different docks that initially represented the employees for unloading are now automated with a Joloda Moving Floor. This means that the processing time of these servers is not taken into account by computing the required hours for this design. This system can unload 36 loading carriers in three minutes, which is five seconds per loading carrier. The exact amount of three docks at a time in use limits the current situation to have a comparable model with the other designs and current layout.
- Improvement 2 – AGV Tugger instead of workers and pallet EPTs:
    - For transporting roll containers, thermos, and bread dollies, 15 AGV tuggers are used. Each AGV has a capacity of 3 loading carriers. The amount of 15 AGVs is based on the assumption that an AGV Tugger with three loading carriers needs 40 square meters for safe traveling. In total, 600 meters are available for transporting, which results in 15 AGVs. The driving speed of these AGVs is assumed to be one m/s based on production videos. Before an AGV could pick up the loading carrier, an employee needs to store the loading carrier in the correct position to couple this loading carrier to the AGV. This is why the server called ‘EnterAGV’ is added. The server processing time is assumed to be 7-13 seconds per loading carrier. The capacity of this server is 4, which are needed to process the first peak amount of loading carriers. This amount is based on the input and output buffer and coupling point space.
- Improvement 3 – Waste processing directly sorted:
    - Each waste container has its tilt table. The transfer-in-time of the server waste processing is assumed to be 5 seconds. This represents when the AGV pulls the roll container on the right Tilt table. However, empty roll containers need to be coupled to the AGV again. An employee does this at the waste processing server. The processing time of this server represents the time that an employee (de)couples a loading carrier on the AGV. This processing is also assumed to be 7-13 seconds per loading carrier.
- Improvement 4 – Relocating RICS storage:
    - The storage of the RICs is reallocated to reduce the transport time.
- Improvement 5 – Relocating Empty pallets sorting:
    - The sorting location for empty pallets is relocated to the midst of the return hall. This connects efficiently with the elevator for empty pallets, which brings empty pallets to the first floor. These empty pallets will be used as loading carriers for sorted beer and CBL crates on the first floor. The processing time of sorting pallets will be extended to include sending pallets to the first floor. The computation for this processing time is done based on the assumption that 10% of the sorted pallets are used on the first floor. This is modeled with a second sink called ‘Pallet_CrateLoadingCarrier’ with a path weight of 0.1. Entering these pallets in the empty pallet elevator is modeled with a

transit-in-time of 1 minute, assuming that it took one minute to store these pallets in some elevator.

- Improvement 6 – Automated CBL crate sorting on the first floor:
  - As described in the section, 'Proposed solutions', an automatic crate sorter and crate piler can be used to automate the process of CBL sorting. However, an automated sorting machine takes up a lot of space. This is why a first floor needs to be built (which uses the height of the return hall). The main requirement for this first floor is that loading carriers can be transported easily to this floor. This is why, on the ground floor, these loading carriers are put on the chain track by employees. Then, the loading carriers are transported along a chain track on a particular slope to a new build second floor. Empty loading carriers are transported down a chain track to the infeed points.
  - Even as it is in the current situation, a particular share of the CBL crates is infeeded in the system of Hoogvliet. This infeed point is also transferred to the first floor (this eliminates an elevator to the butchery, which is already on the first floor).
  - The capacity of the automated CBL sorter is, according to Elten (2021), 700 crates per hour. With an average supply (for the current situation) of 140 loading carriers with 20 crates = 2800 crates per hour, four of these automated sorters need to be installed.
- Improvement 7 – (Semi) automated Beer crate sorting on the first floor:
  - As shown in Figure 4-6: Design 3a - First floor - Completely automated layout (manual beer sorting) and Figure 4-7: Design 3b - First floor - Completely automated layout, two different beer sorting solutions are proposed. The fully automated solution goes like the automated CBL sorting machine but sorts different types of beer crates. The processing time of the beer sorting is not considered for the required (manual) hours because the system should do this fully automated. Because such machine is quite expensive, such machine could be probably only profitable with very high future volumes. This is why a semi-automated solution is proposed separately. The semi-automated beer sorting layout uses conveyor belts to transport beer crates to the different work stations.
  - The modeling difference between the first and second options is the processing time for beer sorting and how this time is allocated. According to Sidel (2020), 1200 crates per hour can be sorted. One sorting machine would be enough with an average supply (for the current situation) of 25 loading carriers with 28 crates = 700 crates. The semi-automated beer sorting solution uses conveyor belts to transport beer crates and an EPT to transport full pallets with beer crates. The assumption is made that this will reduce the processing time for beer sorting by 50%

Modeling path lengths per design

To simulate the loading of the trucks in an accurate way, a time path object is used. As explained per design, because of the change in layout, the time length per path need to be improved. This is done in a linear way which means that a reduction of 50% of the loading distance results in 50% reduction of the loading time. The path lengths are summarized in Table 5-6: Time paths for loading activities per design in minutes

Table 5-6: Time paths for loading activities per design in minutes

	Current lay-out	Design 1	Design 2	Design 3
Loading beer	2,6	1,6	1,6	1,6
Loading empty pallets	1	1	1,5	1,5
Loading RIC's	12	12	8	4
Loading CBL crates	2,5	2,5	2,5	1,8

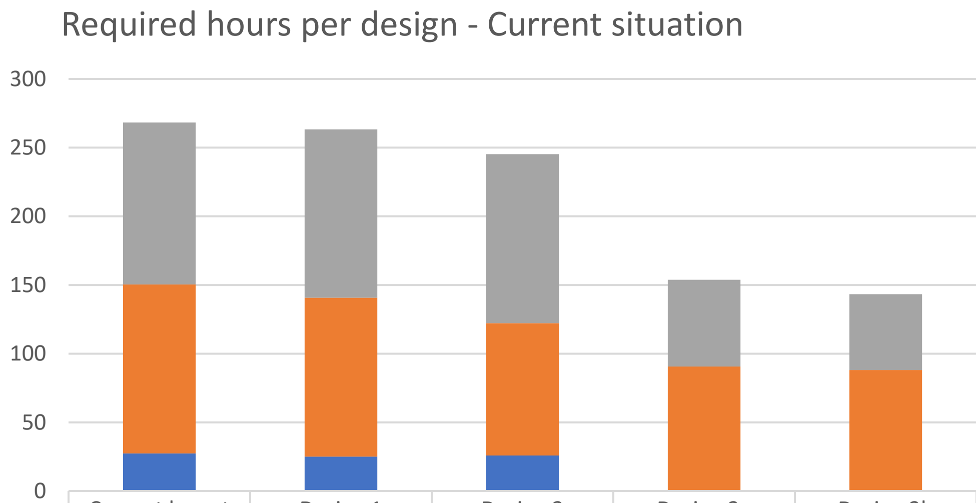
minutes per path length

5.3.2 Simulation outcomes scenario 0

The current layout and three preferred designs are simulated on the current scenario as defined in section 'Input'. The required hours are split into unloading, transport+loading and processing. For all designs, this is done with the same amount of workers and work schedule (as far as possible). With an equal availability of employees and equipment, the differences in occupation can be compared.

(1) Hours spend per interchangeable container

The manual hours that are spent within the 24 hours per design are showed in detail in section G.1 Current situation based on 1 - the average percentage time idle. The summation per category is given in the following figure.



	Current layout	Design 1	Design 2	Design 3a	Design 3b
Processing	118	123	123	63	55
Transport + loading	123	116	96	91	88
Unloading	27	25	26	0	0

Figure 5-9: Manual working hours per design - Current situation

Figure 5-9: Manual working hours per design - Current situation shows that for designs 1 and 2, the main impact on the required hours is caused by the transport and loading hours. This can be explained by the different chain tracks used in this design and the relocation of some sorting stations. Because the transportation is organized more efficiently, the unloading hours are slightly reduced by preventing blocking of the output buffers of the unloading servers. Comparing designs 1 and 2 shows that the chain tracks in design 2 are more efficiently used.

Of a different order are designs 3a and 3b. Because the Joloda Moving Floors are used for unloading, the required hours for unloading are reduced to zero. Although the transportation is primarily done with AGVs, the amount of manual hours for transportation is relatively high. This can be declared as follows: loading carriers need to be coupled manually on the AGV tugger (at both the inbound dock and the waste processing station). These manual hours are allocated to the category transport and loading. The processing time leftover in design 3a en 3b can be referred to as the infeeding of loading carriers and the sorting of pallets. For design 3a, also the beer sorting is performed manually.

The following table shows the decrease of working hours per design and expresses these hours in hours per loading carrier.

Table 5-7: Working hours per loading carrier - Current situation

	Current layout	Design 1	Design 2	Design 3a	Design 3b
The total amount of working hours	268	263	245	154	146
Decrease of working hours	-	-2%	-9%	-43%	-46%
Hours per loading carrier	1,31	1,28	1,20	0,75	0,71

(2) Payback period and estimated savings (cost – efficiency)

The total investment costs as shown in section 'F.5 Quantities per solution and additional investment costs per scenario' are compared with the saving in hours per day which is shown in the previous section. This results in the payback time in day's based on the following ratio:

$$\frac{total\ investment\ costs\ scenario\ 0}{(req.hours\ current\ layout, scenario\ x - req.hours\ design\ y, scenario\ 0) * average\ wage}$$

For all scenarios is assumed that the share of temp workers / own employees is 50/50. This results in an average wage of € 26,68 *0.5 + € 24,30 * 0.5 = € 25,49

The estimated savings are based on a lifetime of 10 years: $savings\ per\ day * 365 * 10 - total\ investment\ costs$

These computations result in Table 5-8: Comparison payback period and total savings per design show that design 2 has the shortest payback period. However, by assuming an average lifetime of 10 years for all the solutions, design 3a will have the highest estimated savings.

Table 5-8: Comparison payback period and total savings per design

	Design 1	Design 2	Design 3a	Design 3b
Total investment costs	€ 54.800	€ 78.950	€ 2.361.000	€ 4.431.200
Saving per day	€ 127	€ 586	€ 2.906	€ 3.110
Payback period (days)	430	135	812	1425
Payback period (years)	1,18	0,37	2,23	3,90
Total estimated savings (based on 10 year lifetime)	€ 410.393	€ 2.060.936	€ 8.245.389	€ 6.919.497

(3) Queue length on inbound docks

The maximum queue length per design is given in the table below.

Table 5-9: Maximum queue length per design - Current arrival

	Current layout	Design 1	Design 2	Design 3
Max queue length (loading carriers)	320	183	299	80
Max queue length (interchangeable containers)	9	5	9	3

According to Table 5-9: Maximum queue length per design - Current arrival each design results in a better-streamlined arrival process for loading carriers. If this amount is expressed in interchangeable containers (Roundup (max queue length loading carriers / 36)), the second design equals the current situation. Although design 3 has a far better performance on the inbound queue length, none of the designs eliminates the queue of loading carriers (based on three unloading docks at a time).

(4) Limited space per process

Even for the current situation, the different designs should fit within the return hall. As said before, this space is extended for the third design to the first floor. It is hard to validate if this additional space would be enough and assumed to be unlimited.

The first and second design has the same number of servers for the main sorting stations: ' waste processing,' 'beer sorting,' and 'CBL sorting.' Because the same amount of loading carriers arrive for this simulation, the space used is validated in section 'Validation of simulation model'.

5.3.3 Defining scenarios based on forecasts

As explained in section 'Volumes and future scenarios', quantities will change in the future. Therefore, two different forecasts are made based on the expected growth of Hoogvliet as a supermarket. The forecast with 100 supermarkets is marked with an 'A,' the forecast with 120 supermarkets is marked with a 'B.' The current situation is marked with a '0'. Regarding forecasts, 'A' and 'B' are assumed that the number of interchangeable loading carriers will increase linearly with the number of supermarkets that must be served.

Besides the forecast in terms of growth, there is some difference in quantities due to the year, week, and day. This is why the peak weeks around Easter and Christmas, as shown in section 'Volumes and future scenarios', are also considered as forecasts.

Because the simulation runs a 24-hour operation, the daily peak is involved in all these forecasts. However, there are differences in throughput per working day, as shown in Figure 3-11: Containers per day on average, comparison 2019 with future scenarios (Hoogvliet internal source, 2021). Three scenarios are simulated to see whether bottlenecks arise in throughput and compare other performance criteria among the designs for different forecasts. These scenarios are based on the various quantities that may occur. Table 5-10: Expected amount of interchangeable containers per forecast and scenario, translated into three scenarios, gives an overview of the expected amount of interchangeable containers that will arrive.

Table 5-10: Expected amount of interchangeable containers per forecast and scenario

	Current situation	Forecast A	Forecast B	
Average Week - Average Day	205	293	351	
Average Week - Peak Day	261	373	447	
Peak Week - Peak Day	306	438	525	
Scenario 0 (Validation)	205	205	205	Factor
Scenario 1	308	308	308	1,5
Scenario 2	410	410	410	2,0
Scenario 3	513	513	513	2,5

Based on these levels, three scenarios are defined with factor 1.5, 2.0 and 2.5 respectively, which cover the inbound levels of the different quantities as shown in Figure 5-10: Forecasts and scenario. These levels are computed by the linear growth from 70 to 100 (A) or 120 (B) supermarkets. The peak day for an average weak is 27% higher than the average daily volume (which is also shown already in Figure 3-13: Amount of hours needed per day (Hoogvliet, internal source, 2021). The average amount for a peak weak is also based on the measurements which are shown in Figure 3-10: Containers per week, comparison 2019 with future scenario's (Hoogvliet internal source, 2021). For peak weeks is known form practice that the volumes per day are more equally spread. This is why the peak day in a peak week is assumed to be 20% above the average volume in this peak week.

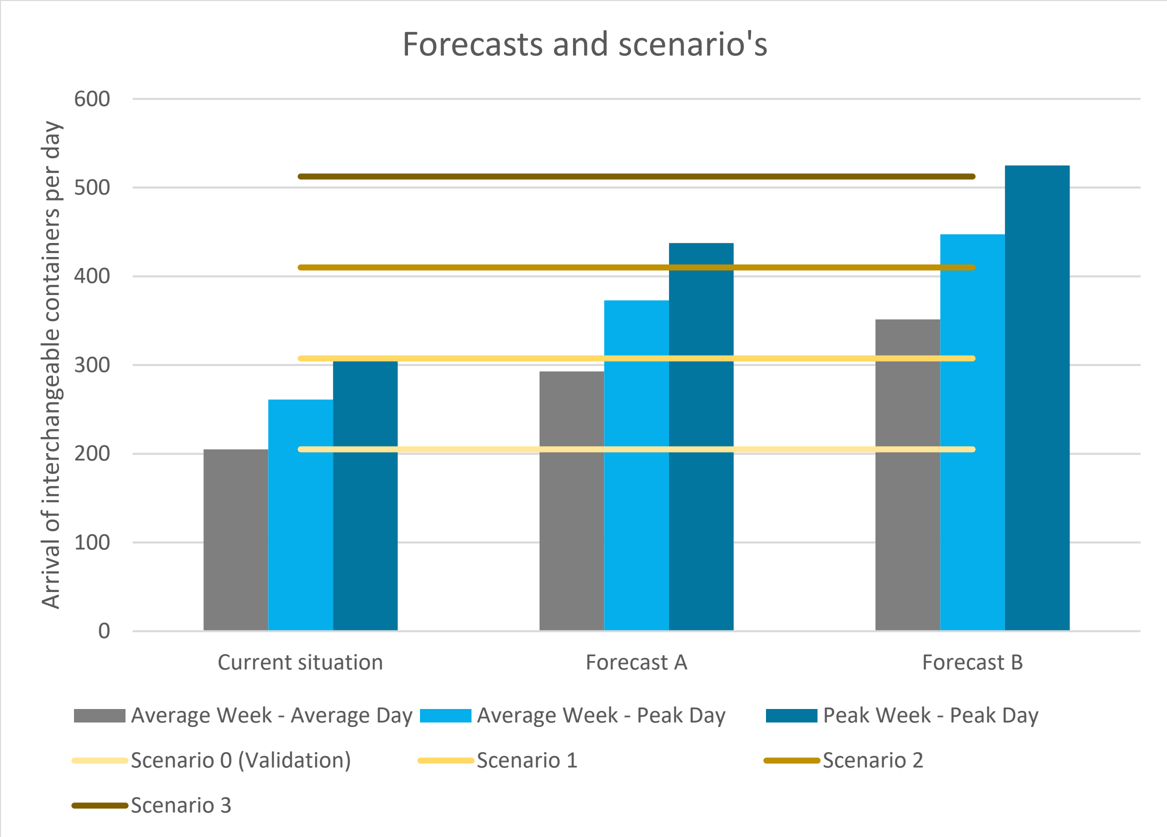


Figure 5-10: Forecasts and scenario

Summarizing the upper table, the following 3*3*5 simulations are done:

- Scenario 1, 2 and 3 for the Current layout (average of three runs - arrival 1, 2, 3)
- Scenario 1, 2 and 3 for Design 1 (average of three runs - arrival 1, 2, 3)
- Scenario 1, 2 and 3 for Design 2 (average of three runs - arrival 1, 2, 3)
- Scenario 1, 2 and 3 for Design 3a (average of three runs - arrival 1, 2, 3)
- Scenario 1, 2 and 3 for Design 3b (average of three runs - arrival 1, 2, 3)

5.3.4 Capacity improvement per scenario and design

The factors for scenarios 1, 2 and 3, which are 1.5, 2.0, 2.5 respectively, are applied to both the input volume and the capacity of the resources. Both the regular input volumes with arrivals of interchangeable containers (all three arrival runs) and outfeed of the Witron system, are multiplied by the scenario factor.

Also some small improvements are done for the current layout and designs to prepare these layout for the scenario volumes. The improvements for the current situation contain: transporting empty roll containers from the waste processing, beer and cbl sorting servers only with pallet EPT's instead of using both workers and EPT's. Four docks are used for unloading and six infeed stations for roll containers are installed instead of four. The increase of amount of docks for unloading and six infeed points applies for all designs.
In section 'F.5 Quantities per solution and additional investment costs per scenario' for each scenario the amount of solutions that needs to be ordered are given. This results also in the total investment costs per scenario which will be elaborated in section 'Results per performance criteria'.
In section 'F.6 Capacity constraints per scenario' the capacity and additional servers per design and scenario are given. This capacity is not always multiplied by the factor for the certain scenario because the current capacity is not exceeded (as can be found in appendix 'G – Simulation Results'). Also work schedules are no longer used because this will be too complex to estimate in the future. Therefore, the most reasonable solution is a fixed amount as capacity per server is chosen.

5.4 Results and evaluation of the designs

5.4.1 Results per performance criteria

(1) Scenario 0 till 3 - Hours spend per interchangeable container

The results per design and scenario are computed by Simio. This gives the following results, categorized by unloading (blue), transport + loading (orange) and processing (grey) in Figure 5-11: Required hours per scenario and design, stacked per category. The management and productivity loss hours are neglected because these are not simulated.

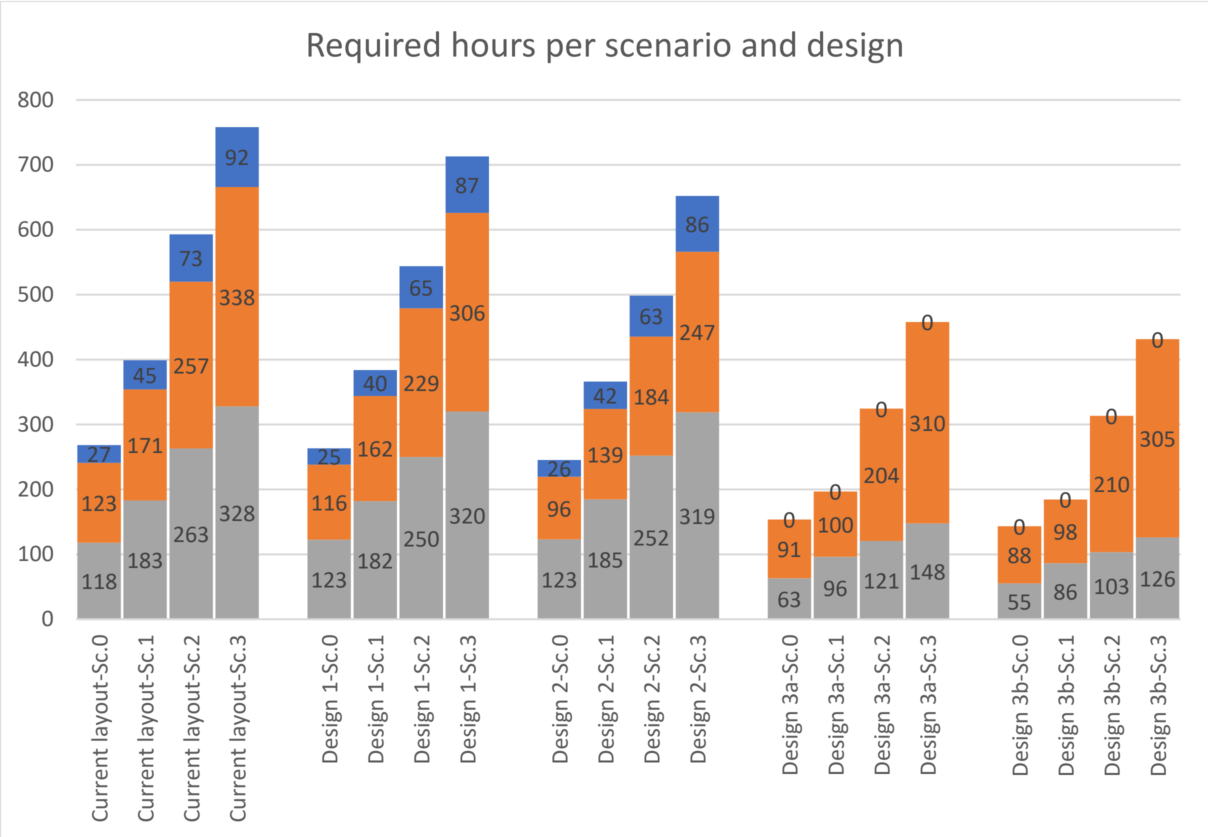


Figure 5-11: Required hours per scenario and design, stacked per category

This shows that for all scenarios, design 3a and 3b has the lowest amount of required hours and that the current layout has the worst score. For each category (unloading, processing and transport + loading), the total amount of required hours per design and scenario are given in Figure 5-12: Required hours per scenario and category.

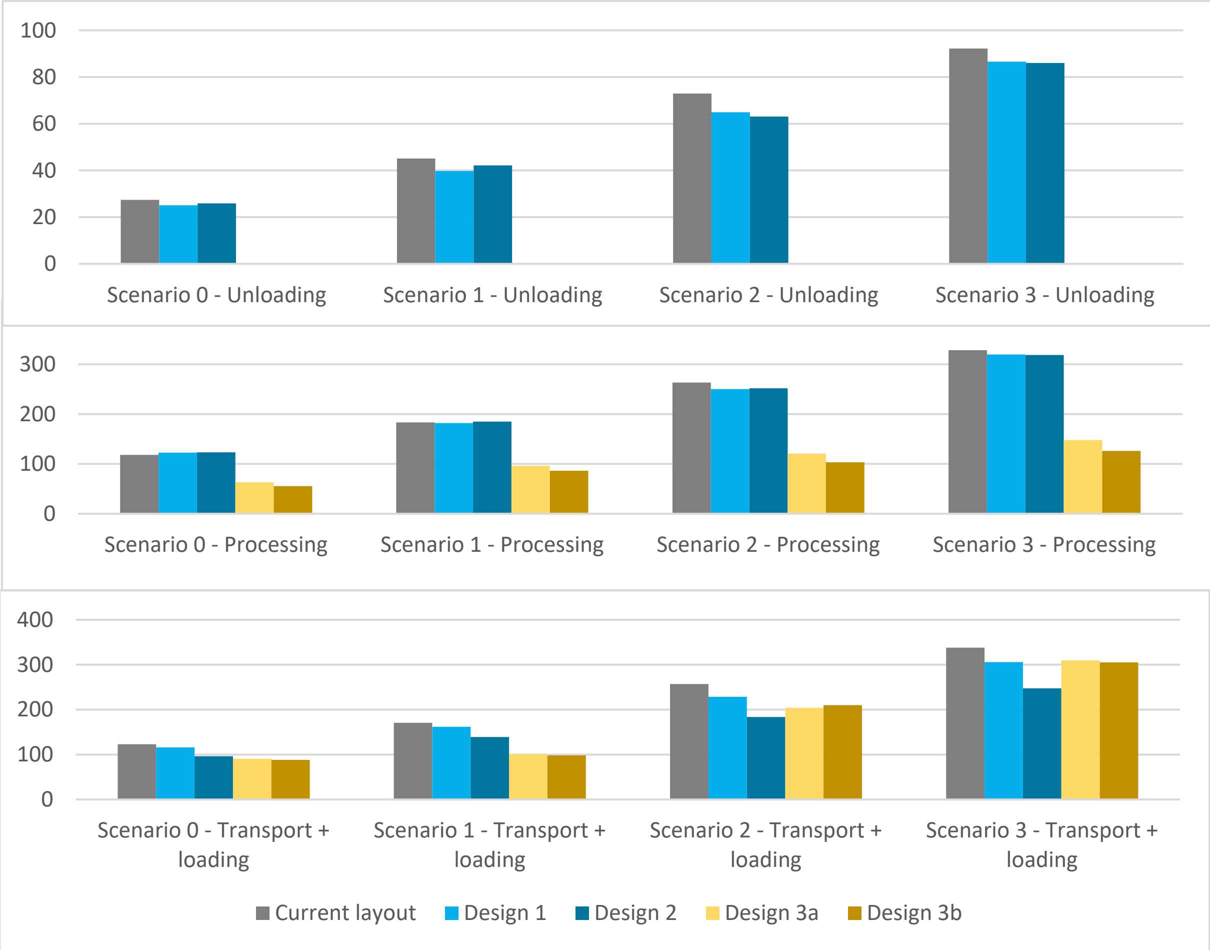


Figure 5-12: Required hours per scenario and category

The ratio of hours per loading carrier is compared with scenario 0. All required hours per simulation run can be found in section 'G.2 Scenario 1-3'. In Figure 5-13: Required hours per interchangeable container is shown what the ratio of required hours per loading carriers is per scenario.

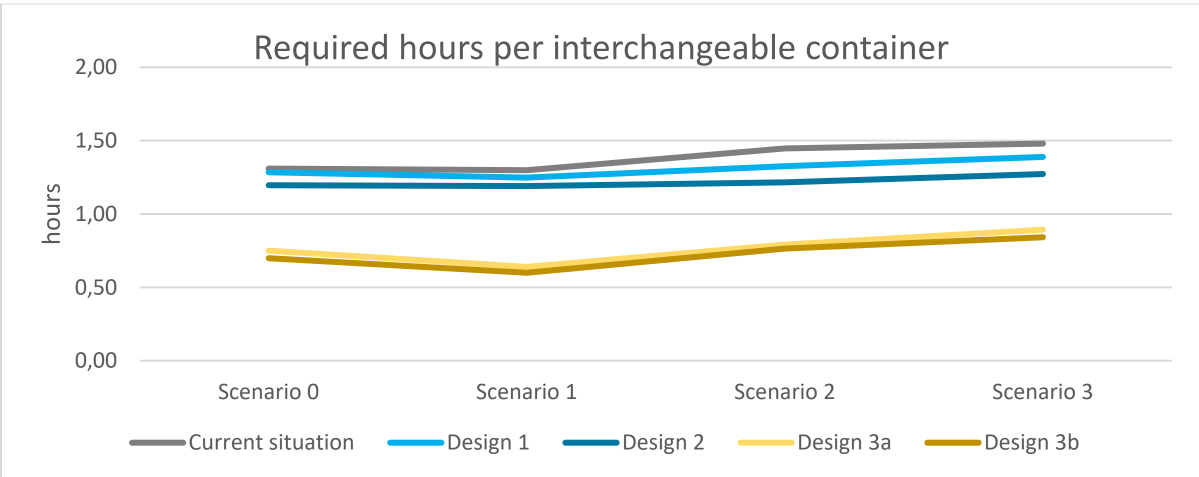


Figure 5-13: Required hours per interchangeable container

The kink in the line by scenario 1 for design 3 in this figure could be explained by the additional inbound and infeed servers as shown in section 'Modeling improvements per design'. In general, design 1 and 2 are slightly lower than the current situation, design 3a and 3b score on a way better level because of their level of automation. However, this can be analyzed in more detail. Therefore, the same ratio is given for separately unloading hours, transport and loading hours and processing hours.

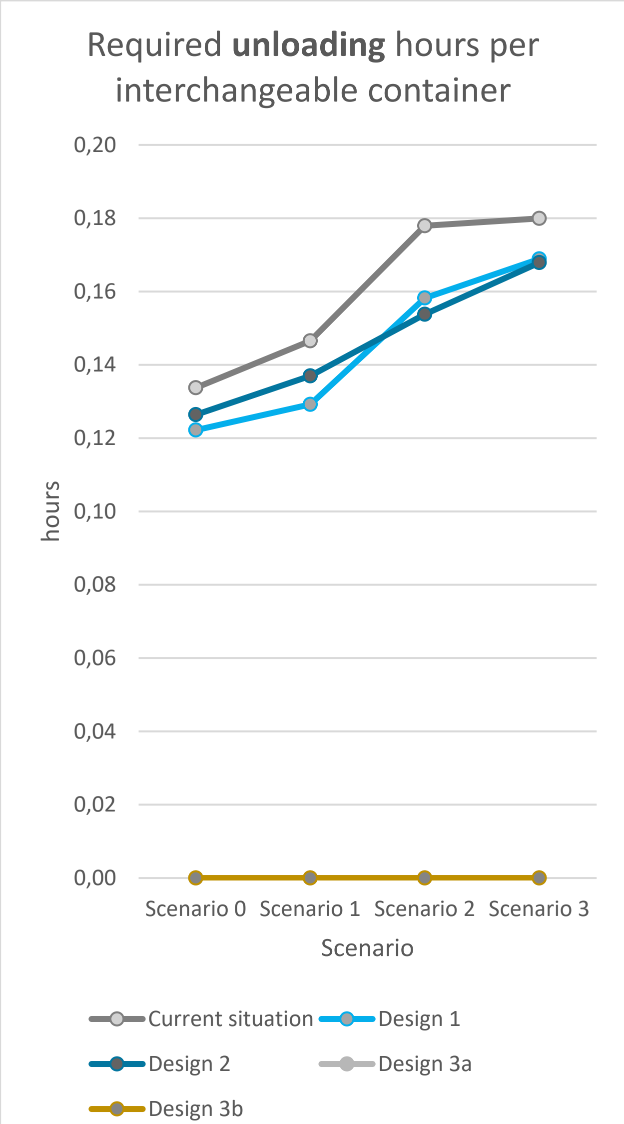


Figure 5-16: Required unloading hours per interchangeable container

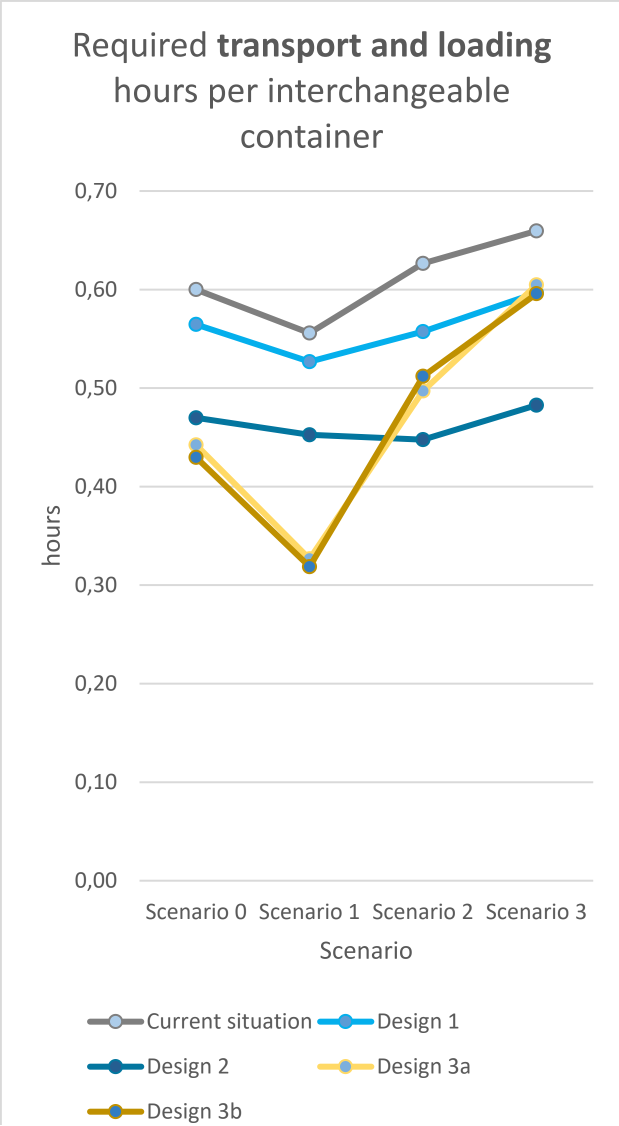


Figure 5-14: Required transport and loading hours per interchangeable container

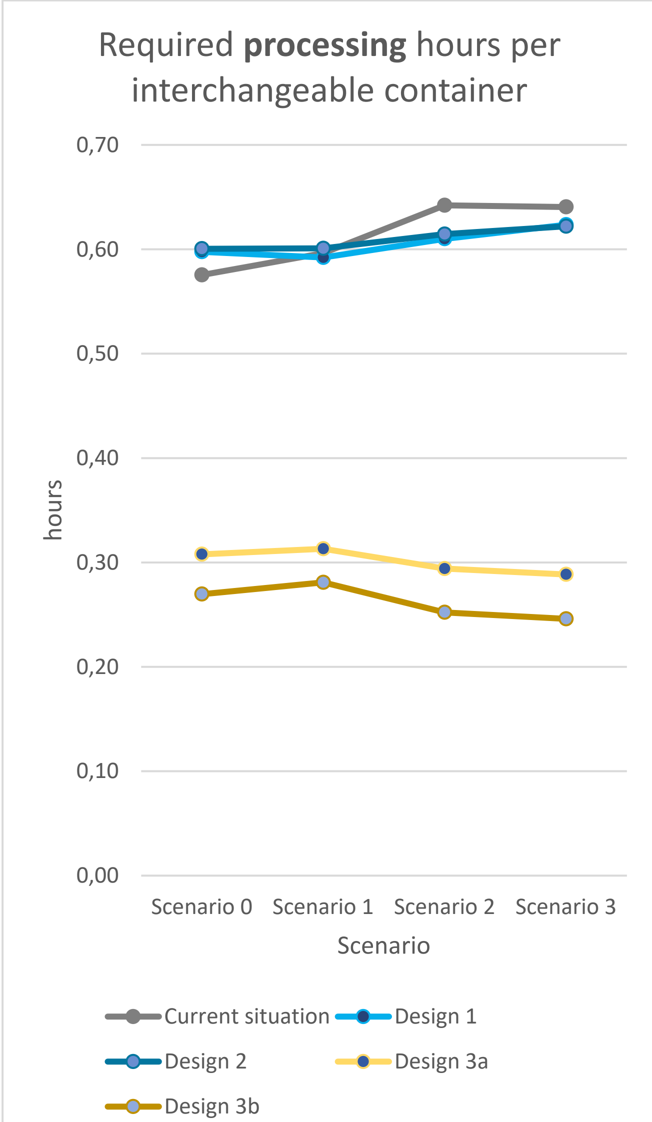


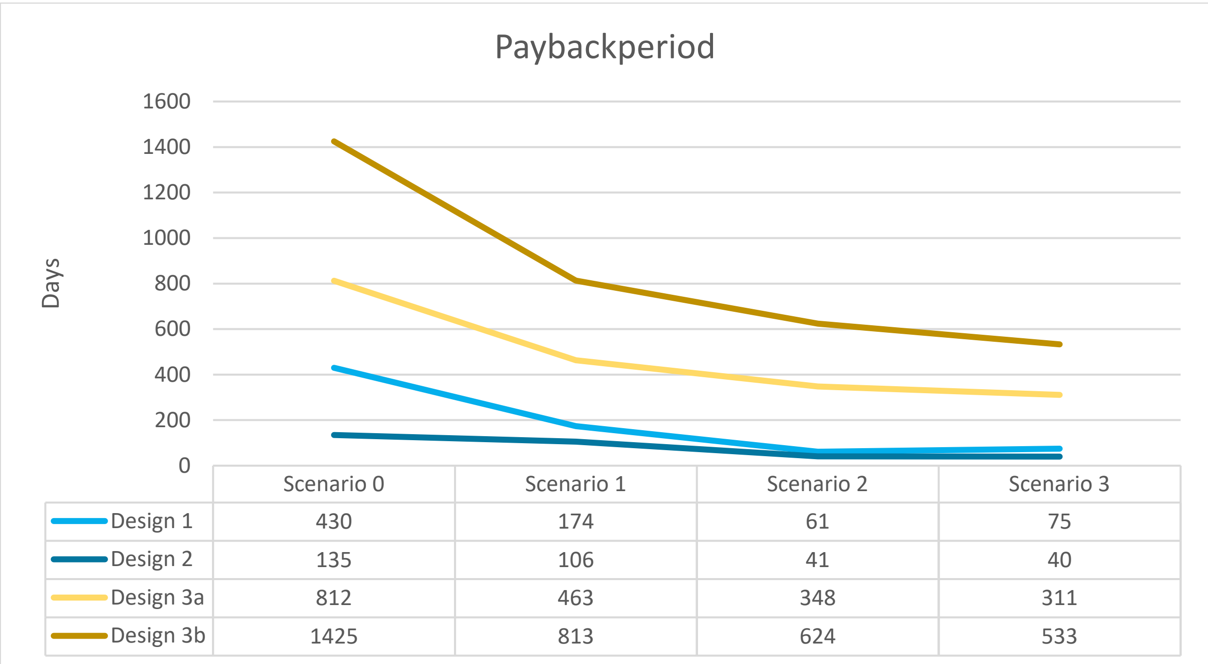
Figure 5-15: Required processing hours per interchangeable container

Figure 5-14: Required unloading hours per interchangeable container showed that design 3a and 3b has a fully automated unloading process, resulting in 0 hours per loading carrier. Design 1 and 2 have a comparable score; with the increase of loading carriers per scenario, the amount of hours needed for unloading increases as well what does mean that the unloading process becomes less efficient.

Figure 5-15: Required transport and loading hours per interchangeable container reveal the performance of the different designs in terms of transport and loading hours per interchangeable container. From section 'Workload analysis' is known that this is one of the main components of hours. Scenario 1 is performed more efficiently than scenario 0. Especially design 3a and 3b have a low amount of required hours per container. However, shifting to scenario 2 results in a very upward bending line for designs 3a and 3b and to a lesser extent for the current layout and design 1. The only design that is still improving his efficiency is design 2. It obtains even a better score in scenarios 2 and 3 than all other designs.

Figure 5-16: Required processing hours per interchangeable container shows that for scenario 0, designs 1 and 2 score a bit worse than the current layout. However, by increasing the volume in scenarios 1, 2, and 3, the processing hours per container for designs 1 and 2 remain stable, but the current layout slightly increases. A far better score is obtained by designs 3a and 3b, which halve the required hours.

(2) Scenario 1 till 3 – Payback period and estimated savings (cost – efficiency)
The total investment costs as shown in section 'F.5 Quantities per solution and additional investment costs per scenario' are compared with the saving in hours per day indicated in the previous section. The formulas are already defined in the section 'Simulation outcomes per design for current situation.' These computation results in Figure 5-17: Payback period per design in days. This figure shows that the second design obtains the best result with 40-135 days and that design 3b has the worst score, which is not strange because of the high automation level of this design. Furthermore could be concluded that all designs benefit from the increasing volumes.



	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Design 1	430	174	61	75
Design 2	135	106	41	40
Design 3a	812	463	348	311
Design 3b	1425	813	624	533

Figure 5-17: Payback period per design in days

If all solutions will have an average lifetime of 10 years, the total estimated savings will increase to 25 million for design 3, which is 2.5 million per year. Design 2's savings are estimated to be 10 million which is 1 million per year. The lowest savings are expected for design 1 with the highest savings in scenario 2 with almost 5 million which is half of the amount of design 2. This is summarized in Figure 5-18: Total estimated savings per design (over 10 years).

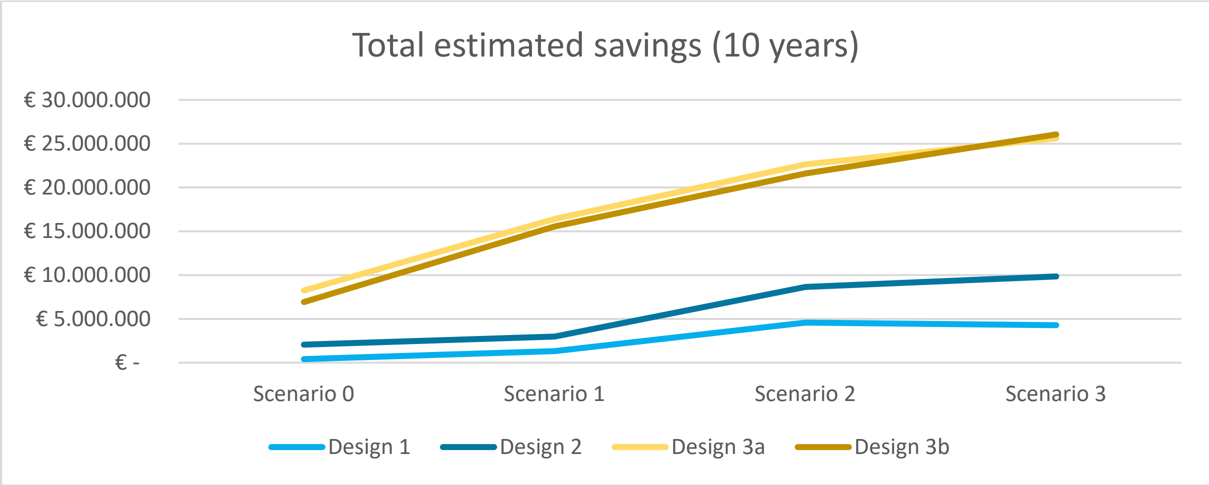


Figure 5-18: Total estimated savings per design (over 10 years)

(3) Scenario 1 till 3 – Queue length on inbound docks

For each arrival, the queue on the inbound docks is plotted in terms of loading carriers through the day. A full overview of these plots can be found in section 'H – Simulation Results – Queue length'. These results are summarized in Table 5-11: Min/Max queue length of loading carriers on inbound docks. It shows that for scenario 1, the most efficient unloading process is performed by design 3a. However, because of the limited space to install more Joloda Moving Floors, a huge queue is created for scenario 2 and 3. A more stable queue is found for mainly design 1, followed by design 2.

Table 5-11: Min/Max queue length of loading carriers on inbound docks

Scenario	Shortest queue	Max amount of loading carriers	Longest queue	Max amount of loading carriers
1	Design 3	350	Current layout	490
2	Design 1	590	Design 3	1340
3	Design 1	950	Design 3	4300

(4) Scenario 1 till 3 – Limited space per process

In section 'Capacity improvement per scenario and design', for each design and scenario, the capacity of the servers is adjusted. This is done in a linear way and basted on the current occupation and limited space of the return hall. Two main sever groups are restricted by the limited space: the amount of inbound docks and the amount of infeed servers for roll containers. This results in queue's for inbound docks as shown in the previous section, but also queue's inside the system, especially for the third scenario. In Figure 5-19: Example of queue's inside the system - Design 2 - Scenario 3, an example of such queue is given. Whether such a queue fits within the return hall depends on the space that is allocated for this queue. Besides the space for the infeed queue, other process should continue as well. In the situation as visualized below this is a big issue (not in the

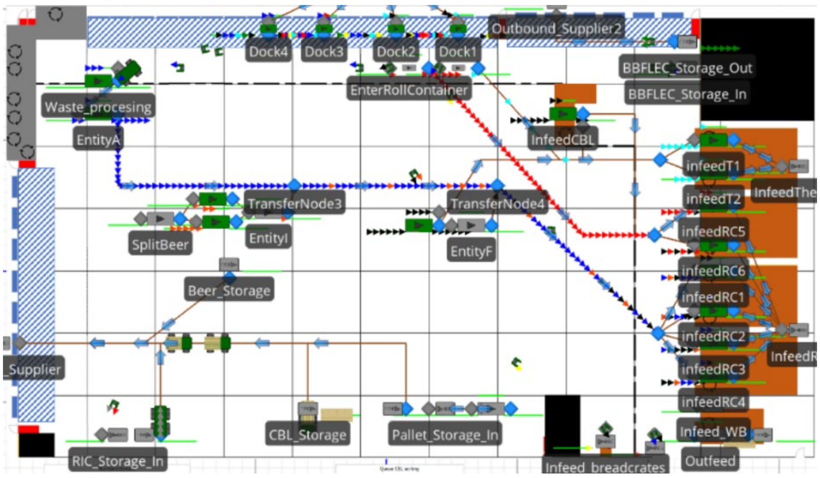


Figure 5-19: Example of queue's inside the system - Design 2 - Scenario 3

simulation model but if this is the case in reality). This queue arises for the current layout, design 1 and 2, because their inbound and infeed capacity is the same for all these designs. A possible solution could be a separate floor which functions as a buffer location for roll containers. How this floor is connected with the processes on the ground floor could be investigated in future research.

5.4.2 Evaluation per design – pros and cons

Current layout

Pro(s): The performance of the current layout is relatively stable for all categories and scenarios.
Con(s): As stated in the previous section, the amount of required hours per loading carrier grows linear, which means that the total required hours grows exponentially. Especially the hours needed for transport and loading increases faster than the number of loading carriers.

Design 1

Pro(s): The processing and unloading hours are comparable with the current layout but better. This means that the tilt tables do not significantly impact the processing hours. However, the relocation of different processing stations such as waste processing and beer sorting positively affects the transport hours. Besides, this design obtains the most efficient unload performance for scenarios 2 and 3, resulting in the lowest inbound queues. The payback period of this design is a decreasing trend except for the third scenario.
Con(s): This design has a low score with 430, 174, 61, and 75 days as payback periods for scenarios 0, 1, 2, and 3, respectively. In comparison with other designs, is this a long payback period.

Design 2

Pro(s): With a payback period of 135, 106, 41, and 40 days for scenarios 0, 1, 2, and 3, respectively, this design has the best score. As shown in Figure 5-13: Required hours per interchangeable container, design 2 is the most durable. With three chain tracks, many manual transportation hours are eliminated, which results in the most efficient design for transportation.
*Con(s): O*nce the chain tracks are filled, this could block the whole operation. This is why a high enough infeed capacity or a buffer zone is essential.

Design 3a and 3b

Pro(s): The category of processing obtains the most favorable performance by these designs. Because the automated beer sorting and CBL is sorting machine has enough capacity to process the supplied loading carriers, the remaining required hours per loading carrier for processing decreases for scenarios 2 and 3.
Con(s): Although it seems nice that these designs have no unloading hours required since this process is fully automated, however, the queue length exceeds the number of trucks that could park outside. This is why the Joloda Moving Floor could only be used for scenarios 0 and 1. Another remarkable fact is the increase in transport and loading hours. These hours are primarily related to pin loading carriers on the AGV's at the inbound docks or servers on the ground floor. For scenarios 2 and 3, this hour increases rapidly, which leads to a less efficient situation than design 2.

Also, the difference between designs 3a and 3b becomes visible in processing hours. The difference between 3a and 3b in required hours is 0.05 hours (3 minutes), reduced by the automated beer sorting machine. This results in +/- 735 beer loading carriers * 3 minutes = 37 hours per day.

This difference in saving of required hours versus the additional investment costs for the beer sorter results in a higher payback period for design 3b. Also is shown in Figure 5-17: Payback period per design in days, that for the third scenario, the payback period decreases to approximately a year.

5.4.3 Most preferred designs

The results from the previous sections are summarized in Table 5-12: Average result per performance criteria.

Table 5-12: Average result per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Unloading hours per container	0,14	0,15	0,00	0,00
Transport and loading hours per container	0,56	0,46	0,47	0,46
Processing hours per container	0,61	0,61	0,30	0,26
Required hours per container	1,31	1,22	0,77	0,73
Payback period	185	80	484	849
Estimated savings per day	€ 1.198	€ 2.727	€ 7.672	€ 8.361
Queue length on inbound	647	717	1980	1917
Limited space per process	limited by sc. 3	limited by sc. 3	limited by sc. 3	limited by sc. 3

Results are based on the average of scenario 1-3.

To determine which two designs are the most preferred designs, a ranking score is given per criteria. The two solutions which has overall the best ranking are chosen as the preferred designs.

Table 5-13: Ranking per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Required hours per container	4	3	2	1
Payback period	2	1	3	4
Estimated savings per day	4	3	2	1
Queue length on inbound	1	2	4	3
Limited space per process	1	1	1	1
Total ranking	12	10	12	10

Based on Table 5-13: Ranking per performance criteria is concluded that design 2 and 3b are the preferred designs which will be fine-tuned in the next chapter. This fine-tuning will refer to the problems that are found during simulation and extension or optimization of solutions that are already proposed.

Operational problems that are found by simulation:

- Limited space per process in scenario 3 for both design 2 as design 3b (see Figure 5-19: Example of queue's inside the system - Design 2 - Scenario 3).
    - This applies to the chain track capacity in design 2 and the AGV Tugger capacity in design 3b.
- Long inbound queue's, for design 3b.
- Prevent waiting times for the AGV's at the bread infeed point, for design 3b.
- Prevent long walk trips for employee's with return or cross dock loading carriers, for design 2.
- Infeed points not optimal used, for design 2 and design 3b.

5.5 Conclusion of modeling and evaluating the design

3. How can the preferred designs be tested or simulated to evaluate the performance criteria?

a. How can the preferred designs be tested?

Almost all conceptual design processes are modeled in Simio (except the process of changing the Renewi container). This model is verified based on the animation of the simulation and the location of the servers compared with the conceptual drawings of the current situation. The model is also qualitatively and quantitatively validated. This is done based on the performance criteria defined in section 'Key performance criteria'.

b. What is the score of the preferred designs on the defined criteria?

Because each design contains different server (processing times) and equipment, all improvements are listed. All designs are simulated and compared for the current situation, which is defined as scenario 0. This shows that design 1, 2, 3a, and 3b, has 2%, 9%, 43%, and 46% fewer required hours to process the current volume of loading carriers.

Design 1 has the shortest payback period for all designs. However, based on the assumption that all solutions will last for ten years, the estimating savings of design 3 are the highest.

Then, based on different forecasts, three future scenarios are defined, which are 1.5, 2, and 2.5 times the current arrival volume of interchangeable containers. Because for each design and scenario 3 arrivals are simulated this results in 5 designs * 3 scenarios * 3 arrivals are 45 simulations. Because the average of the three arrivals is taken 15 total results can be compared as shown in Figure 5-11: Required hours per scenario and design, stacked per category.

c. How can the preferred designs be evaluated based on this score?

The different performance criteria and designs are analyzed in more detail. This showed that design 1 has the most efficient unloading process, and designs 3a and 3b, although they have no required hours because of automation, do not have enough capacity to unload in the future. The transport processes are the most efficient and stable design in the second layout. This layout is also the most stable layout in terms of hours used for transporting. Design 3b has the most efficient design for processing interchangeable containers/loading carriers and has a high expected savings.

Finally could be concluded based on a ranking per criteria, that the second design is preferred together with design 3b. These designs will be fine-tuned in next chapter based on the operational problems which are found during simulation such as waiting times for AGV's or limited space in the third scenario.

6 Optimize and implement Design

Based on the results which are presented in the previous chapter, this chapter will answer the following questions to evaluate and implement the proposed design. These improvements focus on scenario 3 because this scenario is the most challenging scenario for all designs. This is shown by the inbound queue's for scenario 3 but also by the inside queue's as shown in Figure 5-19: Example of queue's inside the system - Design 2 - Scenario 3.

First two sub questions are listed to evaluate and improve the designs:

4. *How can the preferred designs be improved based on the evaluation?*
    a. *What modifications can be made to the preferred designs?*
    b. *How affect these modifications the preferred designs?*

After all, this will lead to a preferred design which should be implemented by Hoogvliet. This will answer the last question:

5. *How can the preferred designs be implemented?*

To answer this question, a stepwise implementation plan is given based on the final proposed design.

6.1 Fine-tuning designs

6.1.1 Operational improvements

The average results in Table 5-12: Average result per performance criteria in previous chapter shows that design 2 and 3b are the most preferred designs. In this section, some improvements for design 2 and 3b are given, based on the cons of the previous chapter and operational problems which were detected during simulation as listed in section 'Most preferred designs'. Also, the use of the solutions that contribute significantly to the performance, can be more extended.

Improvements Design 2

1. Although the chain track is already introduced to cover a lot of the transport activities, this chain could be further extended for the transport activities from the inbound dock to the waste processing, beer sorting and CBL sorting server. The loading carriers are switched to a bypass at these servers, as shown in Figure 6-1: Improved Design 2 - Carousel.
2. The use of the infeed points could be optimized by one central transfer node, which divides the empty roll containers over the six infeed points.
3. Because of the vast amount of (empty) roll containers in scenarios 2 and 3, a buffer floor must be made. When a queue is formed, the loading carriers are redirected to the buffer location on the first floor. At the end of the day, when the supply of interchangeable containers decreases, the buffer zone supplies empty roll containers to the infeed points.
4. Bread dollies and cross-dock loading carriers are moved with an EPT. Because the distance to the other corner of the return hall is quite a long walk trip, these loading carriers could be more efficient with an EPT. The infeeding and cross-docking itself is still done by workers. However, to prevent long walking trips, a small group of three dedicated workers is assigned to this job.
5. All big bags, e-commerce, and flower racks roll containers are loaded with EPTs to optimize the loading process.

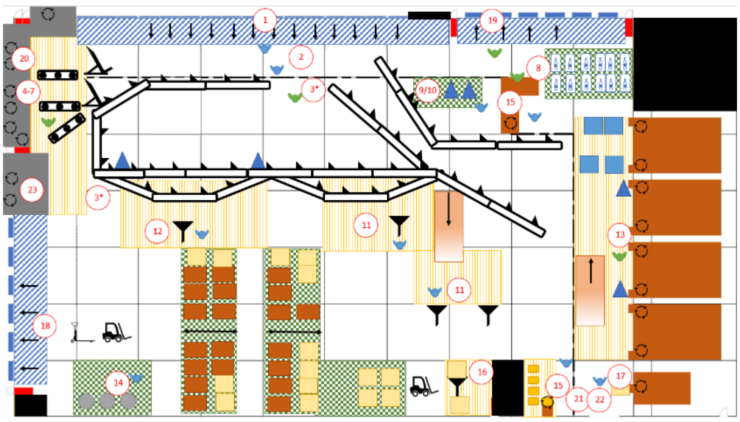


Figure 6-1: Improved Design 2 - Carousel

Improvements Design 3b

1. The main disadvantage of design 3 is the low inbound efficiency. This is why the dock servers are modeled as manual servers.
2. To have a sufficient flow for the AGVs, the AGV's are split into two groups. One group arrange the transport from the inbound dock to the different servers. The other group arranges the transportation from the waste processing server to the infeed servers. Besides, the capacity of the AGVs is increased to 4 loading carriers, and the number of employees who could attach loading carriers to the AGVs at the EnterAGV server is doubled.
3. Because the automatic beer and CBL sorter already use the first floor, a small area on the ground floor needs to be reserved as a buffer location for empty roll containers. This area is arranged below the waste processing server as shown in Figure 6-2: Improved design 3b - Completely automated.
4. The use of the infeed points could be optimized by one central transfer node, which divides the empty roll containers over the six infeed points.
5. To prevent waiting times for the AGV's at the infeed of bread crates and cross-dock, a dedicated manual workers team is assigned to perform these actions.
6. All big bags, e-commerce, and flower racks roll containers are loaded with EPTs to optimize the loading process.

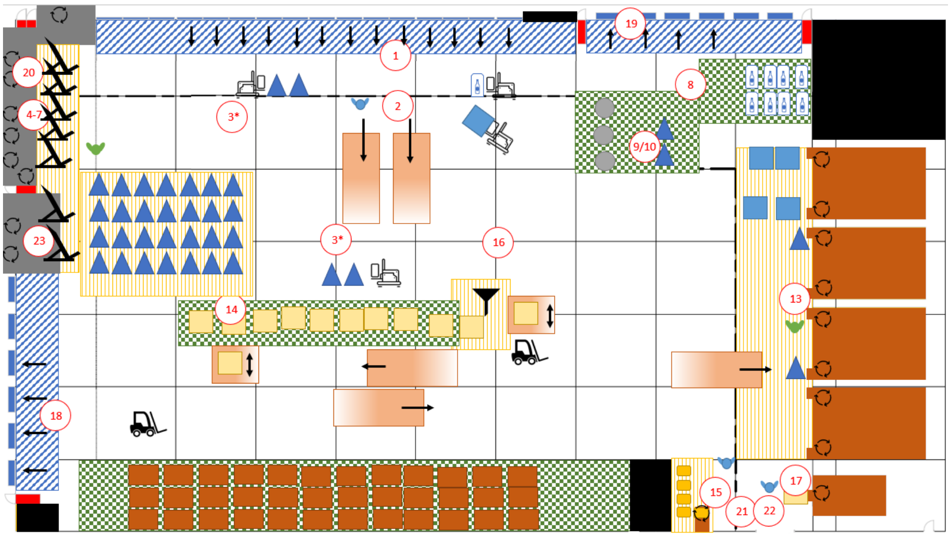


Figure 6-2: Improved design 3b - Completely automated

How these improvements affects the investment costs is shown in section 'I.4 Quantities per solution and additional investment costs improved designs'.

6.1.2 Improvements translated into simulation objects

The improvements which are listed per number in the previous section are modeled in Simio. Per improvement number is explained how this improvement is implemented in Simio.

Improvements design 2

1. *Modeled with a server called 'EnterOther' and chain tracks from this server to the waste processing server, beer sorting server, and cbl sorting server.*
2. *The transfer node for infeed servers 5 and 6 is eliminated and all path are connected to the original transfer node for infeed servers 1 till 4.*
3. *Modeled with an server called 'BufferRC' which supplies the central transfer node which divides the roll containers over the infeed points.*
4. *With server called 'EnterLD' (long distance), all bread crate dollies and cross docks loading carriers are combined. With a specific path, these loading carriers are brought with transport type pallet_EPT to the server called 'Buffer LD'. From this server, three dedicated workers brings loading carriers to the sink for bread crates and sink for returns/cross dock.*
5. *Modeled by changing the transport type to 'Pallet_EPT' at the source 'BBFLEC_Storage_Out'.*

Improvements design 3b

1. *The servers called 'Dock1, Dock2, Dock3 and Dock 4' has a capacity of two unloaders with regular processing time (for scenario 3).*
2. *Modeled with 12 AGV tuggers called 'AGV_Tugger' and 3 AGV's called 'AGV_TuggerP'.*
3. *Modeled with an outfeed buffer for the server waste processing with capacity 'infinity'.*
4. *The transfer node for infeed servers 5 and 6 is eliminated and all path are connected to the original transfer node for infeed servers 1 till 4.*
5. *A separate server called 'BufferLD' is assigned as decoupling point for the AGV's. From this server, three dedicated workers brings loading carriers to the sink for bread crates and sink for returns/cross dock.*
6. *Modeled by changing the transport type to 'Pallet_EPT' at the source 'BBFLEC_Storage_Out'.*

6.2 Results and Second evaluation

Both designs are evaluated based on the performance criteria as done in previous chapters. This is especially done for the third scenario since this scenario is the most challenging scenario.

6.2.1 Evaluation improved design 2

(1) Hours spend per interchangeable container

The results in hours per interchangeable container for scenario 3 (513 interchangeable containers) per category are shown for the improved design 2 in Table 6-1: Hours spend per interchangeable container - Improved design 2. In total this results in a decrease of 6% in required hours for fully processing interchangeable containers.

Table 6-1: Hours spend per interchangeable container - Improved design 2

	Design 2	Imp. Design 2
Unloading time per interchangeable container	0,17	0,14
Transport + loading time per interchangeable container	0,48	0,45
Processing time per interchangeable container	0,62	0,61
Total	1,27	1,19
		-6%

(2) Payback period and estimated savings (cost – efficiency)

The improvements in payback period and estimated savings are shown in section 'Comparing improved designs'.

(3) Queue length on inbound docks

As already shown in section 'H – Simulation Results – Queue length' also design 2 has a long queue on inbound docks for scenario 3. Below, a plot of the loading carriers in queue for arrival 3 for scenario 3 of design 2 is given and compared with the same situation for the improved layout of design 2.

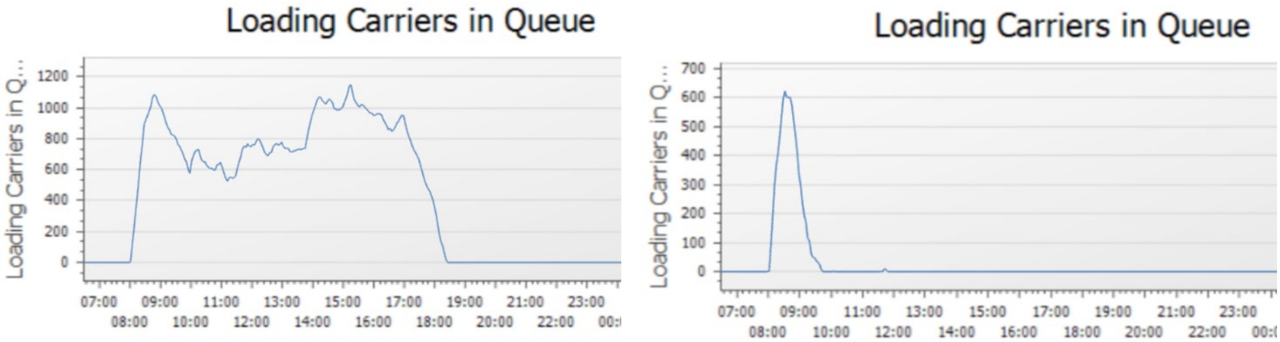


Figure 6-3: Comparison queue length on inbound - design 2 versus improved design 2

The left figure shows the old situation for design 2, which results in a long queue of more than 1000 loading carriers around the morning and afternoon peak, and on average 900 loading carriers waiting (which are +/- 25 trucks waiting on average). The right picture shows the new situation for the future scenario with still four inbound docks in use. Only around the morning peak, +/- 600 loading carriers are waiting. From this figure can be concluded that a more efficient processing flow inside the return hall results in far less waiting hours for trucks.

(4) Limited space per process

Because of the high volume of (empty) loading carriers and the limited capacity of the infeed points, a temporary buffer zone is needed. However, on the ground floor, the whole surface is used. This is why a buffer floor is proposed. The surface of this floor could be 30*40 meters (based on the plan of the return hall as given in Figure 3-2: Brownfield layout of the return hall at Hoogvliet) which is 1200 m2.

The capacity of roll containers, which are defined with a surface of 0.56m2 in section 'Quantitative validation', results in 1200/0.56 = 2142 roll containers (unfolded).

Based on a simulation for scenario 2 and 3 on the improved design 2, this amount results in a maximum buffer storage of 560 and 2190 roll containers respectively. A full plot can be found in section 'I – Simulation results – Improved designs'

6.2.2 Evaluation improved design 3b

(1) Hours spend per interchangeable container

The results in hours per interchangeable container for scenario 3 (513 interchangeable containers) per category are shown for the improved design 3b in Table 6-2: Hours spend per interchangeable container - Adjusted design 3b. In total this results in a increase of 22% in required hours for fully processing interchangeable containers. The main reason for this is the manual unloading to shorten the inbound queue. The transport + loading time and processing time remain stable.

Table 6-2: Hours spend per interchangeable container - Improved design 3b

	Design 3b	Imp. Design 3b
Unloading time per interchangeable container	0,00	0,15
Transport + loading time per interchangeable container	0,60	0,62
Processing time per interchangeable container	0,25	0,25
Total	0,84	1,01
		21%

(2) Payback period and estimated savings (cost – efficiency)

The improvements in payback period and estimated savings are shown in section 'Comparing improved designs'.

(3) Queue length on inbound docks

One of the main disadvantages for the third design is the long queue on inbound. This is why in the improved design, the inbound process is performed manually and the internal transporting of the loading carriers is made more efficient. In Figure 6-4: Comparison queue length on inbound - design 3b versus improved design 3b, the old and new queue are plotted and can be compared for scenario 3, arrival 3. This shows that the old peak (4000+) is reduced to around 1300 loading carriers but that there is still a queue during the whole day (1300/35 loading carriers per truck =37 trucks).

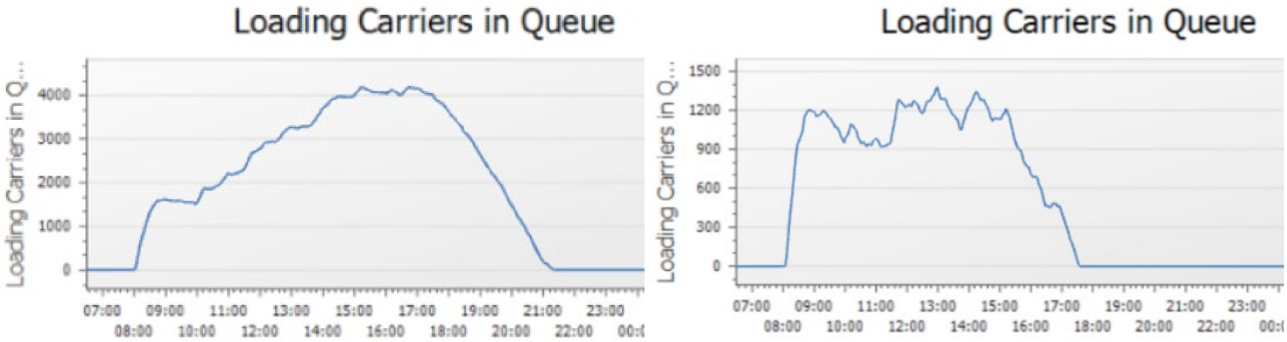


Figure 6-4: Comparison queue length on inbound - design 3b versus improved design 3b

(4) Limited space per process

As shown in Figure 6-2: Improved design 3b - Completely automated, a temporary storage space is made at the waste processing server of 10*10 meters which is 100 m2. The capacity of this space is around 100/0.56 = 178 loading carriers (unfolded) and 100/0.28 = 357 loading carriers (folded). This can be compared with the output queue for waste processing which is plotted in section 'I – Simulation results – Improved designs'. This results in a maximum amount of 2300 loading carriers in the buffer which is more than 6 time the capacity of the (folded) capacity.

6.2.3 Comparing improved designs

(1) Hours spend per interchangeable container

In Figure 6-5: Comparing required hours per interchangeable container per category the hours for the basic and improved designs 2 and 3b are shown for scenario 3.

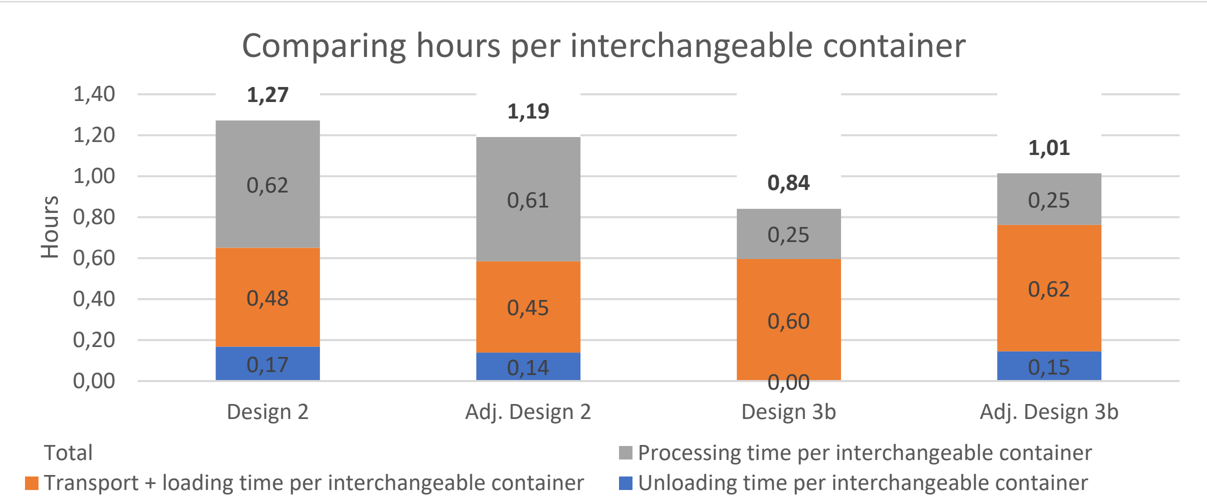


Figure 6-5: Comparing required hours per interchangeable container per category

The improved designs converge in the total amount of required hours per interchangeable containers. In the end, improved design 2 has the best score in the unloading and transport + loading hours. Improved design 3b has the most efficient processing solutions. Overall, improved design 3b requires 1.01 hours per interchangeable container and improved design 2 requires1.19 hours which differ 0.18 hours, 10.8 minutes per interchangeable container.

(2) Payback period and estimated savings (cost – efficiency)
In Table 6-3: Comparison payback period - Fine-tuned designs a comparison is made for the improved design 2 and 3b. Improved design 2 has additional investment costs which results in a longer payback period. Design 3b has less investment cost but a lower reduction of hours which also result in a longer payback period. However, the difference in estimated savings results in a positive result of 3.6 million for design 2 and a negative result of 8 million for design 3b. In total, the saving of 3b is still higher.

Table 6-3: Comparison payback period - Fine-tuned designs

	Design 2	FT - Design 2	Design 3b	FT - Design 3b
Reduction in hours	107	148	328	239
Total investment costs	€ 117.250	€ 312.850	€ 4.456.200	€ 4.356.200
Saving per day	€ 2.727	€ 3.773	€ 8.361	€ 6.092
Payback period (years)	0,12	0,23	1,46	1,96
Total estimated savings (based on 10 year lifetime)	€ 9.837.870	€13.456.848	€ 26.060.428	€ 17.880.002
Difference in estimated savings		€ 3.618.979		€ -8.180.427

(3) Queue length on inbound docks
The queue on inbound is plotted for both improved design 2 and 3b.

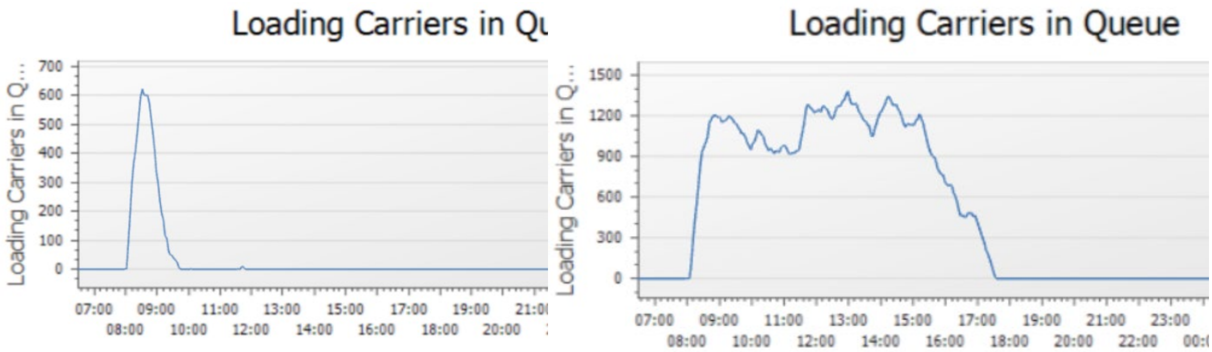


Figure 6-6: Comparison queue length on inbound - improved design 2 versus improved design 3b

Both improved designs has an improved inbound flow as shown in Figure 6-3: Comparison queue length on inbound - design 2 versus improved design 2 and Figure 6-4: Comparison queue length on inbound - design 3b versus improved design 3b. However, because the capacity of the AGV's in improved design 3 is still limited and a long queue rises during the whole day. Based on Figure 6-6: Comparison queue length on inbound - improved design 2 versus improved design 3b can be concluded that the queue length of improved design 3b is much longer and takes longer than the queue of improved design 2.

(4) Limited space per process
A space limitation in scenario 3 rises by the transporting and infeeding of the empty roll containers. Because the capacity of the infeed points is lower than the amount of roll containers that are unloaded and processed, a buffer zone is needed for these loading carriers. Improved design 2 have to use a separate floor to store these empty loading carriers (even for scenario 2). Improved design 3b has only some space on the ground floor. However, based on the computation given in section 'Evaluation adjusted design 3b' this space is not enough. This is why improved design 2 scores better on this criteria.

Overview comparison improved design 2 and improved design 3b

The table below shows a summery of the evaluation on the performance criteria as discussed in this section, based on scenario 3.

Table 6-4: Comparison improved design 2 and improved design 3b

Criteria	Improved design 2	Improved design 3b
Unloading hours per container	0.14	0.15
Transport and loading hours per container	0.45	0.62
Processing hours per container	0.61	0.25
Required hours per container	1.19	1.01
Payback period	0.23 year	1.96
Estimated savings	€13.456.848	€ 17.880.002
Queue length on inbound	One small peak of 600 loading carriers waiting	900 loading carriers on average waiting (26 trucks)
Limited space per process	Does almost not exceed capacity	Exceeds capacity

Although improved design 3b has a lower amount of required hours per interchangeable container, the queue length of 26 trucks on average waiting and exceeding the space capacity of the return hall (which is the first constraint) is not acceptable for Hoogvliet. Therefore, based on Table 6-4: Comparison improved design 2 and improved design 3b can be concluded that improved design 2 is advised and should be implemented.

6.3 Implementation advise

The implementation of the improved design 2 should fit the different stages and scenarios that Hoogvliet is in. As already shown in Figure 5-10: Forecasts and scenario, the first scenario covers the throughput of the current peak weeks and days. By growing to forecast A (100 supermarkets) or B (120 supermarkets), scenario 3 becomes relevant. This means that a separate floor is not necessary for the short term. For the other solutions which are proposed, Hoogvliet should make a concrete business case based on quotations from different suppliers. The costs as defined in section 'Proposed solutions' are an indication based on open-source information. Further negotiation on these prices could increase the expected savings and give insight into the pros and cons of the solutions. To implement design 2, the following steps should be taken.

Implementation lead

As a first step, Hoogvliet should someone make responsible for improving the return hall with a target based on the expected savings and potential as shown in the previous section. This person should coordinate the implementation steps as defined below:

Job allocation: The second design contains new solutions and different locations of stations and also has several improvements in how processes are organized. This means that some employees will be made responsible for the input and output buffer of 'their' station, which results in practice that one employee responsible for the input buffer of waste processing is processing the waste roll containers continuously and that the employee responsible for the output buffer of waste processing station with empty roll containers (as long as the chain tracks are not installed), transports these loading carriers with it's EPT. As a side effect of assigning one or multiple tasks to employees, as defined in this thesis, their performance could be measured and evaluated.

Relocation: The third step in transferring the current layout to design 2 is the relocation of the beer sorting and pallet sorting. These processes can be shifted in one night not to interrupt the daily processes. The same yields for relocating the RICs.

Tilt tables and conveyor belts: A phase-based implementation is advised to implement the tilt tables and conveyor belts for this design. This means that the separate waste processes could be transformed into the tilt table and conveyor belt solution step by step. The employees will get used to these solutions and have improvement ideas for the other waste processes that can be used in the next phase of implementation. As defined in section 'E.4 Quantities per solution and investment cost per design', two tilt tables and a 15-meter conveyor belt must be ordered. This could be extended for future scenarios with the quantities found in section 'F.5 Quantities per solution and additional investment costs per scenario'.

Chain tracks: The most used solution for (improved) design 2 is the chain track. The chain tracks proposed in section 'Proposed solutions' have multiple variants: just a rail, on a slope, or a hanging cable track (an example can be found in Figure D- 6: Chain tracks (Vorning, 2016)). Before ordering chain tracks, a pilot set-up of a supplier could probably be used to test whether the chain tracks fit with the roll containers and thermos. A simple rail from inbound to infeed points can be made to start up with the use of these chain tracks inside the return hall. Based on this experience, the chain tracks could be further extended, as shown in Figure 6-1: Improved Design 2 - Carousel.

In section 'I.5 Implementation timeline' a timeline is proposed to implement the steps which are described above. The expected lead time of the whole implementation is approximately half a year.

6.4 Conclusion of the optimization of the design

4. How can the preferred designs be improved based on the evaluation?

a. What modifications can be made to the preferred designs?

In this section, some minor improvements were made on designs 2 and 3b based on the pros and cons as defined in section 'Evaluation per design – pros and cons' and operational problems as defined in section 'Most preferred designs'. The improvements on design 2 are: extending the chain track from the inbound docks to the sorting stations, assigning specific employees for infeeding bread crates and cross-docking, assign pallet EPTs for remaining transport activities. Lastly, a separate floor is added as a buffer zone for empty loading carriers for scenarios 2 and 3. The improvements for design 3b are that the inbound will be performed manually to increase the throughput of unloading, adding a buffer zone at the waste processing station for empty loading carriers and assigning some manual workers for the infeed of bread crates and cross-docking instead of AGV's.

b. How affect these modifications the preferred designs?

For design 2, extending the chain track and adding a buffer zone makes the design more future-proof on the inbound side and results in a better efficiency level on all categories. Although improved design 3b has a lower amount of required hours per interchangeable container, the queue length of 26 trucks on average waiting and exceeding the space capacity of the return hall (which is the first constraint) is not acceptable for Hoogvliet. Therefore, based on Table 6-4: Comparison improved design 2 and improved design 3b can be concluded that improved design 2 is advised and should be implemented.

5. How can the preferred designs be implemented?

The first step is making someone responsible for the coordination and implementation of the design. The costs as defined in section 'Proposed solutions' indicate the costs, but these should be evaluated in more detail by requesting a quote from multiple suppliers.

Then, job allocation per employee should be introduced as far as possible to streamline the processes and, as a side effect, better evaluate the performance of your employees.

The implementation of this design should be done step by step to avoid interrupting the business. This should be possible by first relocating some servers. Then, step by step, the proposed solutions can be implemented using the conceptual drawings and estimated quantities per scenario as defined in section 'E.4 Quantities per solution and investment cost per design' and 'F.5 Quantities per solution and additional investment costs per scenario'.

7 Conclusion

7.1 Conclusion per chapter

Since 2020, Hoogvliet supplies its supermarkets from a new automated DC in Bleiswijk. Although this DC uses advanced technology and has automated most of its in- and outbound flows, the return hall was left out of scope until now. Because of the expected growth in the number of supermarkets and the capacity problems in terms of employees and space, Hoogvliet wants to re-design their DC's return hall. This results in the following objective of this thesis: *'Design an efficient, flexible, scalable, and future-proof return and packaging hall of an automated retail distribution center, which solves the capacity issues in employees and workspace and increases the throughput of containers per hour.'* This objective is achieved using the design method, which is derived from the method according to Dym (1999).

Based on a literature review is found that 'an article which shows the efficiency of all different processes within the return hall and to a certain extent the flexibility and scalability of these different processes, is still missing.' This knowledge gap is closed by comparing multiple conceptual designs of a whole return hall from a Dutch retailer and by evaluating the designs based on how their performance will evolve, facing other throughput volumes.

7.1.1 Problem definition

Qualitative analysis

There are two input sources which are the interchangeable containers carried by trucks that return from the supermarkets. These interchangeable containers contain different types of loading carriers which needs to be sorted within the return hall.
The return hall is part of the automatic DC of Hoogvliet. The return hall is connected to the DC with different infeed points for crates and loading carriers but also with an outfeed for empty pallets and waste boxes from the DC. The second input source is the DC itself which supplies empty pallets that needs to be sorted and waste boxes which must be emptied and returned to the DC.
Based on a qualitative analysis of the return hall is found that 23 different processes take place within the return hall that needs to be designed. These are described based on a Gemba walk and shown in detail in process flows. The following processes are in scope for this design:

1. Receiving and unloading container
2. Sorting roll containers / thermos / RIC's / bread dolly
3. Transport loading carrier
4. Process roll container with old bread
5. Process roll container with carton
6. Process roll container with bio / residual waste
7. Process roll container with orange peels
8. Process roll container with big bags
9. Process roll container with e-commerce bags and crates
10. Process roll container with flower racks
11. Process roll container with CBL crates
12. Process roll container beer crates
13. Infeed loading carrier
14. Process dairy roll-in container (RIC)
15. Infeed (bread) crate
16. Process empty pallets
17. Process waste bin with seal residuals
18. Loading reusable packaging
19. Loading big bags
20. Change waste container Renewi
21. Process non-food returns
22. Cross-docking
23. Process roll container with trash cans (future process)

There are three outbound flows: waste containers, suppliers that pick up reusable packaging, and the Witron system.

Quantitative analysis

The qualitative analysis consists in the first place on the key performance criteria which Hoogvliet uses. These criteria are the interchangeable containers that arrive per day and the hours used to process these containers. The team leader analyzes how many loading carriers are infeeded and how many interchangeable containers are not unloaded. These performance criteria are transformed into 'required hours per interchangeable container', 'payback period', 'estimated savings', 'queue length on inbound docks', and 'limited space per process' to make the design *efficient, flexible, scalable, and future-proof.* Also part of the quantitative analysis is the forecast Hoogvliet has made regarding the number of supermarkets. These forecasts contain (A) 100 supermarkets and (B) 120 supermarkets. The two forecasts are based on the situation in 2040. Based on the volume with 70 supermarkets in 2019 and the corresponding interchangeable containers, a linear forecast is made for interchangeable containers that arrive each day.

Business problem

The quantitative analysis is done on a more detailed level, the workload analysis, to identify the actual business problem inside the return hall. Based on own and historical measurements, a complete workload analysis is done to see which activity is most time-consuming and the share of productivity loss within the return hall. The 386 hours which are used on average per day can be split into six categories: unloading (9%), transport (27%), processing (29%), loading (6%), management (10%), and productivity loss (19%).

Design constraints, functional and non-functional requirements

Based on this thesis's objective and the problems found in the business problem section, some constraints and (non)-functional requirements are listed in consultation with Hoogvliet. The main general constraints are that the design must fit within the return hall and be possible to implement the solutions within five years. The only functional requirement that summarizes the return hall's performance is 'Throughput as many loading carriers per hour as possible. For some processes unit of 'loading carriers' is varied in a specific unit. There are five non-functional requirements listed: 'Should have as small as possible amount of working hours, 'Should have a short as possible payback period,' 'Should be as flexible as possible to cope with extreme peak hours/days/weeks,' 'Should have a lifetime which is as long as possible' and 'Should have the ability to identify deviant goods between the load.'
Because all proposed solutions are scored based on these (non-)functional requirements, a 5-points scale is made. The best solution is given 5 points and with this solution as reference point, other solutions are given lower points.

7.1.2 Conceptual design

Listing solutions

The relevant solutions for the design of the return hall are based on the current solutions and the solutions found in literature and input from operational experts. All solutions are based on proven technology to satisfy the constraint that the solution could be implemented within five years. The current solutions consist of Employee, Temp worker, Shredder, and Cardboard press. The proposed solution consists of Joloda Moving Floor, Conveyor belt, Scale, EPT, AGV Tugger, Chain track, CBL crates sorter, CBL stacker, Pusher, Beer crates sorter, Tilt table, R-CNN + Conveyor belt.

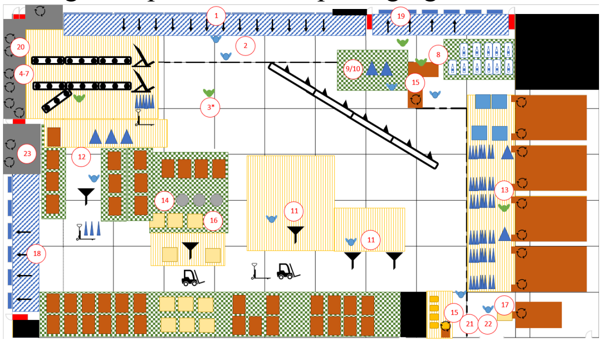
Scoring solutions

These solutions are connected based on their functionality to the subprocesses defined during the qualitative analysis. The score for the functional requirement is based on the numeric scale in main terms of loading carriers or interchange containers. To score the solutions for the non-functional requirements, in consultation with Hoogvliet, all solutions are scored at once per requirement. An explanation is given why some of the solutions have obtained a higher score.
This scoring results in a total ranking with solutions above and below average. The solutions that score far below average are eliminated to narrow the solution space to concrete designs.

Drawing designs

The proposed solutions results in three designs which are shown below (a bigger picture can be found in section 'Drawing preferred designs'). A legend table can be found in Table 4-2: Legend regarding conceptual designs.

Design 1: Split waste and packaging



Design 2: Carousel

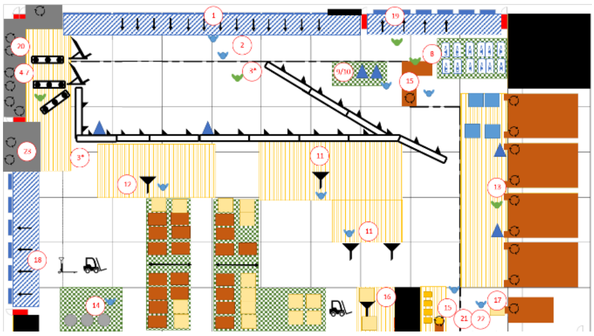


Figure 7-1: Conceptual layout of design 1 and 2

Design 1 tries to split all waste and packaging as soon as possible from the loading carriers. Also the beer sorting location and is relocated to shorten the distance for beer crates within the return hall. All empty loading carriers at the sorting stations are transported with pallet EPT's to the infeed points and the loading carriers that arrive empty in the return hall can be transported with the chain track.
Design 2 uses the chain track to deliver the loading carriers to the different sorting locations, but also to transfer the empty loading carriers from this sorting locations to the infeed points. Also the location for sorting empty pallets is relocated to a location which is close to the outfeed point of the Witron system to reduce this transport time.

Design 3: Completely automated – Ground floor

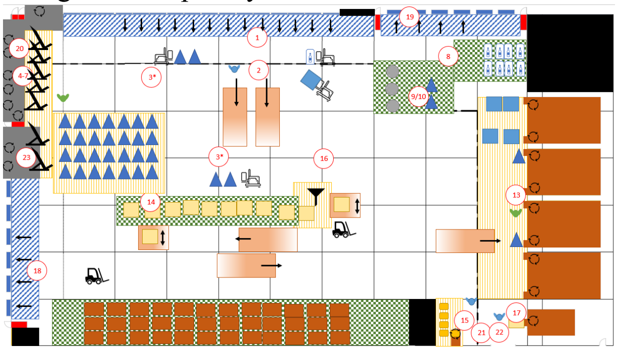
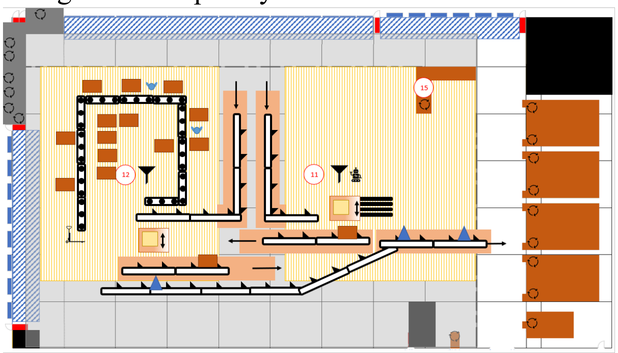


Figure 7-2: Conceptual layout of design 3 - Ground floor

Design 3a: Completely automated - First floor



Design 3b: Completely automated - First floor

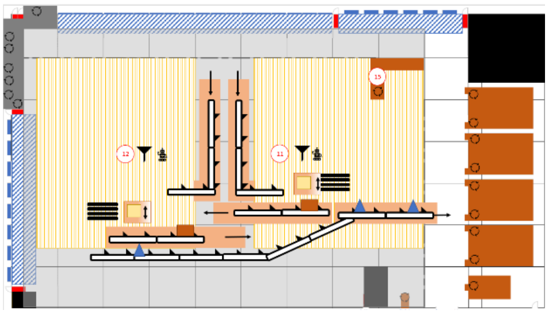


Figure 7-3: Conceptual layout of design 3a and 3b - First floor

Design 3 is the most advanced design which automates the return hall as far as possible. On the ground floor, AGV tuggers transport the loading carriers to the sorting or processing station. Full pallets are still transported with reach EPT's. This design requires a separate floor in the return hall for an automatic beer crate and CBL sorter. However, because automatic beer sorting is quite expensive, a manual alternative for beer sorting is proposed in design 3a. All (empty) loading carriers are transported with a chain track on a slope which connects the ground and first floor in this design.

7.1.3 Model and evaluate design

All layouts are modeled in a simulation model to estimate the required manual labor hours and compare the performance of the throughput of these designs.

Implementation of the simulation model

The designs are transferred per process into a modeling description and modeling objects. A simulation on scale is made in Simio which corresponds with the 22 of the 23 processes which are defined in the first phase (only the change of the Renewi container is not implemented since this process is performed by assistant team leaders which does not count for the required manual labor hours). The input, throughput and output are defined on the workload analysis. However, the input of the interchangeable containers is varied into three different arrivals to create a more realistic performance. The simulation outcome is based on the average of these three arrivals. The verification and validation are done by simulating the current layout for the current situation. Based on the outcome of required hours and the animation of the simulation model, could the model be validated and verified.

Experimental plan and motivation

The forecasts of 100 and 120 supermarkets and the differences in interchangeable containers could result in many scenarios. Therefore, three scenarios in the number of interchangeable containers are defined, which refer to the different inbound flows in the future. Currently, on average, 205 interchangeable containers arrive on an average day. Scenarios 1, 2, and 3 use a factor of 1.5, 2, and 2.5, respectively, which results in 308, 410, and 513 interchangeable containers. Because the layout and capacity per design may slightly change in the future, the modeling improvements are defined for each design. In the end, the current layout (as reference), design 1, design 2, design 3a, and design 3b are simulated for the three scenarios, resulting in 15 simulations.

Results and evaluation

The simulation results are evaluated based on the performance criteria as defined in section 'Key performance criteria'.

<u>Required hours per interchangeable container</u>

The required hours per process are split into unloading hours, transport + loading hours, and processing hours. Design 3 obtains, of course, the lowest score for unloading since this process can be fully automated. The transport and loading hours are most stable and efficient performed by design 2. The required hours for processing activities are the lowest for design 3b.

<u>Payback period</u>

Compared with the current layout and additional investments for future scenarios, the shortest payback period is obtained by design 2, which has an expected payback period of 0,5 years for the current situation. The most extended payback period is the complete automated design 3b with a period of 4 years, which can be reduced to 1.5 years in scenario 3.

<u>Estimated savings</u>

The estimated savings assume that all solutions will last for ten years. For the current situation, design 3a has the highest expected savings of €8.2 million, which is €820.000 per year. The lowest expected savings are obtained by design 1 with €41.000 per year. Increasing the volume as defined for scenario 3, design 3b will have the highest expected savings of €2.6 million per year.

Queue length on inbound docks
The higher the inbound volumes of interchangeable containers, the higher the pressure on the inbound docks. For the current situation (scenario 0), the shortest queue is obtained by design 3; however, for scenarios 2 and 3, the longest queue rises for design 3. The most temporary queue for scenario 3 is obtained by design 1.

Limited space per process
The allocation of the surface for each sorting station is computed whether the amount of loading carriers in the input or output buffer does not exceed the limited space. Especially for scenario 3 is shown that a buffer zone is needed for empty loading carriers since the capacity of infeeding these loading carriers is too low to process the supplied amount of loading carriers.

The results per criteria and design are summarized based on an average of scenario 1-3 in Table 7-1: Average result per performance criteria.

Table 7-1: Average result per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Unloading hours per container	0,14	0,15	0,00	0,00
Transport and loading hours per container	0,56	0,46	0,47	0,46
Processing hours per container	0,61	0,61	0,30	0,26
Required hours per container	1,31	1,22	0,77	0,73
Payback period	185	80	484	849
Estimated savings per day	€ 1.198	€ 2.727	€ 7.672	€ 8.361
Queue length on inbound	647	717	1980	1917
Limited space per process	limited by sc. 3	limited by sc. 3	limited by sc. 3	limited by sc. 3

Results are based on the average of scenario 1-3.

To determine which two designs are the most preferred designs, a ranking score is given per criteria. The two solutions which has overall the best ranking are chosen as the preferred designs.

Table 7-2: Ranking per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Required hours per container	4	3	2	1
Payback period	2	1	3	4
Estimated savings per day	4	3	2	1
Queue length on inbound	1	2	4	3
Limited space per process	1	1	1	1
Total ranking	12	10	12	10

Based on Table 7-2: Ranking per performance criteria is concluded that design 2 and 3b are the preferred designs which will be fine-tuned in the next chapter. This fine-tuning will refer to the problems that are found during simulation and extension or optimization of solutions that are already proposed.

Operational problems that are found by simulation:

- Limited space per process in scenario 3 for both design 2 as design 3b.
    - This applies to the chain track capacity in design 2 and the AGV Tugger capacity in design 3b.
- Long inbound queue's, for design 3b.

- Prevent waiting times for the AGV's at the bread infeed point, for design 3b.
- Prevent long walk trips for employee's with return or cross dock loading carriers, for design 2.
- Infeed points not optimal used, for design 2 and design 3b.

7.1.4 Optimize and implement design

Improvements to design 2 and 3b

Because design 2 and design 3b obtain overall the best performance for the defined criteria, these layouts are improved to get better performance, based on the evaluation per design.
For design 2, the chain track is extended to put the loading carriers on this track in front of the inbound docks. Also, a separate floor is proposed, which functions as a buffer zone for empty loading carriers. Design 3b has to improve the inbound performance. However, this unloading should be performed manually because of the limited space at the inbound docks. Also, some minor improvements on job allocation are made for both designs.

Results and second evaluation

The results for per criteria are summarized in the table below.

Table 7-3: Comparison improved design 2 and improved design 3b

Criteria	Improved design 2	Improved design 3b
Unloading hours per container	0.14	0.15
Transport and loading hours per container	0.45	0.62
Processing hours per container	0.61	0.25
Required hours per container	1.19	1.01
Payback period	0.23 years	1.96 years
Estimated savings	€13.456.848	€ 17.880.002
Queue length on inbound	One small peak of 600 loading carriers waiting	900 loading carriers on average waiting
Limited space per process	Does almost not exceed capacity	Exceeds capacity

Based on the last two rows of this table can be concluded that improved design 3b has still no stable inbound flow and that the inside capacity is exceeded. This is why a layout like design 2 is advised.

Implementation

The first step is making someone responsible for the coordination and implementation of the design. The costs as defined in section 'Proposed solutions' gives an indication of the costs but these should be evaluated in more detail by requesting a quote of multiple suppliers.

Than, job allocation per employee should be introduced as far as possible to streamline the processes and, as a side effect, better evaluate the performance of your employees.

The implementation of this design should be done step by step to avoid interrupting the business. This should be possible by first relocating some servers. Then, step by step the proposed solutions can be implemented with the use of the conceptual drawings and estimated quantities per scenario as defined in section 'E.4 Quantities per solution and investment cost per design' and 'F.5 Quantities per solution and additional investment costs per scenario'.

7.1.5 Closing knowledge gap

Research on the efficiency of all different processes within the return hall and to a certain extent the flexibility and scalability of these different processes is still missing, as shown in section 'Knowledge gap'. Besides the missing knowledge in literature, the business problem of Hoogvliet is related to the objective in section 'Design problem and objective' and 'From business problem to the objective.'

The objective is achieved with a transformed design method, according to Dym (1999). Using a morphological chart, different solutions are scored based on requirements connected to the objective in section ‘From objective to requirements.’ The conceptual designs are simulated and evaluated based on the performance criteria defined and related to the objective in section ‘Key performance criteria’. Based on these criteria, two designs are improved. The second design shows a very efficient transport process which is further enhanced to increase this advantage. The complete automated design offers a very efficient processing solution but has a long queue on the inbound docks as a result of a limit throughput capacity. Based on the outcomes presented in section ‘Results and evaluation,’ the following findings refer to the knowledge gap and objective.

- Peak arrival rates result in long queues throughout the whole day;
- Manual inbound processes for small return halls with higher capacity and throughput;
- Transportation within return halls with the same processes has a significant impact on the workload and should be eliminated or automated as far as possible;
- In the short term (<3 years), transport solutions could result in significant savings;
- In the long term (>3 years), more advanced automated sorting systems have a higher savings than minor improvements;
- Work standardization, also for manual transportation, streamlines the whole throughput;
- Enough output capacity (such as infeeding capacity for roll containers), solves many blocking issues in previous processes;
- Enough (buffer) space is essential for an efficient throughput.

Regarding to the efficiency, and to a certain extend, flexibility, scalability and future-proof level of the return hall, it can be concluded that:

- A stable inbound process at the return hall is important for an efficient throughput;
- Automating transport activities will most likely pay for itself;
- Job standardization will increase the efficiency of the return hall;
- Using multiple docks makes the return hall more flexible because of the higher inbound capacity. However, this flexibility is limited as long as the transport, processing and buffer capacity are not as high as the inbound capacity;
- Important to allocate allowable space per process in future scenario’s and use buffer zones to ensure the scalability of the return hall.

7.2 Recommendations and future research

7.2.1 Academic recommendations and future research

The design proposed in the previous sections aims to be efficient, flexible, scalable, and future-proof. The evaluation of this design has shown that a primary limiting factor is an available space for all processes that need to be performed. Therefore, it is recommended to research the general area or optimal layout for an efficient, flexible, scalable, and future-proof return hall. To see whether a return process is flexible and scalable, it is recommended to investigate the use of multiple return halls and different arrivals.

Besides the available space and layout of the return hall, it is recommended to do further research on the efficiency of the detailed processes within the return hall. Especially the processes of CBL crate sorting and beer crate sorting, which are hard to automate, can be further investigated. Since this automation is not commonly used, there is not much knowledge on the pros and cons of these systems and their performance level.

Thirdly, with the detailed knowledge of these automation systems, extending the simulation model, which is built for the return hall of Hoogvliet. With this information, it is possible to investigate the impact of the reliability and performance of the servers on the throughput of the return hall. In the simulation, which is done, is chosen to model the processing times in a random triangular way with 10% above and below average as a limit. However, since most of these processing times rely on manual activities, this could differ per employee. Scoping to a (couple of) process(es) and fine-tuning parameters could improve the outcome's reliability and give opportunities to enhance the design further. Also, improvements can be made regarding the employees and vehicles that are modeled. The capacity of these employees and cars is now fixed based on an average. Still, in practice, the amount of loading carriers that an employee or EPT can transport depends on the loading carriers' weight and stability. A possible subject for future research is to investigate the impact of more standardized loading carriers (prepared at the supermarket) on the efficiency of the return hall processes.

7.2.2 Practical recommendations based on design limitations

This thesis aims to make a conceptual design for the whole return hall. Because this design is conceptual, it is possible to design 23 processes simultaneously, but on the other hand, some practical details can be overlooked in this thesis. For a detailed implementation plan, doing thorough research per process instead of 23 processes simultaneously would be recommended. Based on the workload analysis, this detailed research can be prioritized regarding potential working hours that can be saved.

Besides optimizing the processes themselves, improving the performance management within the return hall is recommended. Also shown in the workload analysis is that 19% of the hours spent per day are based on productivity loss. It is an illusion to reduce this percentage to 0, but a better task division, job standardization, and logging activities per employee could result in a higher productivity level.

An extra floor is proposed regarding the advised design in the third scenario. This seems possible because of the return hall's height; however, this must be analyzed from an architectural expert and constructors point of view.

The functionality and the efficiency of the proposed solutions are based on the information that suppliers give. However, a pilot setup is advised to evaluate the actual performance or efficiency increase for some answers, such as the tilt table and chain track.

7.3 Reflection

Four conceptual designs of one return hall with 23 processes in three different scenarios are analyzed on five criteria with a simulation model. From a theoretical point of view, this is big scope, making it difficult to state specific findings or create fully weighted conclusions. It could have been better to conduct this study with fewer variables. For example, the objective could have been adjusted with only the efficiency of the return hall as a target or by analyzing only the current volume.

The scoring of the solutions was based on the requirements connected to the objective. However, due to many scores in the case of total factorial scoring (solutions * subprocesses * requirements), it is chosen to score all solutions one time per requirement based on operational knowledge from Hoogvliet using a relative scale for the non-functional requirements. Because of this method, it is hard to make well-founded statements about the performance of a specific solution, and therefore, only the worst scoring solutions are eliminated. If future research subprocesses are analyzed, a numeric ranking scale and the scores are given based on pilot set-ups should be used.

The derived design method was chosen for this thesis also contains an evaluation step. This step is made in chapter 6 based on the two best outcomes of chapter 5. However, these iterations of simulation, evaluation, improvement, and analysis could have been done for all designs or multiple times and maybe led to better outcomes.

Appendices

A. Scientific article

Designing an automated efficient, flexible, scalable and future-proof return hall in an automated retail distribution center

A conceptual design for a return hall at Hoogvliet Supermarkets

E.W. Beekman, Prof. Dr. R.R. Negenborn[1], Ir. M.W. Ludema[2], Ir. M.B. Duinkerken[1], J. Berkheij[3]

[1] TU Delft - Department of Maritime and Transport Technology
[2] TU Delft - Department of Engineering Systems and Services
[3] Return Management Department - Hoogvliet Supermarkets

Abstract: During the past years, more companies have become aware of the importance of efficient reversed logistics (Senthil et al., 2018). By optimizing this upward stream, the return hall of supermarkets plays an important role. With the expected increase of supermarkets that the same return hall must serve and the limited capacity of employees in mind, Hoogvliet wants to redesign its return hall. However, based on literature research, research is primarily done on reusable packaging systems instead of processes and the dynamics of these processes within a return hall. This article closes this knowledge gap with a conceptual design of Hoogvliet, which is a retailer in the Netherlands. Based on the brownfield of the return hall of Hoogvliets DC in Bleiswijk, this article aims to 'design an efficient, flexible, scalable and future-proof return and packaging hall, which solves the capacity issues in employees and workspace and increases the throughput of containers per hour.'

This design is made on a method derived from the design method of Dym (1999). The first phase contains the problem definition, which describes the current and future processes and volumes and the design requirements for all processes. The second phase proposes three designs based on validated solutions. The third phase model and evaluate these designs, resulting in two improved and simulated designs. In the end, one conceptual design is advised, and a short implementation plan is given.

Based on these conceptual designs and simulations, the workload within a return hall can be improved with several transport solutions shaped like a chain track or conveyor belt. Improvements like job allocation per employee, tilt tables, and performance management could improve the processing jobs' performance. Also is found that, in the long term (>3 years), automation of these processes could result in high savings for the retailer. Besides could be concluded that enough in- and outbound (or buffer) capacity is necessary to obtain an efficient flow within the return hall, especially for future scenario's. A step-by-step, process-specific implementation plan is advised with this conceptual design in mind.

1. Introduction

1.1 Introduction to Hoogvliet

In this article, a design is made for a return hall at a distribution center of a small retailer in the Netherlands named Hoogvliet B.V.. Hoogvliet is one of the smaller supermarkets in the Netherlands. With around 70 supermarkets, it has a market share of 2.1% (Distrifood, 2020). Nevertheless, is Hoogvliet an innovative company with its recent automated warehouse in Bleiswijk near the A12. This distribution center covers almost all supplying activities to the 70 supermarkets. Hoogvliet has the ambition to increase to 100 supermarkets which can be delivered from this DC (De Weerd, 2020).

The DC in Bleiswijk contains almost all supplying activities for Hoogvliet with a bakery, butchery, and fresh goods in-store. Daily fresh articles such as milk and flowers are cross docked at the DC. The same method applies to the E-commerce supply. The preparation of E-commerce orders is currently done in the old location of Hoogvliet in Alphen aan de Rijn and transported by trailers to the DC of Hoogvliet. All these flows are combined and distributed in interchangeable containers at the expedition hall in DC.

This article uses the receiving and unloading of the interchangeable containers at the DC as a starting point of the return process. The DC manager of Hoogvliet explained that this manual processes of sorting and processing the goods from these containers are too costly at the moment. Besides, the limited capacity of enough skilled employees, the limited space within the return hall, and the low throughput are problems that Hoogvliet experiences.

A lot of processes take place within the return hall, such as the sorting of crates and waste. The crates are re-used in the automated picking warehouse, bakery, and butchery. One of the first steps will be to identify these subprocesses and their average workload. During the automatization of the new DC, the return hall has not the focus of the management of Hoogvliet, which leads to a practical, manual solution for the return hall.

Another challenge of the design will be optimizing and synchronizing the return process with the other warehouse processes. Currently, employees are assigned ad hoc to their task, depending on which subprocess has the highest priority. This makes it hard for the team leaders of Hoogvliet to manage the performance of the employees, and at the same time, synchronizing the return hall subprocesses with the bakery and butchery becomes difficult.

1.2 Knowledge gap

Regarding conceptual designs for reversed logistic processes, only a subprocess or a whole chain is designed, such as by Langevelde (2021), Supriyanto (2021), Stuijt (2021), Hooft (2020). And, as an example, for the process of delivering waste containers to a return hall, a wrapping solution is proposed (Dixon-Hardy et al., 2009).

However, an article that shows the efficiency of all different processes within the return hall and, to a certain extent, the flexibility and scalability of these other processes is still missing. This knowledge gap will be closed by comparing multiple conceptual designs of a whole return hall from a Dutch retailer. Besides varying the layout of the return hall, the different designs will be evaluated based on how their performance evolves with varying throughput volumes.

2. Design objective and questions:

The knowledge gap and design problem of Hoogvliet is combined in the following objective:

Design an efficient, flexible, scalable, and future-proof return and packaging hall of an automated retail distribution center, which solves the capacity issues in employees and workspace and increases the throughput of containers per hour.

This objective is achieved with an adjusted version of the design method derived from the method according to Dym (1999), with for each phase, some questions will result in a conceptual design.

Phase 1: Problem definition

1. *What does the return process look like?*

Phase 2: Conceptual design

2. *What are the preferred designs which solves the requirements and functions?*

Phase 3: Model and evaluate design

3. *How can the preferred designs be tested or simulated to evaluate the performance criteria?*

Phase 4: Optimize and implement design

4. *How can the preferred designs be improved based on the evaluation?*
5. *How can the preferred designs be implemented?*

Phase 5: Conclusion and recommendation

3. Problem definition

3.1 Qualitative analysis

There are two input sources which are the interchangeable containers carried by trucks that return from the supermarkets. These interchangeable containers contain different types of loading carriers which needs to be sorted within the return hall.

The return hall is part of the automatic DC of Hoogvliet. The return hall is connected to the DC with different infeed points for crates and loading carriers but also with an outfeed for empty pallets and waste boxes from the DC. The second input source is the DC itself which supplies empty pallets that needs to be sorted and waste boxes which must be emptied and returned to the DC.

Based on a qualitative analysis of the return hall is found that 23 different processes take place within the return hall that needs to be designed. These are described based on a Gemba walk and shown in detail in process flows. The following processes are in scope for this design:

1. Receiving and unloading container
2. Sorting roll containers / thermos / RIC's / bread dolly
3. Transport loading carrier
4. Process roll container with old bread
5. Process roll container with carton
6. Process roll container with bio / residual waste
7. Process roll container with orange peels
8. Process roll container with big bags
9. Process roll container with e-commerce bags and crates
10. Process roll container with flower racks
11. Process roll container with CBL crates
12. Process roll container beer crates
13. Infeed loading carrier
14. Process dairy roll-in container (RIC)
15. Infeed (bread) crate
16. Process empty pallets
17. Process waste bin with seal residuals
18. Loading reusable packaging
19. Loading big bags
20. Change waste container Renewi
21. Process non-food returns
22. Cross-docking
23. Process roll container with trash cans (future process)

There are three outbound flows: waste containers, suppliers that pick up reusable packaging, and the Witron system.

3.2 Quantitative analysis

The qualitative analysis consists in the first place on the key performance criteria which Hoogvliet uses. These criteria are the interchangeable containers that arrive per day and the hours used to process these containers. The team leader analyzes how many loading carriers are infeeded and how many interchangeable containers are not unloaded. These performance criteria are transformed into 'required hours per interchangeable container', 'payback period', 'estimated savings', 'queue length on inbound docks', and 'limited space per process' to make the design *efficient, flexible, scalable, and future-proof.* Also part of the quantitative analysis is the forecast Hoogvliet has made regarding the number of supermarkets. These forecasts contain (A) 100 supermarkets and (B) 120 supermarkets. The two forecasts are based on the situation in 2040. Based on the volume with 70 supermarkets in 2019 and the corresponding interchangeable containers, a linear forecast is made for interchangeable containers that arrive each day.

3.3 Business problem

The quantitative analysis is done on a more detailed level, the workload analysis, to identify the actual business problem inside the return hall. Based on own and historical measurements, a complete workload analysis is done to see which activity is most time-consuming and the share of productivity loss within the return hall. The 386 hours which are used on average per day can be split into six categories: unloading (9%), transport (27%), processing (29%), loading (6%), management (10%), and productivity loss (19%).

3.4 Design constraints, functional and non-functional requirements

Based on this thesis's objective and the problems found in the business problem section, some constraints and (non)-functional requirements are listed in consultation with Hoogvliet. The main general constraints are that the design must fit within the return hall and be possible to implement the solutions within five years. The only functional requirement that summarizes the return hall's performance is 'Throughput as many loading carriers per hour as possible. For some processes unit of 'loading carriers' is varied in a specific unit. There are five non-functional requirements listed: 'Should have as small as possible amount of working hours, 'Should have a short as possible payback period,' 'Should be as flexible as possible to cope with extreme peak hours/days/weeks,' 'Should have a lifetime which is as long as possible' and 'Should have the ability to identify deviant goods between the load.'
Because all proposed solutions are scored based on these (non-)functional requirements, a 5-points scale is made. The best solution is given 5 points and with this solution as reference point, other solutions are given lower points.

4. Conceptual design

4.1 Listing solutions

The relevant solutions for the design of the return hall are based on the current solutions and the solutions found in literature and input from operational experts. All solutions are based on proven technology to satisfy the constraint that the solution could be implemented within five years. The current solutions consist of Employee, Temp worker, Shredder, and Cardboard press. The proposed solution consists of Joloda Moving Floor, Conveyor belt, Scale, EPT, AGV Tugger, Chain track, CBL crates sorter, CBL stacker, Pusher, Beer crates sorter, Tilt table, R-CNN + Conveyor belt.

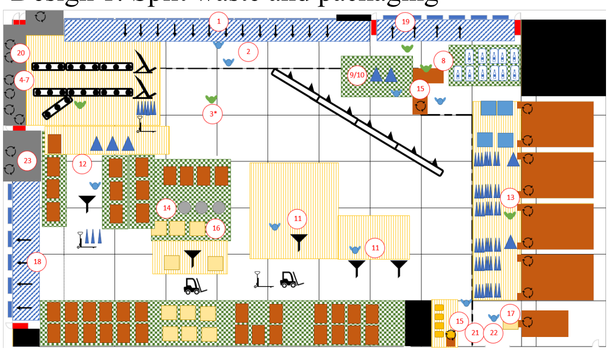
4.2 Scoring solutions

These solutions are connected based on their functionality to the subprocesses defined during the qualitative analysis. The score for the functional requirement is based on the numeric scale in main terms of loading carriers or interchange containers. To score the solutions for the non-functional requirements, in consultation with Hoogvliet, all solutions are scored at once per requirement. An explanation is given why some of the solutions have obtained a higher score.
This scoring results in a total ranking with solutions above and below average. The solutions that score far below average are eliminated to narrow the solution space to concrete designs.

4.3 Drawing designs

The proposed solutions results in three designs which are shown below. A legend table can be found in the appendix.

Design 1: Split waste and packaging



Design 2: Carousel

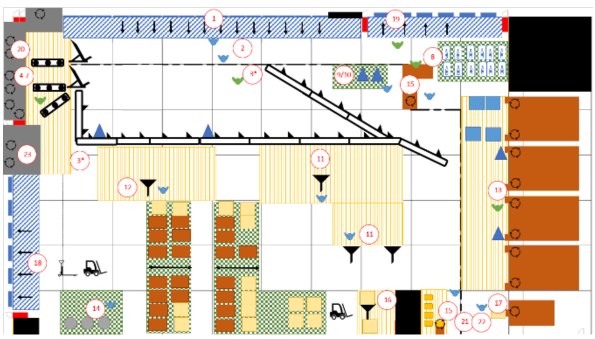


Figure A- 1: Conceptual layout of design 1 and 2

Design 1 tries to split all waste and packaging as soon as possible from the loading carriers. Also the beer sorting location and is relocated to shorten the distance for beer crates within the return hall. All empty loading carriers at the sorting stations are transported with pallet EPT's to the infeed points and the loading carriers that arrive empty in the return hall can be transported with the chain track.

Design 2 uses the chain track to deliver the loading carriers to the different sorting locations, but also to transfer the empty loading carriers from this sorting locations to the infeed points. Also the location for sorting empty pallets is relocated to a location which is close to the outfeed point of the Witron system to reduce this transport time.

Design 3: Completely automated – Ground floor

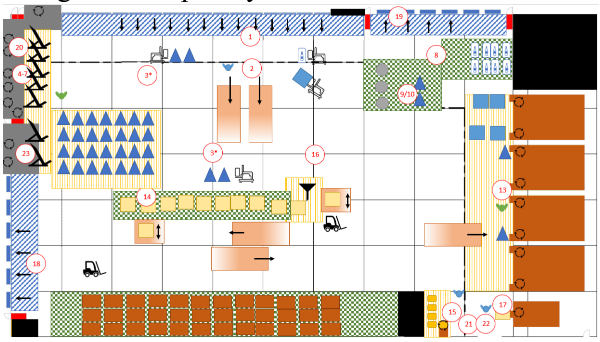


Figure A- 2: Conceptual layout of design 3 - Ground floor

Design 3a: Completely automated - First floor   Design 3b: Completely automated - First floor

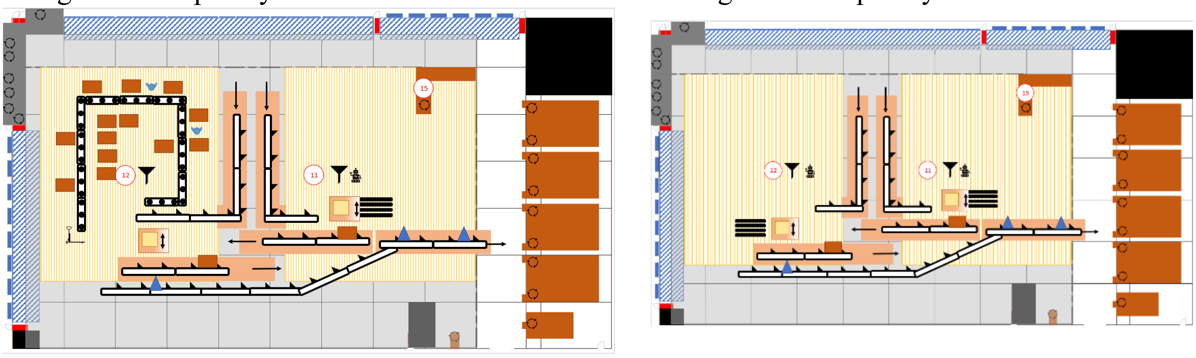


Figure A- 3: Conceptual layout of design 3a and 3b - First floor

Design 3 is the most advanced design, which automates the return hall as far as possible. AGV tuggers transport the loading carriers to the sorting or processing station on the ground floor. Full pallets are still transported with reach EPTs. This design requires a separate floor in the return hall for an automatic beer crate and CBL sorter. However, because automatic beer sorting is quite expensive, a manual alternative for beer sorting is proposed in design 3a. All (empty) loading carriers are transported with a chain track on a slope that connects the ground and first floor in this design.

5. Model and evaluate design

All layouts are modeled in a simulation model to estimate the required manual labor hours and compare the performance of the throughput of these designs.

5.1 Implementation of the simulation model

The designs are transferred per process into a modeling description and modeling objects. A simulation on scale is made in Simio which corresponds with the 22 of the 23 processes which are defined in the first phase (only the change of the Renewi container is not implemented since this process is performed by assistant team leaders which does not count for the required manual labor hours). The input, throughput and output are defined on the workload analysis. However, the input of the interchangeable containers is varied into three different arrivals to create a more realistic performance. The simulation outcome is based on the average of these three arrivals. The verification and validation are done by simulating the current layout for the current situation. Based on the outcome of required hours and the animation of the simulation model, could the model be validated and verified.

5.2 Experimental plan and motivation

The forecasts of 100 and 120 supermarkets and the differences in interchangeable containers could result in many scenarios. Therefore, three scenarios in the number of interchangeable containers are defined, which refer to the different inbound flows in the future. Currently, on average, 205 interchangeable containers arrive on an average day. Scenarios 1, 2, and 3 use a factor of 1.5, 2, and 2.5, respectively, which results in 308, 410, and 513 interchangeable containers. Because the layout and capacity per design may slightly change in the future, the modeling improvements are defined for each design. In the end, the current layout (as reference), design 1, design 2, design 3a, and design 3b are simulated for the three scenarios, resulting in 15 simulations.

5.3 Results and evaluation

The simulation results are evaluated based on the performance criteria as defined in section 3.2

<u>Required hours per interchangeable container</u>

The required hours per process are split into unloading hours, transport + loading hours, and processing hours. Design 3 obtains the lowest score for unloading since this process can be fully automated. The transport and loading hours are most stable and efficient performed by design 2, regarding the future methods as shown in Figure A- 4: Req. transport and loading hours per int. container. The required hours for processing activities are the lowest for design 3b.

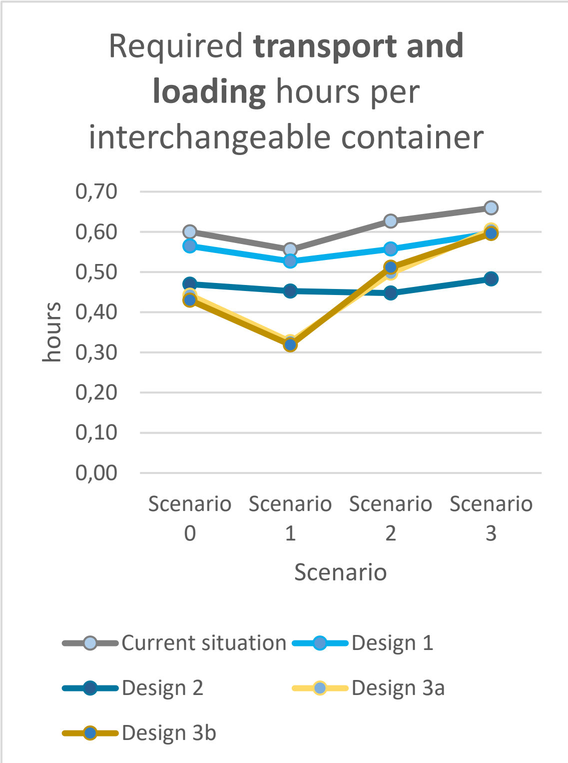


Figure A- 4: Req. transport and loading hours per int. container

<u>Payback period</u>

Compared with the current layout and additional investments for future scenarios, the shortest payback period is obtained by design 2, with an expected payback period of 0,5 years for the current situation. The most extended payback period is the complete automated design 3b with a period of 4 years, which can be reduced to 1.5 years in scenario 3.

<u>Estimated savings</u>

The estimated savings assume that all solutions will last for ten years. For the current situation, design 3a has the highest expected savings of €8.2 million, which is €820.000 per year. The lowest expected savings are obtained by design 1 with €41.000 per year. Increasing the volume as defined for scenario 3, design 3b will have the highest expected savings of €2.6 million per year.

<u>Queue length on inbound docks</u>

The higher the inbound volumes of interchangeable containers, the higher the pressure on the inbound docks. For the current situation (scenario 0), the shortest queue is obtained by design 3; however, for scenarios 2 and 3, the longest queue rises for design 3. The most temporary queue for scenario 3 is obtained by design 1.

<u>Limited space per process</u>

The allocation of the surface for each sorting station is computed whether the amount of loading carriers in the input or output buffer does not exceed the limited space. Especially for scenario 3 is shown that a buffer zone is needed for empty loading carriers since the capacity of infeeding these loading carriers is too low to process the supplied amount of loading carriers.

The results per criteria and design are summarized based on an average of scenario 1-3 in the table below.

Table A- 1: Average result per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Unloading hours per container	0,14	0,15	0,00	0,00
Transport and loading hours per container	0,56	0,46	0,47	0,46
Processing hours per container	0,61	0,61	0,30	0,26
Required hours per container	1,31	1,22	0,77	0,73
Payback period	185	80	484	849
Estimated savings per day	€ 1.198	€ 2.727	€ 7.672	€ 8.361
Queue length on inbound	647	717	1980	1917
Limited space per process	limited by sc. 3	limited by sc. 3	limited by sc. 3	limited by sc. 3

Results are based on the average of scenario 1-3.

To determine which two designs are the most preferred designs, a ranking score is given per criteria. The two solutions which has overall the best ranking are chosen as the preferred designs.

Table A- 2: Ranking per performance criteria

Criteria	Design 1	Design 2	Design 3a	Design 3b
Required hours per container	4	3	2	1
Payback period	2	1	3	4
Estimated savings per day	4	3	2	1
Queue length on inbound	1	2	4	3
Limited space per process	1	1	1	1
Total ranking	12	10	12	10

Based on the table above is concluded that design 2 and 3b are the preferred designs which will be fine-tuned in the next chapter. This fine-tuning will refer to the problems that are found during simulation and extension or optimization of solutions that are already proposed.

Operational problems that are found by simulation:

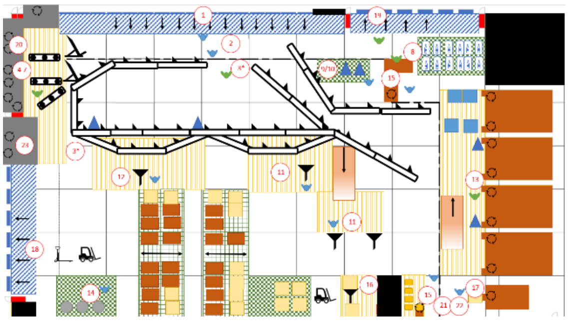
- Limited space per process in scenario 3 for both design 2 as design 3b.
  - This applies to the chain track capacity in design 2 and the AGV Tugger capacity in design 3b.
- Long inbound queue's, for design 3b.
- Prevent waiting times for the AGV's at the bread infeed point, for design 3b.
- Prevent long walk trips for employee's with return or cross dock loading carriers, for design 2.
- Infeed points not optimal used, for design 2 and design 3b.

6. Optimize and implement design

6.1 Improvements to design 2 and 3b

Because design 2 and design 3b obtains overall the best performance for the defined criteria, these layouts are improved to obtain a better performance, , based on the evaluation per design.
For design 2, the chain track is extended so that the employees could put the loading carriers on this track in front of the inbound docks. Also a separate floor is proposed which functions as a buffer zone for empty loading carriers. Design 3b has to improve the inbound performance. However, because of the limited space at the inbound docks this unloading should be performed manually. Also some small improvements on job allocation are made for both designs.

Design 2: Carousel



Design 3b: Completely automated - First floor

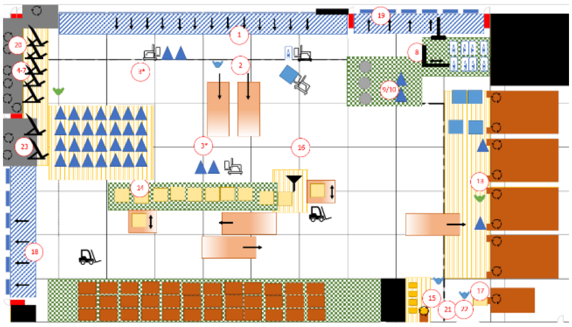


Figure A- 5: Conceptual layout of improved design 2 and 3b

6.2 Results and second evaluation

The results for per criteria are summarized in the table below.

Table A- 3: Comparison improved design 2 and improved design 3b

Criteria	Improved design 2	Improved design 3b
Unloading hours per container	0.14	0.15
Transport and loading hours per container	0.45	0.62
Processing hours per container	0.61	0.25
Required hours per container	1.19	1.01
Payback period	0.23 year	1.96
Estimated savings	€13.456.848	€ 17.880.002
Queue length on inbound	One small peak of 600 loading carriers waiting	900 loading carriers on average waiting
Limited space per process	Does almost not exceed capacity	Exceeds capacity

Based on this table can be concluded that improved design 3b has still no stable inbound flow and that the inside capacity is exceeded. This is why improved design 2 is advised.

6.3 Implementation

The first step is making someone responsible for the coordination and implementation of the design. As defined in section 4.1 indicate the costs but these should be evaluated in more detail by requesting a quote from multiple suppliers.

Then, job allocation per employee should be introduced as far as possible to streamline the processes and, as a side effect, better evaluate the performance of your employees.

The implementation of this design should be done step by step to avoid interrupting the business. This should be possible by first relocating some servers. Then, step by step, the proposed solutions can be implemented using the conceptual drawings and estimated quantities per scenario.

7. Conclusion and Recommendations

7.1 Conclusion

Research on the efficiency of all different processes within the return hall and to a certain extent the flexibility and scalability of these different processes is still missing, as shown in section 1.2. Besides the missing knowledge in literature, the business problem of Hoogvliet is related to the objective in section 1.1.

The objective is achieved with a transformed design method, according to Dym (1999). Using a morphological chart, different solutions are scored based on requirements connected to the objective. The conceptual designs are simulated and evaluated based on the performance criteria defined and related to the objective in section 3.2. Based on these criteria, two designs are improved. The second design shows a very efficient transport process which is further enhanced to increase this advantage. The complete automated design offers a very efficient processing solution but has a long queue on the inbound docks as a result of a limit throughput capacity. Based on the outcomes presented in section 5 the following findings refer to the knowledge gap and objective.

- Peak arrival rates result in long queues throughout the whole day;
- Manual inbound processes for small return halls with higher capacity and throughput;
- Transportation within return halls with the same processes has a significant impact on the workload and should be eliminated or automated as far as possible;
- In the short term (<3 years), transport solutions could result in significant savings;
- In the long term (>3 years), more advanced automated sorting systems have a higher savings than minor improvements;
- Work standardization, also for manual transportation, streamlines the whole throughput;
- Enough output capacity (such as infeeding capacity for roll containers), solves many blocking issues in previous processes;
- Enough (buffer) space is essential for an efficient throughput.

Regarding to the efficiency, and to a certain extend, flexibility, scalability and future-proof level of the return hall, it can be concluded that:

- A stable inbound process at the return hall is important for an efficient throughput;
- Automating transport activities will most likely pay for itself;
- Job standardization will increase the efficiency of the return hall;
- Using multiple docks makes the return hall more flexible because of the higher inbound capacity. However, this flexibility is limited as long as the transport, processing and buffer capacity are not as high as the inbound capacity;
- Important to allocate allowable space per process in future scenario's and use buffer zones to ensure the scalability of the return hall.

7.2 Recommendations and future research

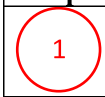
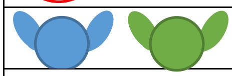
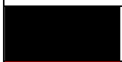
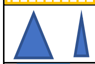
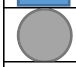
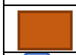
The design proposed in the previous sections aims to be efficient, flexible, scalable, and future-proof. The evaluation of this design has shown that a primary limiting factor is an available space for all processes that need to be performed. Therefore, it is recommended to research the general area or optimal layout for an efficient, flexible, scalable, and future-proof return hall. To see whether a return process is flexible and scalable, it is recommended to investigate the use of multiple return halls and different arrivals.

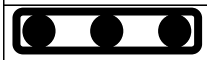
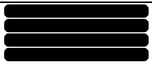
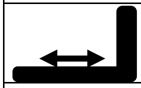
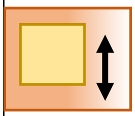
Besides the available space and layout of the return hall, it is recommended to do further research on the efficiency of the detailed processes within the return hall. Especially the processes of CBL crate sorting and beer crate sorting, which are hard to automate, can be further investigated. Since this automation is not commonly used, there is not much knowledge on the pros and cons of these systems and their performance level.

Thirdly, with the detailed knowledge of these automation systems, extending the simulation model, which is built for the return hall of Hoogvliet. With this information, it is possible to investigate the impact of the reliability and performance of the servers on the throughput of the return hall. In the simulation, which is done, is chosen to model the processing times in a random triangular way with 10% above and below average as a limit. However, since most of these processing times rely on manual activities, this could differ per employee. Scoping to a (couple of) process(es) and fine-tuning parameters could improve the outcome's reliability and give opportunities to enhance the design further. Also, improvements can be made regarding the employees and vehicles that are modeled. The capacity of these employees and cars is now fixed based on an average. Still, in practice, the amount of loading carriers that an employee or EPT can transport depends on the loading carriers' weight and stability. A possible subject for future research is to investigate the impact of more standardized loading carriers (prepared at the supermarket) on the efficiency of the return hall processes.

Appendix

Table A- 4: Legend table conceptual designs

Shape	Definition
	Process indication with a number that refers to a specific process as defined in section Gemba walk.
	Employee and temp worker
	Processing station: at this location, goods are processed and leave the return hall. For example: waste processing of old bread or infeeding roll containers.
	Sorting station: at this location, goods are sorted such as CBL crates, beer crates and empty pallets.
	Flow of goods: for example the incoming or outgoing flow by (un)loading of trailers.
	'Dead' objects which cannot be removed.
	Emergency door, must be accessible
	Docks
	Shredder / cardboard press
	Infeed system, used for crates and loading carriers
	Temporary storage location for loading carriers, big bags or pallets
	(Un)loading space
	Queue area
	Roll container unfolded and roll container folded
	Thermo
	RIC
	Bread dolly
	Empty pallet
	Full pallet (with reusable packaging)
	Big bag

	EPT, different types
	AGV tugger
	Tilt table
	Conveyor belt
	Chain track
	CBL stacker
	Sorting machine such as cbl or beer crate sorter
	Manual sorting
	Joloda Moving Floor system
	Empty pallet elevator

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Senthil, S., Murugananthan, K., & Ramesh, A. (2018). Analysis and prioritisation of risks in a reverse logistics network using hybrid multi-criteria decision making methods. Journal of Cleaner Production, 179, 716–730. https://doi.org/10.1016/j.jclepro.2017.12.095

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Supriyanto, A. A. W. (2021). Reverse supply chain improvement strategies for returnable packaging material | TU Delft Repositories. Retrieved February 16, 2022, from https://repository.tudelft.nl/islandora/object/uuid%3A194f8f0c-516b-4b49-b4e4-2fcb1e45c6f2?collection=education

Weerd, de P. (2020, December 7). Zo automatiseert Picnic zijn distributiecentrum in Utrecht. Retrieved December 14, 2021, from https://www.logistiek.nl/warehousing/nieuws/2020/07/zo-automatiseert-picnic-zijn-distributiecentrum-in-utrecht-101174266?_login=1

B. Process flows

B.1 Functional flow block diagram – detailed functions

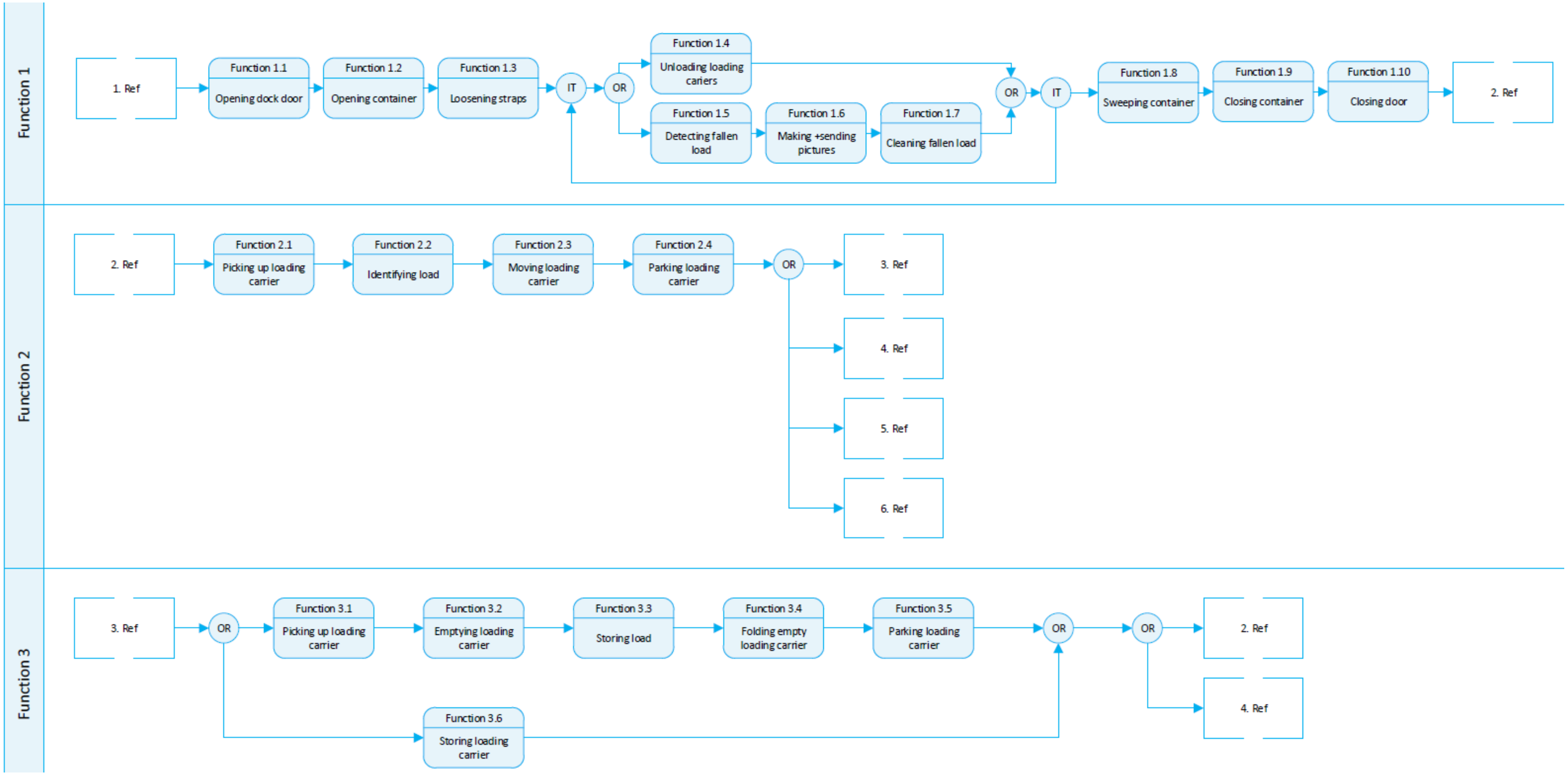


Figure B- 1: Functional flow block diagram - Detailed functions 1-3

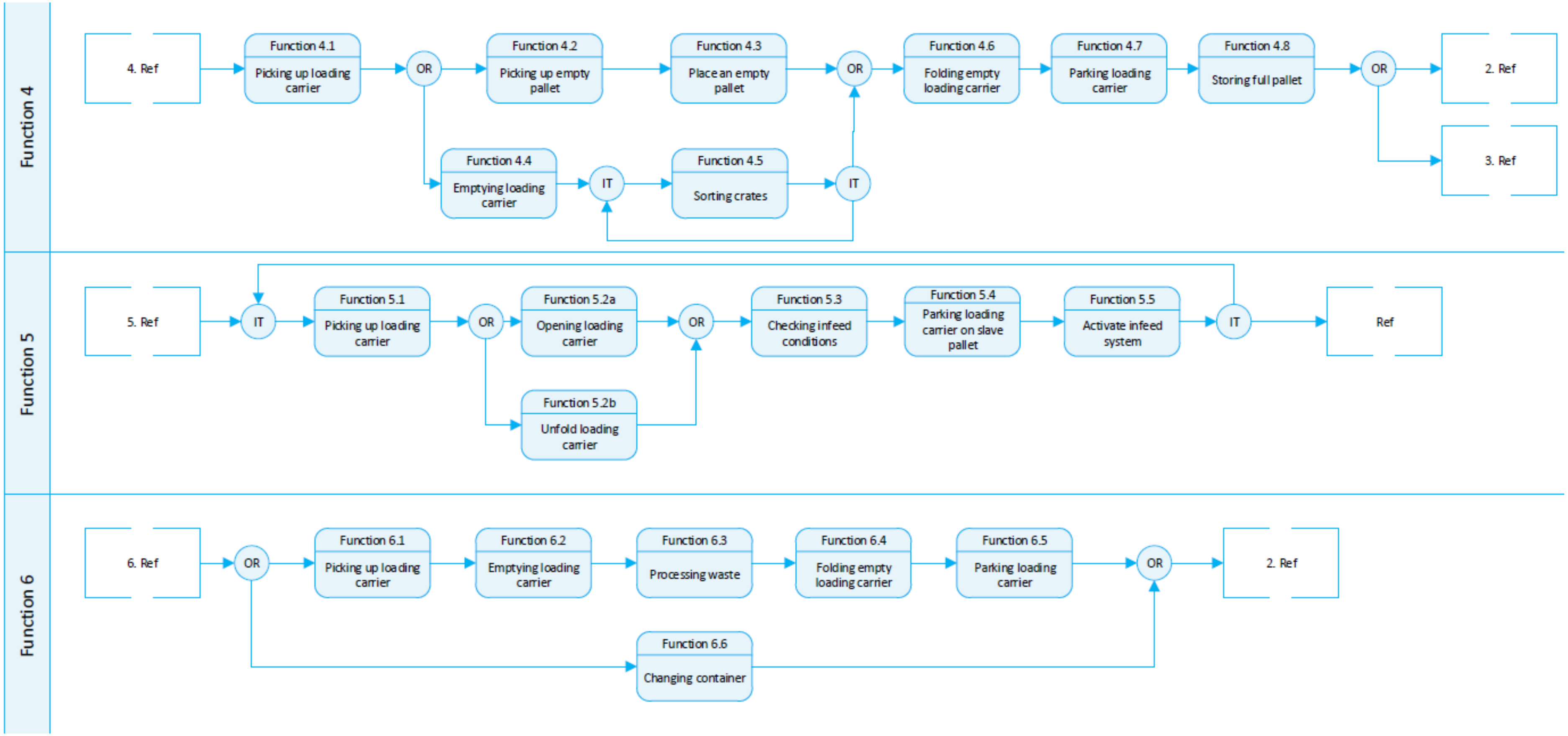


Figure B- 2: Functional flow block diagram - Detailed functions 4-6

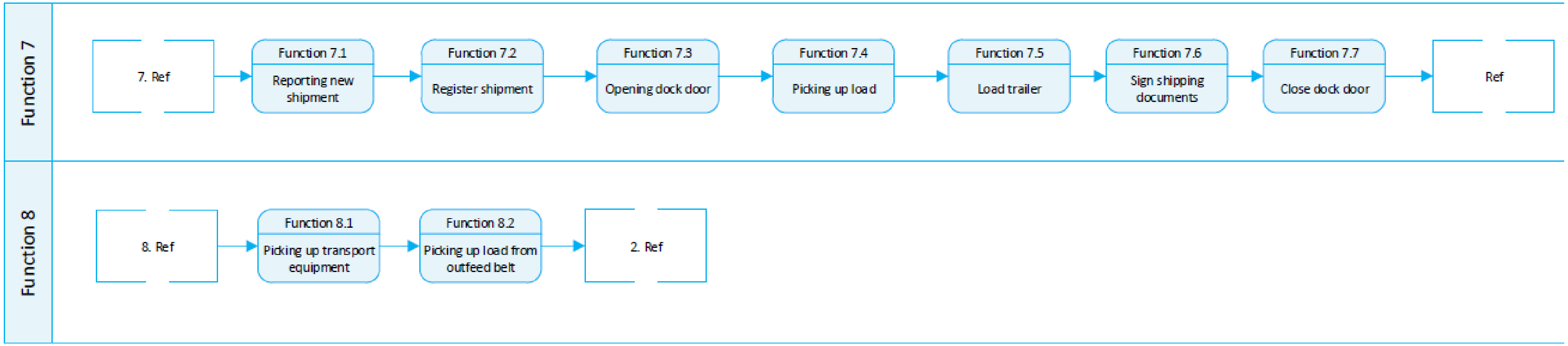


Figure B- 3: Functional flow block diagram - Detailed functions 7-8

B.2 Swimlane diagram - Goods and packaging

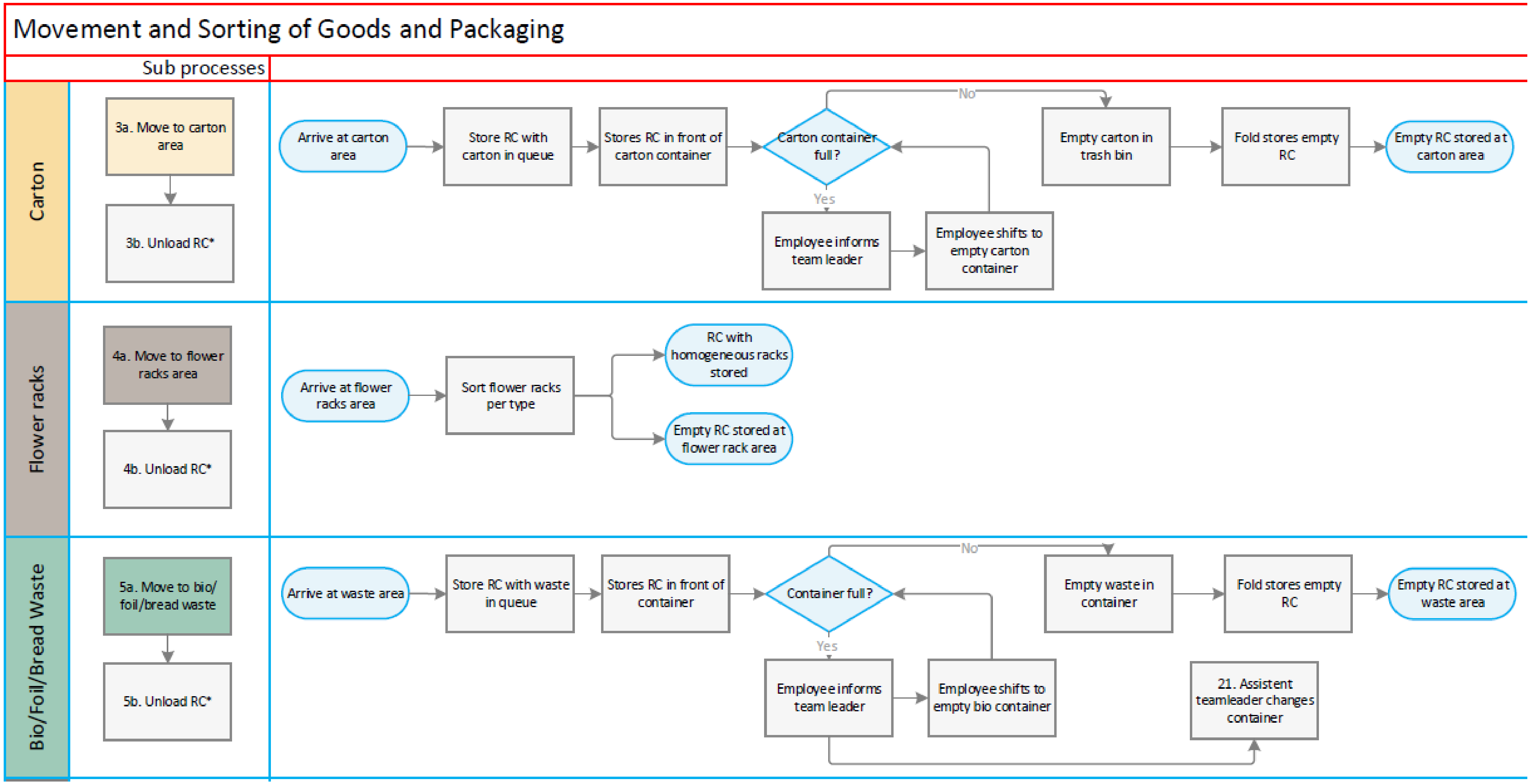


Figure B- 4: Swimlane diagram - Detailed functions 3b, 4b and 5b

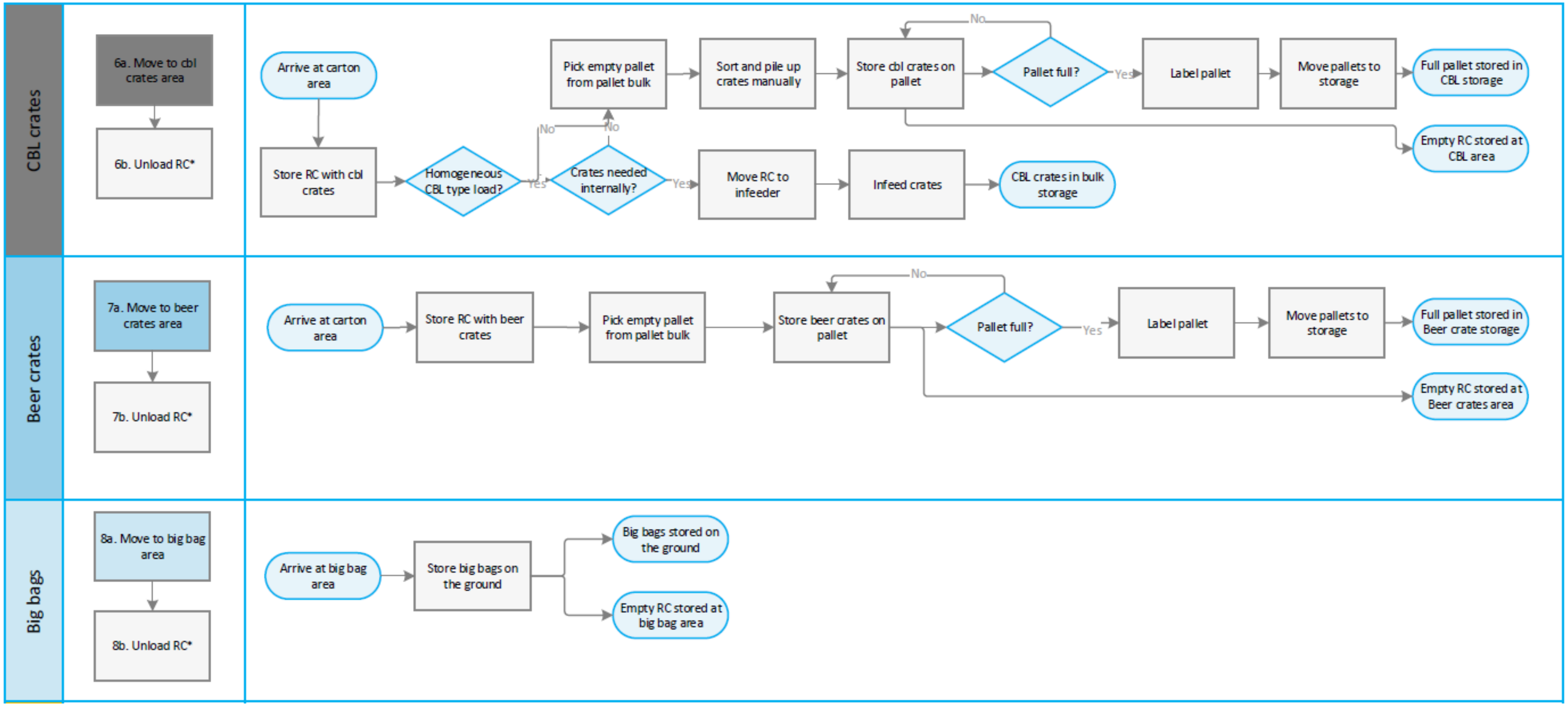


Figure B- 5: Swimlane diagram - Detailed functions 6b, 7b and 8b

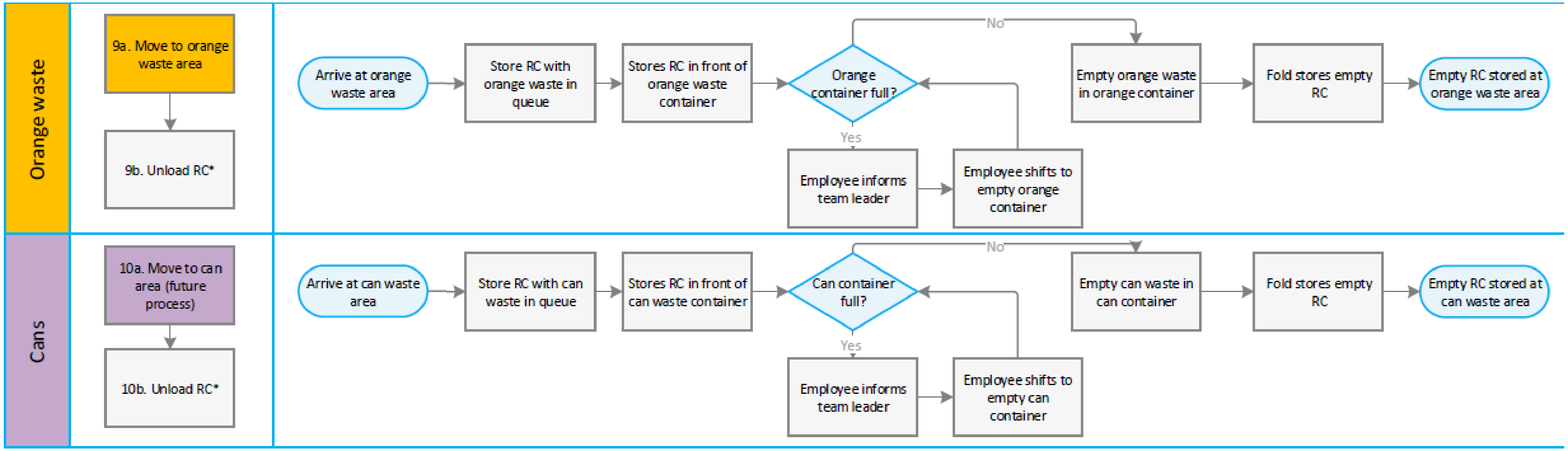


Figure B- 6: Swimlane diagram - Detailed functions 9b,and 10b

B.3 Coding of return hall processes

Table B- 1: Coding of return hall processes

Gemba walk process	Functional flow block diagram	Swimlane diagram
1	1.1-1.10	1a-1d
2	2.1-2.2	1e
3	2.3-2.4	2a-16a
4	6.1-6.5	5b
5	6.1-6.5	3b
6	6.1-6.5	5b
7	6.1-6.5	9b
8	3.1-3.5	8b
9	3.6	13b
10	3.6	4b
11	4.1-4.8	6b
12	4.1-4.8	7b
13	5.1-5.5	2b-2d, 14b
14	3.6	16b
15	5.1, 5.5-5.7	15b, 15c
16	8.1-8.2	17
17	8.1-8.2	18
18	7.1-7.7	20
19	7.1-7.7	19
20	6.6	21
21	2.1-2.4	11b
22	2.1-2.4	12b
23	6.1-6.5	10b

Table B- 1: Coding of return hall processes will be used in section 'Throughput' to translate the processes of the return hall into a simulation model. The detailed processes of the columns functional flow block diagram and swim lane diagram from this table can be found in upper appendices B.1 Functional flow block diagram – detailed functions and B.2 Swimlane diagram - Goods and packaging.

C. Process specifications

C.1 Workload analysis

Below, all activities are listed in Table C- 1: Workload analysis per process The average share of loading carriers per interchangeable container is added in the second column, the time which is measured in the third column.

Sometimes, employees pick up more than 1 loading carriers at a time and thus the total time per container is based on an average per loading carrier. The total hours spend per day in hours are computed by the average containers per day, multiplied with the total time per container in minutes.

Table C- 1: Workload analysis per process

Group	*Type*	*Carriers per container*	*Time per carrier (sec)*	*Combine carriers*	*Total time per container (min)*	*Average Containers per day*	*Hours spend per day (hour)*
Unloading	Unloading	35,97	16,7	1,0	10,0	205	**34,17**
Transport	DPS	0,80	43	2	0,3	205	0,98
Transport	EPS	1,17	40	2	0,4	205	1,33
Transport	Beer	1,23	42	1,5	0,6	205	1,97
Transport	CBL	4,80	35	2	1,4	205	4,78
Transport	Returns	0,10	180	1	0,3	205	1,03
Transport	(Bread) dolly	2,00	69	2	1,2	205	3,93
Transport	Flower racks	0,33	25	1,5	0,1	205	0,32
Transport	E-commerce	0,50	25	1,5	0,1	205	0,47
Transport	RIC's	0,70	43	1,5	0,3	205	1,14
Transport	Big bags	1,50	33	2	0,4	205	1,41
Transport	Thermo	3,50	55	2	1,6	205	5,48
Transport	Folded RC	8,00	62	7	1,2	205	4,03
Transport	Foil	0,40	55	2	0,2	205	0,63
Transport	Orange peels	0,67	60	2	0,3	205	1,14
Transport	Bio waste	0,93	55	2	0,4	205	1,46
Transport	Old bread	2,00	50	2	0,8	205	2,85
Transport	Residual waste	2,17	55	2	1,0	205	3,39
Transport	Carton	5,17	70	2	3,0	205	10,30
Transport	Infeed (other)	20,83	80	7	4,0	205	13,56
	Approaching	56,80	51	3,6	13,3	205	45,52
Transport total							**105,71**

Group	Type	Carriers per container	Time per carrier (sec)	Combine carriers	Total time per container (min)	Average Containers per day	Hours spend per day (hour)
Crates sorting	DPS	0,80	60	1	0,8	205	2,73
Crates sorting	EPS	1,17	60	1	1,2	205	3,99
Crates sorting	Beer Fastmover	0,62	50	1	0,5	205	1,76
Crates sorting	Beer Slowmover	0,62	440	1	4,5	205	15,45
Crates sorting	CBL	4,80	75	1	6,0	205	20,50
Cross-dock	Returns	0,10	180	1	0,3	205	1,03
Infeed	(Bread) dolly	2,00	30	1	1,0	205	3,42
Storage	Flower racks	0,33	0	1	0,0	205	0,00
Storage	E-commerce	0,50	0	1	0,0	205	0,00
Storage	RIC's	0,70	0	1	0,0	205	0,00
Storage	Big bags	1,50	0	1	0,0	205	0,00
Storage/Infeed	Thermo	3,50	40	1	2,3	205	7,97
Storage/Infeed	Folded RC	28,83	45	2	10,8	205	36,94
Waste	Foil	0,40	10	1	0,1	205	0,23
Waste	Orange peels	0,67	10	1	0,1	205	0,38
Waste	Bio waste	0,93	10	1	0,2	205	0,53
Waste	Old bread	2,00	10	1	0,3	205	1,14
Waste	Residual waste	2,17	10	1	0,4	205	1,23
Waste	Carton	5,17	25	1	2,2	205	7,36
Sorting	Empty pallets	105,00	180	1	315,0	1	5,25
Processing							**109,90**

Activity	Type	Hours spend per day (hour)
Loading	EPS	1,5
Loading	Beer	3
Loading	CBL	2
Loading	Flower racks	1
Loading	E-Commerce	2
Loading	RIC's	1
Loading	Big bags	3
Infeed	DPS	0,3
Infeed	CBL	8
Loading		**21,7**

C.2 Process constraints and requirements

Specific constraints

The additional constraints and (non-)functional requirements are listed below. The general sign (G) is now replaced with the process number (e.g. 1C1 instead of GC1).

1. **Receiving and unloading container**
- 1C1 – Compatible with the unload docks of the return hall
2. **Sorting roll containers / thermos / RIC's / bread dolly**
- 2C1 – Compatible with the roll containers, thermos, RIC's and bread dollies, Hoogvliet is currently using.
3. **Transport loading carriers**
- 3C1 – Compatible with the roll containers, thermos, RIC's and bread dollies, Hoogvliet is currently using.
4. **Process roll container with old bread**
- 4C1 – Able to identify the different types of bread
5. **Process roll container with carton**
- *No additional constraint*
6. **Process roll container with bio / residual waste**
- *No additional constraint*
7. **Process roll container with orange peels**
- *No additional constraint*
8. **Process roll container with big bags**
- *No additional constraint*
9. **Process roll container with e-commerce bags and crates**
- 9C1 – Able to store roll container with e-commerce bags and crates
10. **Process roll container with flower racks**
- 10C1 – Able to store roll container with flower racks
11. **Process roll container with CBL crates**
- 11C1 - Able to store full roll containers
- 11C2 – Able to store empty pallets
- 11C3 – Able to sort all different types of CBL crates
- 11C4 – Able to store full pallets with CBL crates
- 11C5 – Able to label each pallet with CBL crates
12. **Process roll container beer crates**
- 12C1 - Able to store full roll containers
- 12C2 – Able to store empty pallets
- 12C3 – Able to sort beer crates in product range Hoogvliet
- 12C4 – Able to store full pallets with beer crates
- 12C5 – Able to label each pallet with beer crates
13. **Infeed loading carriers**
- 13C1 - Able to store empty thermos
14. **Process dairy roll-in container (RIC)**
- 14C1 - Able to store RIC's
15. **Infreed (bread) crates**
- 15C1 - Able to store dolly's with bread crates
16. **Process empty pallets**
- 16C1 - Able to store empty pallets
17. **Process waste bin with seal residuals**
- *No additional constraint*
18. **Loading reusable packaging**
- *No additional constraint*

19. Loading big bags
- *No additional constraint*

20. Change waste container Renewi
- *No additional constraint*

21. Process non-food returns
- 21C1 - Able to store roll containers with non-food returns

22. Cross-docking
- *No additional constraint*

23. Process roll container with trash cans (future process)
- *No additional constraint*

Specific functional requirement scale

In Table C- 2: Functional requirments with unit of measure and scale definition is shown which scale per process is used in terms of throughput. This scale is determined in consultation with Hoogvliet on the regular incoming flow of incoming goods. The same share in amount of loading carriers is applied per process. The other incoming flow with empty pallets and waste boxes is defined on a dataset in week 2, 2022.

Table C- 2: Functional requirments with unit of measure and scale definition

Req.	Description	Unity	Score 1	2	3	4	5
FR1	*Throughput as many xxxx per hour as possible*	*xxxx / hour**	--	-	0	+	++
FR1.1	*Throughput as interchangeable containers per hour as possible*	*interchangeable containers / hour*	<14	14-16	16-18	18-20	20<
FR1.2	*Throughput as many loading carriers per hour as possible*	*loading carriers / hour*	<504	504-576	576-648	648-720	720<
FR1.3	*Throughput as many loading carriers per hour as possible*	*loading carriers / hour*	<504	504-576	576-648	648-720	720<
FR1.4	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<28	28-32	32-36	36-40	40<
FR1.5	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<72	72-83	83-93	93-103	103<
FR1.6	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<49	49-56	56-63	63-70	70<
FR1.7	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<9	9-11	11-12	12-13	13<
FR1.8	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<21	21-24	24-27	27-30	30<
FR1.9	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<7	7-8	8-9	9-10	10<
FR1.10	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<5	5-5	5-6	6-7	7<
FR1.11	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<95	95-108	108-122	122-135	135<
FR1.12	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<17	17-20	20-22	22-25	25<

FR1.13	*Throughput as many loading carriers per hour as possible*	*loading carriers / hour*	<453	453-517	517-582	582-647	647<
FR1.14	*Throughput as many RIC's per hour as possible*	*RIC's / hour*	<10	10-11	11-13	13-14	14<
FR1.15	*Throughput as many crates per hour as possible*	*crates / hour*	<1.-000	1000-1200	1200-1400	1400-1600	1600 <
FR1.16	*Throughput as many empty pallets per hour as possible*	*empty pallets / hour*	<40	40-45	45-50	50-55	55<
FR1.17	*Throughput as many waste bins per hour as possible*	*waste bins / hour*	0.2<	0.2-0.5	0.5-1.0	1.0-2.0	2.0<
FR1.18	*Throughput as many pallets per hour as possible*	*pallets / hour*	<75	75-100	100-125	125-150	150<
FR1.19	*Throughput as many big bags per hour as possible*	*big bags / hour*	<21	21-24	24-27	27-30	30<
FR1.20	*Throughput as many waste containers per hour as possible*	*waste containers / day*	<3	3-4	4-5	5-6	6<
FR1.21	*Throughput as many loading carriers per hour as possible*	*loading carriers / hour*	<1	1-1	1-1	1-1	1<
FR1.22	*Throughput as many loading carriers per hour as possible*	*loading carriers / hour*	<1	1-1	1-1	1-1	1<
FR1.23	*Throughput as many roll containers per hour as possible*	*roll containers / hour*	<10	10-11	11-13	13-14	14<

D. Solutions

<u>i. Joloda Moving Floor</u>

Figure D- 1: Joloda Moving Floor solution (Sales Joloda, 2021)

<u>ii. Conveyor belt</u>

Figure D- 2: Conveyor belts for roll containers (Gebhardt, 2021)

iii. Scale

Figure D- 3: Roll through scale (Bosche, 2021)

iv. EPT

Figure D- 4: Different types of EPT (Crown, 2021)

v. AGV Tugger

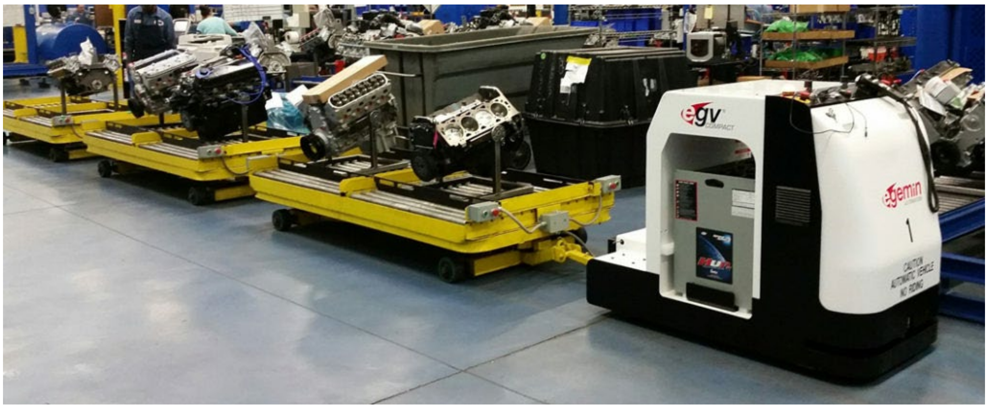


Figure D- 5: AGV Tugger (Ellis systems, 2019)

vi. Chain track

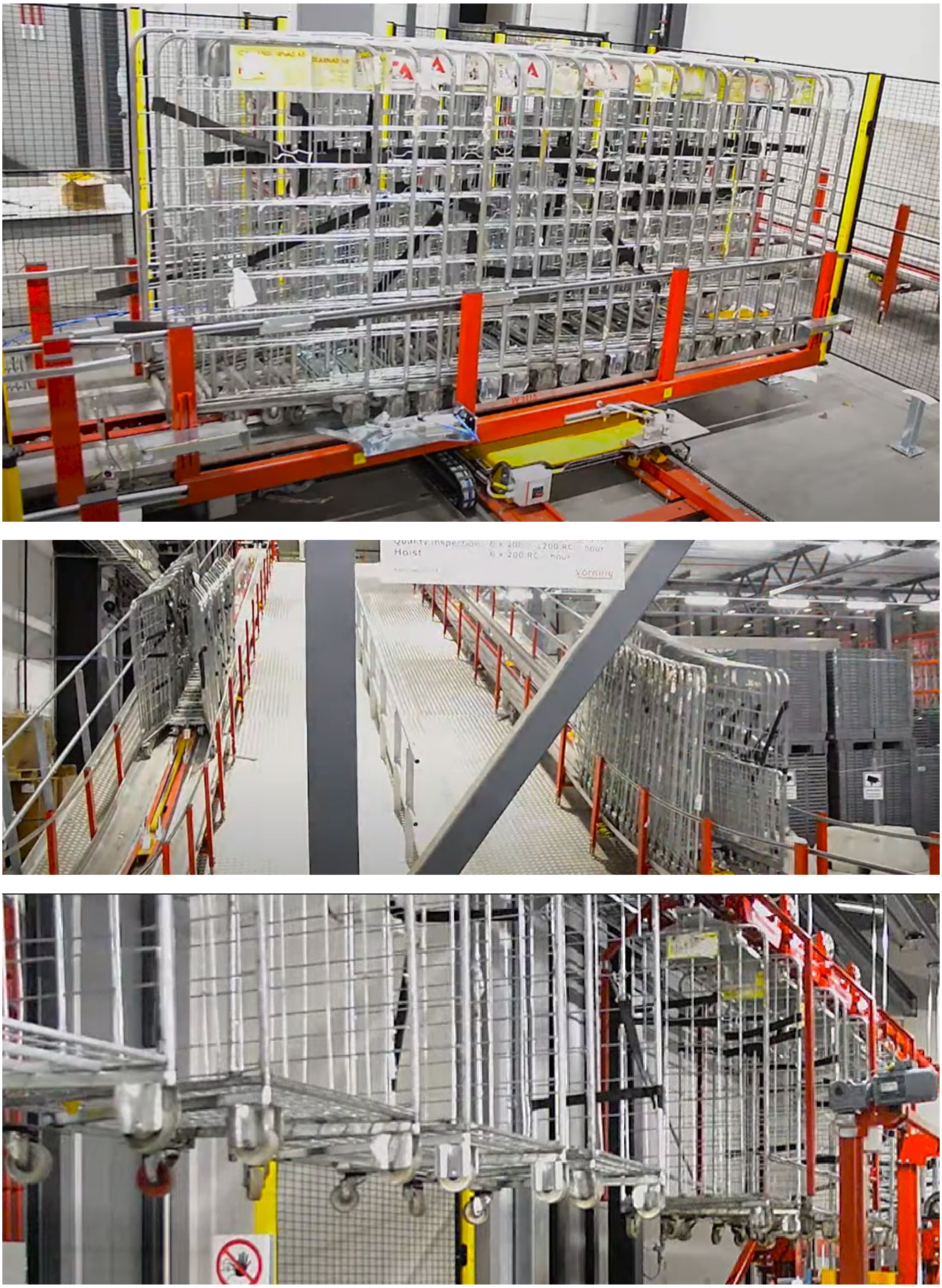


Figure D- 6: Chain tracks (Vorning, 2016)

vii. CBL crate sorter

Elten, (2021) - no picture available

viii. CBL stacker

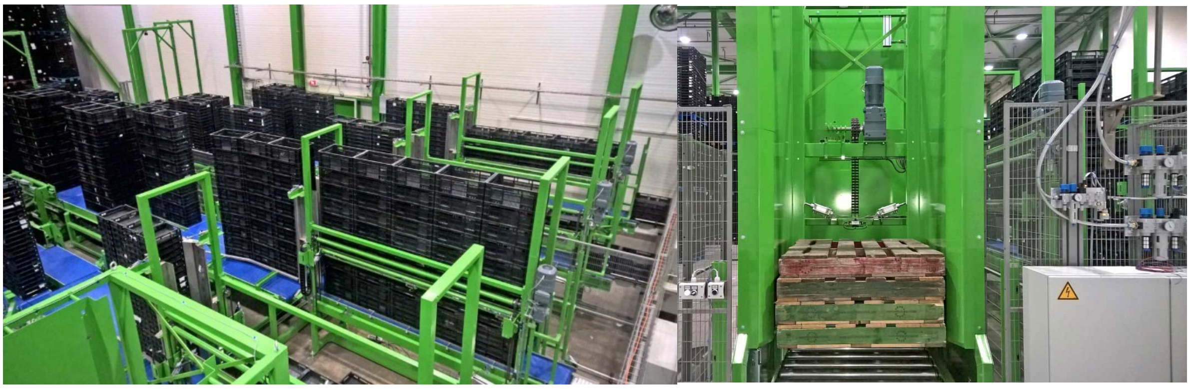


Figure D- 7: CBL stacker (Ridder, 2020)

xi. Pusher

Figure D- 8: Crate pusher (MAAS IL, 2020)

Figure D- 9: Crate pusher (Elten, 2020)

x. Beer crate sorter

Sidel, (2020) - no picture available

xi. Tilt tables (upside down)

Figure D- 10: Tilt tables (Taylor 2020)

E. Morphological chart

E.1 Solutions per process

Table E- 1: Solutions per process

Pro-cess	MORPH-CHART	A	B	C	D	E	F	G	H
1	**Receiving and unloading container**	Employee	Temp worker	Joloda Moving Floor					
2	**Sorting roll containers / thermos / RIC's / bread dolly**	Employee	Temp worker	R-CNN + Conveyor belt	Scale				
3	**Transport loading carrier**	Employee	Temp worker	EPT	AGV Tugger	Chain track	Conveyor belt		
4	**Process roll container with old bread**	Employee	Temp worker	Pusher	Tilt table	Shredder	Chain track	EPT	AGV Tugger
5	**Process roll container with carton**	Employee	Temp worker	Pusher	Tilt table	Shredder	Chain track	EPT	AGV Tugger
6	**Process roll container with bio / residual waste**	Employee	Temp worker	Pusher	Tilt table	Shredder	Chain track	EPT	AGV Tugger
7	**Process roll container with orange peels**	Employee	Temp worker	Pusher	Tilt table	Shredder	Chain track	EPT	AGV Tugger
8	**Process roll container with big bags**	Employee	Temp worker	Pusher	Tilt table	Chain track	EPT	AGV Tugger	
9	**Process roll container with e-commerce bags and crates**								
10	**Process roll container with flower racks**								
11	**Process roll container with CBL crates**	Employee	Temp worker	CBL crates sorter	R-CNN + Conveyor belt	EPT	AGV Tugger	Pusher	Tilt table

		Chain Track	CBL stacker						
12	**Process roll container beer crates**	Employee	Temp worker	Beer crates sorter	R-CNN + Conveyor belt	EPT	AGV Tugger	Pusher	Tilt table
		Chain Track							
13	**Infeed loading carrier**	Employee	Temp worker	EPT	AGV Tugger	Chain track			
14	**Process dairy roll-in container (RIC)**								-
15	**Infeed (bread) crate**	Employee	Temp worker	EPT	AGV Tugger				
16	**Process empty pallets**	Employee	Temp worker	EPT	AGV Tugger		-		
17	**Process waste bin with seal residuals**	Employee	Temp worker	EPT	AGV Tugger	-	-		
18	**Loading reusable packaging**	Employee	Temp worker	EPT	AGV Tugger	Joloda Moving Floor	-		
19	**Loading big bags**	Employee	Temp worker	EPT	AGV Tugger	Joloda Moving Floor			
20	**Change waste container Renewi**	Employee	Temp worker						
21	**Process non-food returns**	Employee	Temp worker	EPT	AGV Tugger	Chain track	Conveyor belt		
22	**Cross-docking**	Employee	Temp worker	EPT	AGV Tugger	Chain track	Conveyor belt		
23	**Process roll container with trash cans (future process)**	Employee	Temp worker	Pusher	Tilt table	Shredder	Chain track	EPT	AGV Tugger

E.2 Solutions per activity

Some of the processes that are defined in the table below, are applicable to multiple processes. Therefore, the processes is related to the functional flow block diagram (FFBD) as shown in section B.1 Functional flow block diagram – detailed functions. Most of the time, the same set of solutions can be applied for each FFBD process which led to some patterns of solutions within this table.

Table E- 2: Solutions per activity

Process	FFBD	Process description	A	B	C	D	E	F
1.1	1.1	Opening dock door	Employee	Temp worker				
1.2	1.2	Opening container	Employee	Temp worker				
1.3	1.3	Loosing straps	Employee	Temp worker				
1.4	1.4	Unloading container	Employee	Temp worker	Joloda Moving Floor			
1.5	1.5	Detecting fallen load	Employee	Temp worker				
1.6	1.6	Making and sending pictures of load	Employee	Temp worker				
1.7	1.7	Cleaning fallen load	Employee	Temp worker				
1.8	1.8	Sweeping container	Employee	Temp worker				
1.9	1.9	Closing container	Employee	Temp worker				
1.10	1.10	Closing door	Employee	Temp worker				
2.1	2.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
2.2	2.2	Identifying load	Employee	Temp worker	R-CNN + Conveyor belt	Scale		
3.1	2.3	Moving loading carrier	Employee	Temp worker	EPT	AGV Tugger	Chain track	Conveyor belt
3.2	2.4	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	Conveyor belt
4.1	6.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		

4.2	6.2	*Emptying loading carrier*	Employee	Temp worker	Pusher	Tilt table		
4.3	6.3	*Processing waste*	Shredder					
4.4	6.4	*Folding empty loading carrier*	Employee	Temp worker				
4.5	6.5	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
5.1	6.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
5.2	6.2	*Emptying loading carrier*	Employee	Temp worker	Pusher	Tilt table		
5.3	6.3	*Processing waste*	Shredder					
5.4	6.4	*Folding empty loading carrier*	Employee	Temp worker				
5.5	6.5	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
6.1	6.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
6.2	6.2	*Emptying loading carrier*	Employee	Temp worker	Pusher	Tilt table		
6.3	6.3	*Processing waste*	Shredder					
6.4	6.4	*Folding empty loading carrier*	Employee	Temp worker				
6.5	6.5	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
7.1	6.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
7.2	6.2	*Emptying loading carrier*	Employee	Temp worker	Pusher	Tilt table		
7.3	6.3	*Processing waste*	Shredder					
7.4	6.4	*Folding empty loading carrier*	Employee	Temp worker				
7.5	6.5	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
8.1	3.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		

8.2	3.2	*Emptying loading carrier*	Employee	Temp worker	Pusher	Tilt table		
8.3	3.3	*Storing load*	*Space*					
8.4	3.4	*Folding empty loading carrier*	Employee	Temp worker				
8.5	3.5	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
9.1	3.6	*Storing loading carrier*	*Space*					
10.1	3.6	*Storing loading carrier*	*Space*					
11.1	4.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
11.2	4.2	*Picking empty pallet*	Employee	Temp worker	EPT	AGV Tugger		
11.3	4.3	*Place empty pallet*	Employee	Temp worker	EPT	AGV Tugger		
11.4	4.4	*Emptying loading carrier*	Employee	Temp worker	Pusher	Tilt table		
11.5	4.5	*Sorting crates*	Employee	Temp worker	CBL crates sorter	R-CNN + Conveyor belt	CBL stacker	
11.6	4.6	*Folding empty loading carrier*	Employee	Temp worker				
11.7	4.7	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
11.8	4.8	*Storing full pallet*	EPT					
12.1	4.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
12.2	4.2	*Picking empty pallet*	Employee	Temp worker	EPT	AGV Tugger		
12.3	4.3	*Place empty pallet*	Employee	Temp worker	EPT	AGV Tugger		
12.4	4.4	*Emptying loading carrier*	Employee	Temp worker	Pusher			
12.5	4.5	*Sorting crates*	Employee	Temp worker	Beer crates sorter	R-CNN + Conveyor belt		

12.6	4.6	*Folding empty loading carrier*	Employee	Temp worker				
12.7	4.7	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
12.8	4.8	*Storing full pallet*	EPT					
13.1	5.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
13.2	5.2	*Unfold loading carrier*	Employee	Temp worker				
13.3	5.3	*Checking infeed conditions*	Employee	Temp worker				
13.4	5.4	*Park loading carrier on system pallet*	Employee	Temp worker				
13.5	5.5	*Activate infeed system*	Employee	Temp worker				
14.1	3.6	*Storing loading carrier*	*Space*					
15.1	5.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
15.2	5.6	*Pile up crates*	Employee	Temp worker				
15.3	5.7	*Place pile on infeed lane*	Employee	Temp worker	EPT	AGV Tugger		
15.4	5.5	*Activate infeed system*	Employee	Temp worker				
16.1	8.1	*Picking up transport equipment*	Employee	Temp worker				
16.2	8.2	*Pickuing up load from outfeed belt*	Employee	Temp worker	EPT	AGV Tugger		
17.1	8.1	*Picking up transport equipment*	Employee	Temp worker				
17.2	8.2	*Pickuing up load from outfeed belt*	Employee	Temp worker	EPT	AGV Tugger		
18.1	7.1	*Reporting new shipment*	Employee	Temp worker				

18.2	7.2	*Register shipment*	Employee	Temp worker				
18.3	7.3	*Openining dock door*	Employee	Temp worker				
18.4	7.4	*Picking up load*	Employee	Temp worker	EPT	AGV Tugger		
18.5	7.5	*Load trailer*	Employee	Temp worker	EPT	AGV Tugger	Joloda Moving Floor	
18.6	7.6	*Sign shipping documents*	Employee	Temp worker				
18.7	7.7	*Close dock door*	Employee	Temp worker				
19.1	7.1	*Reporting new shipment*	Employee	Temp worker				
19.2	7.2	*Register shipment*	Employee	Temp worker				
19.3	7.3	*Openining dock door*	Employee	Temp worker				
19.4	7.4	*Picking up load*	Employee	Temp worker	EPT	AGV Tugger		
19.5	7.5	*Load trailer*	Employee	Temp worker	EPT	AGV Tugger	Joloda Moving Floor	
19.6	7.6	*Sign shipping documents*	Employee	Temp worker				
19.7	7.7	*Close dock door*	Employee	Temp worker				
20.1	6.6	*Changing container*	Employee	Temp worker				
21.1	2.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
21.2	2.2	Identifying load	Employee	Temp worker				
21.3	2.3	Moving loading carrier	Employee	Temp worker	EPT	AGV Tugger	Chain track	Conveyor belt
21.4	2.4	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	
22.1	2.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		

22.2	2.2	Identifying load	Employee	Temp worker				
22.3	2.3	Moving loading carrier	Employee	Temp worker	EPT	AGV Tugger	Chain track	Conveyor belt
22.4	2.4	*Parking loading carrier*	Employee	Temp worker	EPT	Chain track		
23.1	6.1	*Picking up loading carrier*	Employee	Temp worker	EPT	AGV Tugger		
23.2	6.2	*Emptying loading carrier*	Employee	Temp worker	Pusher	Tilt table		
23.3	6.3	*Processing waste*	Shredder					
23.4	6.4	*Folding empty loading carrier*	Employee	Temp worker				
23.5	6.5	*Parking loading carrier*	Employee	Temp worker	EPT	AGV Tugger	Chain track	

E.3 Validating designs

Table E- 3: Design validation based on (process specific) constraints

Constraint	Design 1	Design 2	Design 3
GC1 - Fit within the return hall	Yes	Yes	Yes (by creating a first floor)
GC2 - Be compliant with safety regulations	Yes	Yes	Probably danger of interaction with AGV tuggers and human operators.
GC3 - Be compatible with the existing infeeding and waste processes	Yes	Yes	Yes
GC4 - Implementable in 5 years	Yes	Yes	Yes
GC5 - Accessible for employees	Yes, stairs must have different location	Yes, stairs must have different location	Yes, stairs must have different location
1C1 – Compatible with the unload docks of the return hall	Yes	Yes	No
2C1 – Compatible with the roll containers, thermos, RIC's and bread dollies, Hoogvliet is currently using.	Yes	Yes	Yes
3C1 – Compatible with the roll containers, thermos, RIC's and bread dollies, Hoogvliet is currently using.	Yes	Yes	Yes
4C1 – Able to identify the different types of bread	Yes, but probably more failures	Yes	Yes
9C1 – Able to store roll container with e-commerce bags and crates	Yes	Yes	Yes
10C1 – Able to store roll container with flower racks	Yes	Yes	Yes
11C1 - Able to store full roll containers	Yes	Yes	Yes
11C2 – Able to store empty pallets	Yes	Yes	Yes
11C3 – Able to sort all different types of CBL crates	Yes	Yes	Depends on automated sorting machine
11C4 – Able to store full pallets with CBL crates	Yes	Yes, if the height of the pallet exceeds not the storage height.	Yes
11C5 – Able to label each pallet with CBL crates	Yes	Yes	Yes
12C1 - Able to store full roll containers	Yes	Yes	Yes
12C2 – Able to store empty pallets	Yes	Yes	Yes
12C3 – Able to sort beer crates in product range Hoogvliet	Yes	Yes	Depends on automated sorting machine

12C4 – Able to store full pallets with beer crates	Yes	Yes	Yes
12C5 – Able to label each pallet with beer crates	Yes	Yes	Yes
13C1 - Able to store empty thermos	Yes	Yes	Yes
14C1 - Able to store RIC's	Yes	Yes	Yes
15C1 - Able to store dolly's with bread crates	Yes	Yes	Yes
16C1 - Able to store empty pallets	Yes	Yes	Yes
21C1 - Able to store roll containers with non-food returns	Yes, preference: directly cross-dock	Yes, preference: directly cross-dock	Yes, preference: directly cross-dock

E.4 Quantities per solution and investment cost per design

Table E- 4: Quantities per solutions and investment costs per design - scenario 0

Scenario 0	Current lay-out	Design 1	Design 2	Design 3a	Design 3b	
Joloda Moving Floor	0	0	0	3	3	Amount of Joloda Moving Floors
Conveyor belt	0	40	15	70	0	Conveyor belt meters
Pallet EPT	0	0	0	0	0	Amount of Pallet EPT's*
Reach EPT	0	0	0	0	0	Amount of Reach EPT's**
AGV Tugger	0	0	0	15	15	Amount of AGV Tuggers
Chain track	0	40	75	100	100	Chain track meters
CBL crates sorter	0	0	0	1	1	Amount of CBL crate sorters
CBL stacker	0	0	0	1	2	Amount of CBL stackers
Beer crates sorter	0	0	0	0	1	Amount of Beer crate sorters
Tilt table	0	2	2	7	7	Amount of tilt tables
Additional floor	0	0	0	800	800	Amount of square meters
*: current amount is 3 pallet EPT's	**€ -**	**€ 54.800**	**€ 78.950**	**€ 2.361.000**	**€ 4.431.200**	**Total investment costs**
**: current amount is 2 reach EPT's						

F. Modeling designs

F.1 Input computations

Table F- 1: Share per entity group - Current and future situation

Type	Entity	Share per loading carrier	Total per day	Per hour	Per cluster	Cluster Share
Foil	A	0,4	82	8	232	32
Orange peels	A	0,7	137	14		
Bio waste	A	0,9	191	19		
Old bread	A	2,0	410	41		
Residual waste	A	2,2	444	44		
Carton	A	5,2	1059	106		
(Bread) dolly	B	2,0	410	41	41	6
Flower racks	C	0,3	68	7	48	6
E-commerce	C	0,5	103	10		
Big bags	C	1,5	308	31		
Thermo	D	3,5	718	72	72	10
Folded RC	E	8,0	1640	164	164	22
DPS	F	0,8	164	16	42	6
EPS	F	1,2	239	24		
CBL	F	4,8	984	98		
Returns	G	0,1	21	2	2	1(uprounded)
RIC's	H	0,7	144	14	14	2
Beer	I	1,2	253	25	25	3,4

Table F- 2: Three arrival rates with loading carriers per hour - Current situation

Time	Arrival 1	Arrival 2	Arrival 3
06:30	213	143	161
06:45	116	65	110
07:00	303	270	361
07:15	243	244	242
07:30	581	600	352
07:45	447	594	650
08:00	1198	1477	1941
08:15	1511	1092	1546
08:30	1067	1086	1058
08:45	517	396	519
09:00	600	384	504
09:15	668	678	546
09:30	752	581	472
09:45	385	380	452
10:00	604	857	995
10:15	698	658	457
10:30	467	475	641
10:45	660	501	833
11:00	554	776	520
11:15	858	708	698
11:30	1370	1106	1219

11:45	503	777	621
12:00	621	980	740
12:15	592	556	521
12:30	896	919	841
12:45	763	617	807
13:00	579	500	478
13:15	639	662	543
13:30	883	644	582
13:45	998	743	986
14:00	906	961	823
14:15	559	741	648
14:30	495	471	502
14:45	550	521	649
15:00	759	626	857
15:15	661	635	371
15:30	664	463	461
15:45	517	590	473
16:00	460	557	607
16:15	630	616	434
16:30	876	905	760
16:45	343	604	554
17:00	472	270	283
17:15	269	337	414
17:30	310	266	361
17:45	285	244	252
18:00	189	190	162
18:15	185	143	168
18:30	271	208	177
18:45	54	45	52
19:00	45	63	38
19:15	110	120	94
19:30	29	26	34
19:45	21	19	21

Table F- 3: Average amount of empty pallets and waste boxes per hour (Hoogvliet measurement week 2, 2022)

Tijd	Empty pallets / hour	Waste boxes / hour
0:00	73	0,4
01:00	51	0,6
02:00	43	0,7
03:00	66	0,4
04:00	54	1,0
05:00	39	0,7
06:00	47	0,1
07:00	54	1,0
08:00	60	0,4
09:00	36	0,7

10:00	30	0,6
11:00	44	0,6
12:00	39	0,6
13:00	26	0,1
14:00	13	0,1
15:00	14	0,0
16:00	13	0,3
17:00	16	0,1
18:00	53	0,0
19:00	13	0,3
20:00	29	0,0
21:00	44	0,1
22:00	129	1,1
23:00	67	0,9

F.2 Throughput computations

Table F- 4: Server names, process times and amount of servers - Current situation

Servers	*Random triangular (low, mode, high) minutes*	*servers*
Dock1	0,17; 0,19; 0,21	1*
Dock2	0,17; 0,19; 0,21	1*
Dock3	0,17; 0,19; 0,21	1*
InfeedCBL	0,81; 0,9; 0,99	1
InfeedRC1	0,68; 0,75; 0,83	1
InfeedRC2	0,68; 0,75; 0,83	1
InfeedRC3	0,68; 0,75; 0,83	1
InfeedRC4	0,68; 0,75; 0,83	1
InfeedT1	0,6; 0,67; 0,73	1
InfeedT2	0,6; 0,67; 0,73	1
PalletSort	2,7; 3; 3,3	1
Sorting_Beer_FM	0,75; 0,83; 0,92	1
Sorting_Beer_SM	3,7; 4,1; 4,5	1
Sorting_CBL	0,98; 1,08; 1,19	3*
Waste_processing	0,25; 0,28; 0,31	2*

**: during peak hours, server switch: 1 server for waste processing and sorting CBL, 2 servers for unloading dock 1,2,3*

The infeed of the bread crates is fixed on 30 seconds per entity, which is done by a worker.

F.3 Output validation – Required hours

After several iterations, the outcome of the current situation is as shown in Table F- 5: Required hours per worker, vehicle and server - Current situation. The required hours are computed by (1-(average TimeIdle of run 1-3)) * 24 hours of simulation. This is also why the idle time is quite high, because there are almost no employees working by night.

Table F- 5: Required hours per worker, vehicle and server - Current situation

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	50,7%	52,0%	49,9%	11,8	
Workers2_1	1,3	2	52,5%	53,4%	52,5%	11,3	
Workers2_2	1,3	2	53,5%	54,9%	54,5%	11,0	
Workers2_3	1,3	2	54,6%	55,6%	56,3%	10,7	
Workers2_4	1,3	2	56,2%	55,8%	56,6%	10,5	
Workers2_5	1,3	2	56,4%	57,7%	59,4%	10,1	
CBL Worker	1,3	4	52,2%	52,5%	53,2%	11,4	
Pallet_EPT1	1,2	10	61,1%	61,9%	63,5%	9,1	
Pallet_EPT2	1,2	10	65,3%	65,2%	64,3%	8,4	
Pallet_EPT3	1,2	10	68,7%	68,3%	68,8%	7,5	
Reach1	1,5	1	54,2%	55,4%	56,1%	10,7	
Reach2	1,5	1	55,5%	58,0%	56,0%	10,4	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	**: Average amount of servers*
Dock1	0,17; 0,19; 0,21	1*	65,2%	64,8%	63,8%	9,2	1,08
Dock2	0,17; 0,19; 0,21	1*	64,6%	64,3%	64,7%	9,2	1,08
Dock3	0,17; 0,19; 0,21	1*	64,9%	64,6%	66,7%	9,0	1,08
InfeedCBL	0,81; 0,9; 0,99	1	64,8%	61,5%	63,3%	8,8	1,00
InfeedRC1	0,68; 0,75; 0,83	1	57,9%	58,4%	58,6%	10,0	1,00
InfeedRC2	0,68; 0,75; 0,83	1	57,5%	59,2%	59,2%	9,9	1,00
InfeedRC3	0,68; 0,75; 0,83	1	57,9%	58,5%	58,9%	10,0	1,00
InfeedRC4	0,68; 0,75; 0,83	1	58,1%	58,3%	58,0%	10,0	1,00
InfeedT1	0,6; 0,67; 0,73	1	82,3%	83,3%	84,3%	4,0	1,00
InfeedT2	0,6; 0,67; 0,73	1	82,7%	83,4%	83,3%	4,1	1,00
PalletSort	2,7; 3; 3,3	1	79,1%	72,2%	76,0%	5,8	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	89,6%	91,8%	90,3%	2,3	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	1	57,5%	59,5%	60,0%	9,8	1,00
Sorting_CBL	0,98; 1,08; 1,19	3*	57,5%	59,5%	60,0%	27,9	2,83
Waste_processing	0,25; 0,28; 0,31	2*	66,7%	67,1%	66,4%	15,3	1,92

The *unloading* hours can be derived from the servers 'Dock1', 'Dock2', 'Dock3' and result in:

$$9.2 + 9.2 + 9.0 = 27 \; required \; unloading \; hours$$

All hours of workers and vehicles can be categorized as '*Transport and loading*':

$$11.8 + 11.3 + 11.0 + 10.7 + 10.5 + 10.1 + 11.4 + 9.1 + 8.4 + 7.5 + 10.7 + 10.4 = 123 \; required \; transport \; hours$$

The resulting servers are categorized as '*Processing'*:

$$8.8 + 10.0 + 9.9 + 10.0 + 10.0 + 4.0 + 4.1 + 5.8 + 2.3 + 9.8 + 27.9 + 15.3 = 118 \; required \; processing \; hours$$

F.4 Output validation – Max queue length inbound

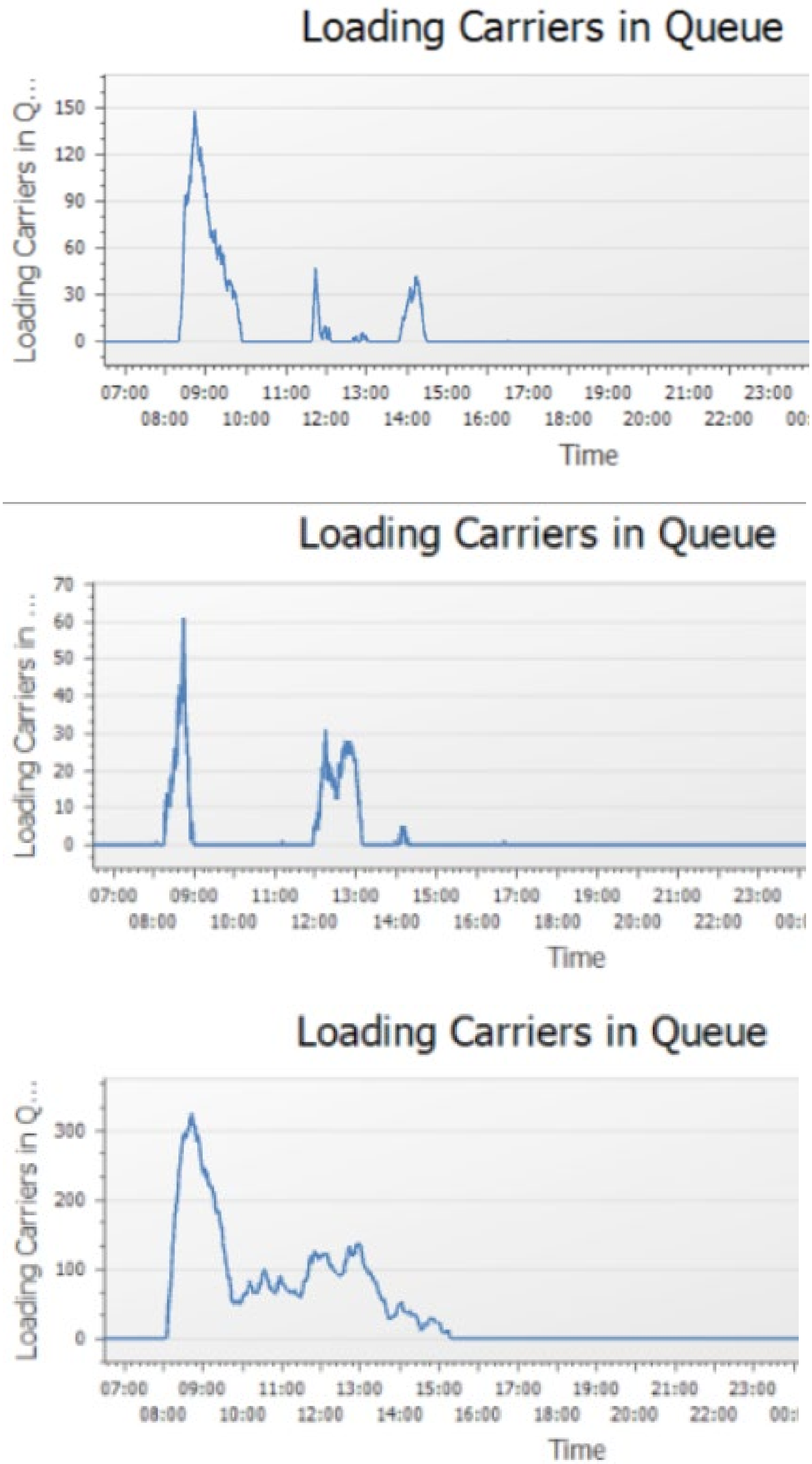


Figure F- 1: Queue length of 'inbounddocks' during arrival 1, 2, 3 - Current situation

F.5 Quantities per solution and additional investment costs per scenario

Table F- 6: Quantities per solutions and additional investment costs per design - scenario 1

Scenario 1	Current layout	Design 1	Design 2	Design 3a	Design 3b	
Joloda Moving Floor	0	0	0	4	4	Amount of Joloda Moving Floors
Conveyor belt	0	60	22,5	70	0	Conveyor belt meters
Pallet EPT	1	1	1	1	1	Additional amount of Pallet EPT's
Reach EPT	1	1	1	1	1	Additional amount of Reach EPT's
AGV Tugger	0	0	0	15	15	Amount of AGV Tuggers
Chain track	0	40	75	100	100	Chain track meters
CBL crates sorter	0	0	0	1	1	Amount of CBL crate sorters
CBL stacker	0	0	0	1	2	Amount of CBL stackers
Beer crates sorter	0	0	0	0	1	Amount of Beer crate sorters
Tilt table	0	3	3	7	7	Amount of tilt tables
Additional floor	0	0	0	800	800	Amount of square meters
	€ 18.800	**€ 66.400**	**€ 88.800**	**€ 2.386.000**	**€ 4.456.200**	**Total investment costs (difference with current layout)**

Table F- 7: Quantities per solutions and additional investment costs per design - scenario 2

Scenario 2	Current layout	Design 1	Design 2	Design 3a	Design 3b	
Joloda Moving Floor	0	0	0	4	4	Amount of Joloda Moving Floors
Conveyor belt	0	80	30	70	0	Conveyor belt meters
Pallet EPT	2	2	2	2	2	Additional amount of Pallet EPT's
Reach EPT	2	2	2	2	2	Additional amount of Reach EPT's
AGV Tugger	0	0	0	15	15	Amount of AGV Tuggers
Chain track	0	40	75	100	100	Chain track meters
CBL crates sorter	0	0	0	1	1	Amount of CBL crate sorters
CBL stacker	0	0	0	1	2	Amount of CBL stackers
Beer crates sorter	0	0	0	0	1	Amount of Beer crate sorters

Tilt table	0	4	4	7	7	Amount of tilt tables
Additional floor	0	0	0	800	800	Amount of square meters
	€ 37.600	**€ 78.000**	**€ 98.650**	**€ 2.386.000**	**€ 4.456.200**	**Total investment costs (difference with current layout)**

Table F- 8: Quantities per solutions and additional investment costs per design - scenario 3

Scenario 3	Current layout	Design 1	Design 2	Design 3a	Design 3b	
Joloda Moving Floor	0	0	0	4	4	Amount of Joloda Moving Floors
Conveyor belt	0	100	37,5	70	0	Conveyor belt meters
Pallet EPT	3	3	3	3	3	Additional amount of Pallet EPT's
Reach EPT	3	3	3	3	3	Additional amount of Reach EPT's
AGV Tugger	0	0	0	15	15	Amount of AGV Tuggers
Chain track	0	40	75	100	100	Chain track meters
CBL crates sorter	0	0	0	1	1	Amount of CBL crate sorters
CBL stacker	0	0	0	1	2	Amount of CBL stackers
Beer crates sorter	0	0	0	0	1	Amount of Beer crate sorters
Tilt table	0	5	5	7	7	Amount of tilt tables
Additional floor	0	0	0	800	800	Amount of square meters
	€ 56.400	**€ 89.600**	**€ 108.500**	**€ 2.386.000**	**€ 4.456.200**	**Total investment costs (difference with current layout)**

F.6 Capacity constraints per scenario

Table F- 9: Capacity adjustment per server per scenario

Object	Design	Current volume	Scenario 1	Scenario 2	Scenario 3
Workers	Current layout	7,0	10,0	14,0	17,0
Workers	Design 1	7,0	10,0	14,0	17,0
Workers	Design 2	7,0	10,0	14,0	17,0
Workers	Design 3a	6,0	9,0	12,0	15,0
Workers	Design 3b	6,0	9,0	12,0	15,0
Pallet_EPT's	Current layout	3,0	4,0	5,0	6,0
Pallet_EPT's	Design 1	3,0	4,0	5,0	6,0
Pallet_EPT's	Design 2	3,0	4,0	5,0	6,0
Pallet_EPT's	Design 3a	3,0	4,0	5,0	6,0
Pallet_EPT's	Design 3b	3,0	4,0	5,0	6,0
Reach_EPT's	Current layout	2,0	3,0	4,0	5,0
Reach_EPT's	Design 1	2,0	3,0	4,0	5,0
Reach_EPT's	Design 2	2,0	3,0	4,0	5,0
Reach_EPT's	Design 3a	2,0	3,0	4,0	5,0
Reach_EPT's	Design 3b	2,0	3,0	4,0	5,0
AGV's	Design 3a	15,0	15,0	15,0	15,0
AGV's	Design 3b	15,0	15,0	15,0	15,0
Dock servers	Current layout	3,3	5,0	7,0	8,0
Dock servers	Design 1	3,3	5,0	7,0	8,0
Dock servers	Design 2	3,3	5,0	7,0	8,0
Dock servers	Design 3a	3* automated	3* automated	4* automated	4* automated
Dock servers	Design 3b	3* automated	3* automated	4* automated	4* automated
Infeed points RC	All	4,0	6,0	6,0	6,0
Infeed points Thermo	All	2,0	2,0	2,0	2,0
PalletSort	Current layout	1,0	1,0	2,0	2,0
PalletSort	Design 1	1,0	1,0	2,0	2,0
PalletSort	Design 2	1,0	1,0	2,0	2,0
PalletSort	Design 3a	1,0	1,0	2,0	2,0
PalletSort	Design 3b	1,0	1,0	2,0	2,0
SortingBeerFM	Current layout	1,0	1,0	1,0	1,0
SortingBeerFM	Design 1	1,0	1,0	1,0	1,0
SortingBeerFM	Design 2	1,0	1,0	1,0	1,0
SortingBeerFM	Design 3a	1,0	1,0	1,0	1,0
SortingBeerFM	Design 3b	1* automated	1* automated	1* automated	1* automated
SortingBeerSM	Current layout	1,0	1,0	2,0	2,0
SortingBeerSM	Design 1	1,0	1,0	2,0	2,0
SortingBeerSM	Design 2	1,0	1,0	2,0	2,0
SortingBeerSM	Design 3a	1,0	1,0	2,0	2,0
SortingBeerSM	Design 3b	1* automated	1* automated	1* automated	1* automated
SortingCBL	Current layout	2,8	4,0	5,0	7,0
SortingCBL	Design 1	2,8	4,0	5,0	7,0
SortingCBL	Design 2	2,8	4,0	5,0	7,0

SortingCBL	Design 3a	1* automated	1* automated	1* automated	1* automated
SortingCBL	Design 3b	1* automated	1* automated	1* automated	1* automated
InfeedCBL	Current layout	1,0	1,0	2,0	2,0
InfeedCBL	Design 1	1,0	1,0	2,0	2,0
InfeedCBL	Design 2	1,0	1,0	2,0	2,0
InfeedCBL	Design 3a	1* automated	1* automated	1* automated	1* automated
InfeedCBL	Design 3b	1* automated	1* automated	1* automated	1* automated
WasteProcessing	Current layout	1,9	3,0	4,0	5,0
WasteProcessing	Design 1	1,9	3,0	4,0	5,0
WasteProcessing	Design 2	1,9	3,0	4,0	5,0
WasteProcessing	Design 3a	2,0	2,0	2,0	2,0
WasteProcessing	Design 3b	2,0	2,0	2,0	2,0

G. Simulation Results – Required hours

G.1 Scenario 0

Orange: transport + loading time; blue: unloading time; grey: processing time

Current layout

Table G- 1: Required hours - Current layout - Scenario 0

Type	**Processing time**	**Units per time**	**TimeIdle 1st run**	**TimeIdle 2nd run**	**TimeIdle 3rd run**	**Required hours**	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	50,7%	52,0%	49,9%	11,8	
Workers2_1	1,3	2	52,5%	53,4%	52,5%	11,3	
Workers2_2	1,3	2	53,5%	54,9%	54,5%	11,0	
Workers2_3	1,3	2	54,6%	55,6%	56,3%	10,7	
Workers2_4	1,3	2	56,2%	55,8%	56,6%	10,5	
Workers2_5	1,3	2	56,4%	57,7%	59,4%	10,1	
CBL Worker	1,3	4	52,2%	52,5%	53,2%	11,4	
Pallet_EPT1	1,2	10	61,1%	61,9%	63,5%	9,1	
Pallet_EPT2	1,2	10	65,3%	65,2%	64,3%	8,4	
Pallet_EPT3	1,2	10	68,7%	68,3%	68,8%	7,5	
Reach1	1,5	1	54,2%	55,4%	56,1%	10,7	
Reach2	1,5	1	55,5%	58,0%	56,0%	10,4	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	1*	65,2%	64,8%	63,8%	9,2	1,08
Dock2	0,17; 0,19; 0,21	1*	64,6%	64,3%	64,7%	9,2	1,08
Dock3	0,17; 0,19; 0,21	1*	64,9%	64,6%	66,7%	9,0	1,08
InfeedCBL	0,81; 0,9; 0,99	1	64,8%	61,5%	63,3%	8,8	1,00
InfeedRC1	0,68; 0,75; 0,83	1	57,9%	58,4%	58,6%	10,0	1,00
InfeedRC2	0,68; 0,75; 0,83	1	57,5%	59,2%	59,2%	9,9	1,00
InfeedRC3	0,68; 0,75; 0,83	1	57,9%	58,5%	58,9%	10,0	1,00
InfeedRC4	0,68; 0,75; 0,83	1	58,1%	58,3%	58,0%	10,0	1,00
InfeedT1	0,6; 0,67; 0,73	1	82,3%	83,3%	84,3%	4,0	1,00
InfeedT2	0,6; 0,67; 0,73	1	82,7%	83,4%	83,3%	4,1	1,00
PalletSort	2,7; 3; 3,3	1	79,1%	72,2%	76,0%	5,8	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	89,6%	91,8%	90,3%	2,3	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	1	57,5%	59,5%	60,0%	9,8	1,00
Sorting_CBL	0,98; 1,08; 1,19	3*	57,5%	59,5%	60,0%	27,9	2,83
Waste_processing	0,25; 0,28; 0,31	2*	66,7%	67,1%	66,4%	15,3	1,92

Design 1 – Split waste and packaging

Table G- 2: Required hours - Design 1 - Scenario 0

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	57,1%	59,1%	56,5%	10,2	
Workers2_1	1,3	2	60,8%	64,5%	61,9%	9,0	
Workers2_2	1,3	2	62,3%	64,9%	62,5%	8,8	
Workers2_3	1,3	2	63,3%	64,3%	63,6%	8,7	
Workers2_4	1,3	2	63,6%	66,3%	65,1%	8,4	
Workers2_5	1,3	2	65,8%	66,4%	66,0%	8,1	
CBL Worker	1,3	4	59,0%	62,3%	59,8%	9,5	
Pallet_EPT1	1,2	10	55,7%	56,1%	55,5%	10,6	
Pallet_EPT2	1,2	10	57,8%	59,7%	57,6%	10,0	
Pallet_EPT3	1,2	10	60,9%	63,6%	61,2%	9,1	
Reach1	1,5	1	49,9%	52,7%	49,6%	11,8	
Reach2	1,5	1	51,9%	52,9%	52,9%	11,4	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	1*	68,1%	68,1%	67,5%	8,3	1,08
Dock2	0,17; 0,19; 0,21	1*	67,0%	68,3%	67,4%	8,4	1,08
Dock3	0,17; 0,19; 0,21	1*	67,7%	69,9%	66,9%	8,3	1,08
InfeedCBL	0,81; 0,9; 0,99	1	60,7%	67,5%	60,6%	8,9	1,00
InfeedRC1	0,68; 0,75; 0,83	1	57,9%	59,3%	58,5%	9,9	1,00
InfeedRC2	0,68; 0,75; 0,83	1	59,0%	58,6%	57,9%	10,0	1,00
InfeedRC3	0,68; 0,75; 0,83	1	57,3%	60,5%	58,1%	9,9	1,00
InfeedRC4	0,68; 0,75; 0,83	1	57,4%	59,9%	58,0%	10,0	1,00
InfeedT1	0,6; 0,67; 0,73	1	82,2%	82,8%	84,2%	4,1	1,00
InfeedT2	0,6; 0,67; 0,73	1	83,3%	82,3%	81,1%	4,3	1,00
PalletSort	2,7; 3; 3,3	1	68,3%	70,1%	67,1%	7,6	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	90,2%	90,6%	91,6%	2,2	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	1	57,4%	61,9%	56,2%	10,0	1,00
Sorting_CBL	0,98; 1,08; 1,19	3*	53,9%	55,6%	53,5%	31,0	2,83
Waste_processing	0,23; 0,252; 0,28	2*	67,0%	68,8%	68,3%	14,7	1,92

Design 2 – Carousel

Table G- 3: Required hours - Design 2 - Scenario 0

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	56,2%	56,6%	55,4%	10,5	
Workers2_1	1,3	2	58,9%	62,0%	59,7%	9,6	
Workers2_2	1,3	2	60,0%	61,3%	59,9%	9,5	
Workers2_3	1,3	2	60,1%	62,4%	60,4%	9,4	
Workers2_4	1,3	2	61,4%	62,2%	61,4%	9,2	
Workers2_5	1,3	2	60,9%	62,6%	61,6%	9,2	
CBL Worker	1,3	4	53,4%	54,2%	53,6%	11,1	
Pallet_EPT1	1,2	10	86,7%	91,3%	89,9%	2,6	
Pallet_EPT2	1,2	10	95,9%	91,5%	93,3%	1,5	
Pallet_EPT3	1,2	10	97,0%	97,2%	97,1%	0,7	
Reach1	1,5	1	52,9%	49,4%	51,4%	11,7	
Reach2	1,5	1	54,3%	51,1%	52,7%	11,3	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	1*	65,7%	67,5%	65,9%	8,7	1,08
Dock2	0,17; 0,19; 0,21	1*	67,2%	67,8%	65,9%	8,6	1,08
Dock3	0,17; 0,19; 0,21	1*	65,8%	68,7%	66,5%	8,6	1,08
InfeedCBL	0,81; 0,9; 0,99	1	60,8%	63,4%	62,3%	9,1	1,00
InfeedRC1	0,68; 0,75; 0,83	1	58,2%	58,4%	57,5%	10,1	1,00
InfeedRC2	0,68; 0,75; 0,83	1	58,3%	59,1%	58,7%	9,9	1,00
InfeedRC3	0,68; 0,75; 0,83	1	57,9%	58,9%	57,8%	10,0	1,00
InfeedRC4	0,68; 0,75; 0,83	1	57,4%	57,9%	58,7%	10,1	1,00
InfeedT1	0,6; 0,67; 0,73	1	82,7%	84,1%	83,2%	4,0	1,00
InfeedT2	0,6; 0,67; 0,73	1	82,6%	83,2%	82,5%	4,1	1,00
PalletSort	2,7; 3; 3,3	1	71,4%	68,3%	69,7%	7,2	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	92,6%	92,4%	90,0%	2,0	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	1	56,1%	55,3%	61,1%	10,2	1,00
Sorting_CBL	0,98; 1,08; 1,19	3*	54,2%	55,1%	54,8%	30,8	2,83
Waste_processing	0,23; 0,252; 0,28	2*	66,2%	66,4%	66,0%	15,6	1,92

Design 3a – Completely automated (manual beer sorting)

Table G- 4: Required hours - Design 3a - Scenario 0

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	76,6%	78,7%	77,0%	5,4	
Workers2_1	1,3	2	75,5%	76,3%	73,8%	5,9	
Workers2_2	1,3	2	79,4%	80,7%	78,8%	4,9	
Workers2_3	1,3	2	83,4%	84,1%	82,4%	4,0	
Workers2_4	1,3	2	88,4%	89,3%	87,0%	2,8	
Workers2_5	1,3	2	92,4%	94,6%	91,3%	1,7	
Pallet_EPT1	1,2	10	97,1%	97,1%	97,7%	0,6	
Pallet_EPT2	1,2	10	97,1%	97,1%	97,7%	0,6	
Pallet_EPT3	1,2	10	98,6%	98,6%	98,8%	0,3	
Reach1	1,5	1	62,0%	60,8%	63,1%	9,1	
Reach2	1,5	1	63,1%	63,1%	65,7%	8,6	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,075; 0,083; 0,092	1	84,6%	85,9%	83,4%	*automated*	1,00
Dock2	0,075; 0,083; 0,092	1	85,0%	84,9%	83,5%	*automated*	1,00
Dock3	0,075; 0,083; 0,092	1	85,1%	86,2%	83,7%	*automated*	1,00
EnterAGV	0,12; 0,17; 0,22	4	63,8%	64,7%	64,7%	34,2	4,00
EnterBeer	0,075; 0,083; 0,092	1	98,2%	98,2%	98,2%	0,4	1,00
EnterCBL	0,075; 0,083; 0,092	1	92,3%	92,3%	92,2%	1,9	1,00
InfeedCBL	0,81; 0,9; 0,99	1	58,7%	59,5%	57,5%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	57,7%	58,6%	58,7%	10,0	1,00
InfeedRC2	0,68; 0,75; 0,83	1	56,9%	57,8%	57,2%	10,2	1,00
InfeedRC3	0,68; 0,75; 0,83	1	58,8%	59,1%	57,8%	9,9	1,00
InfeedRC4	0,68; 0,75; 0,83	1	57,3%	57,7%	58,1%	10,2	1,00
InfeedT1	0,6; 0,67; 0,73	1	83,0%	83,4%	83,7%	4,0	1,00
InfeedT2	0,6; 0,67; 0,73	1	82,0%	82,8%	82,7%	4,2	1,00
PalletSort	2,7; 3; 3,3	1	69,5%	68,5%	70,2%	7,3	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	90,5%	91,5%	90,5%	2,2	1,00
Sorting_Beer_SM	1,8; 2; 2,2	1	79,7%	78,3%	79,3%	5,0	1,00
Sorting_CBL	0,09	1	92,1%	92,1%	92,0%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	78,5%	79,2%	79,7%	10,0	2,00

Design 3b – Completely automated

Table G- 5: Required hours - Design 3b - Scenario 0

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	77,5%	81,7%	76,3%	5,2	
Workers2_1	1,3	2	75,2%	76,7%	73,7%	6,0	
Workers2_2	1,3	2	78,7%	81,1%	79,2%	4,9	
Workers2_3	1,3	2	83,5%	84,9%	82,7%	3,9	
Workers2_4	1,3	2	88,5%	90,0%	88,0%	2,7	
Workers2_5	1,3	2	92,6%	95,1%	91,4%	1,7	
Pallet_EPT1	1,2	10	97,1%	97,1%	97,7%	0,6	
Pallet_EPT2	1,2	10	97,1%	97,1%	97,7%	0,6	
Pallet_EPT3	1,2	10	98,6%	98,6%	98,8%	0,3	
Reach1	1,5	1	62,6%	62,2%	59,9%	9,2	
Reach2	1,5	1	64,4%	65,7%	61,2%	8,7	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,075; 0,083; 0,092	1	84,6%	86,2%	83,8%	*automated*	1
Dock2	0,075; 0,083; 0,092	1	84,9%	85,5%	83,9%	*automated*	1
Dock3	0,075; 0,083; 0,092	1	84,4%	86,1%	83,9%	*automated*	1
EnterAGV	0,12; 0,17; 0,22	4	63,9%	65,2%	64,2%	34,1	4,00
EnterBeer	0,075; 0,083; 0,092	1	98,3%	98,3%	98,2%	0,4	1,00
EnterCBL	0,075; 0,083; 0,092	1	92,1%	92,5%	92,4%	1,8	1,00
InfeedCBL	0,81; 0,9; 0,99	1	52,6%	55,6%	53,3%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	57,7%	59,9%	57,9%	10,0	1,00
InfeedRC2	0,68; 0,75; 0,83	1	59,2%	57,6%	58,2%	10,0	1,00
InfeedRC3	0,68; 0,75; 0,83	1	57,6%	59,1%	58,5%	10,0	1,00
InfeedRC4	0,68; 0,75; 0,83	1	57,4%	58,8%	59,2%	10,0	1,00
InfeedT1	0,6; 0,67; 0,73	1	82,9%	82,9%	83,1%	4,1	1,00
InfeedT2	0,6; 0,67; 0,73	1	82,8%	83,3%	81,5%	4,2	1,00
PalletSort	2,7; 3; 3,3	1	69,6%	70,3%	66,6%	7,5	1,00
Sorting_Beer	0,05	1	91,9%	92,3%	92,2%	*automated*	1,00
Sorting_CBL	0,09	1	99,0%	99,0%	98,9%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	79,5%	79,1%	79,4%	9,9	2,00

G.2 Scenario 1

Orange: transport + loading time; blue: unloading time; grey: processing time

Current layout

Table G- 6: Required hours – Current layout - Scenario 1

Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	54,1%	54,8%	54,3%	10,9	
Workers2_1	1,3	2	56,7%	57,5%	55,5%	10,4	
Workers2_2	1,3	2	56,7%	56,8%	57,3%	10,3	
Workers2_3	1,3	2	56,2%	58,8%	57,6%	10,2	
Workers2_4	1,3	2	57,4%	58,5%	56,5%	10,2	
Workers2_5	1,3	2	58,5%	60,4%	58,4%	9,8	
Workers2_6	1,3	2	57,5%	59,7%	57,0%	10,1	
Workers2_7	1,3	2	58,1%	61,1%	59,2%	9,7	
Workers2_8	1,3	2	59,6%	60,3%	58,0%	9,8	
CBL Worker	1,3	4	46,9%	46,2%	49,7%	12,6	
Pallet_EPT1	1,2	10	57,6%	57,1%	58,6%	10,1	
Pallet_EPT2	1,2	10	60,8%	60,8%	62,1%	9,3	
Pallet_EPT3	1,2	10	63,0%	63,6%	63,3%	8,8	
Pallet_EPT4	1,2	10	67,7%	68,3%	64,3%	8,0	
Reach1	1,5	1	57,0%	55,1%	55,9%	10,6	
Reach2	1,5	1	59,0%	55,4%	59,1%	10,1	
Reach3	1,5	1	59,1%	56,5%	60,0%	9,9	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	1	58,3%	61,8%	58,8%	9,7	1,00
Dock2	0,17; 0,19; 0,21	2	63,4%	68,5%	64,8%	16,5	2,00
Dock3	0,17; 0,19; 0,21	1	60,0%	62,2%	59,5%	9,5	1,00
Dock4	0,17; 0,19; 0,21	1	60,6%	62,0%	60,1%	9,4	1,00
InfeedCBL	0,81; 0,9; 0,99	1	60,6%	62,0%	60,1%	9,4	1,00
InfeedRC1	0,68; 0,75; 0,83	1	57,1%	58,9%	57,1%	10,2	1,00
InfeedRC2	0,68; 0,75; 0,83	1	56,8%	57,2%	57,2%	10,3	1,00
InfeedRC3	0,68; 0,75; 0,83	1	57,8%	56,1%	58,4%	10,2	1,00
InfeedRC4	0,68; 0,75; 0,83	1	57,4%	58,0%	57,9%	10,1	1,00
InfeedRC5	0,68; 0,75; 0,83	1	59,0%	60,5%	60,3%	9,6	1,00
InfeedRC6	0,68; 0,75; 0,83	1	61,6%	59,9%	59,2%	9,5	1,00
InfeedT1	0,6; 0,67; 0,73	1	59,0%	60,5%	60,3%	9,6	1,00
InfeedT2	0,6; 0,67; 0,73	1	74,6%	75,2%	74,7%	6,0	1,00
PalletSort	2,7; 3; 3,3	1	69,5%	62,8%	66,4%	8,1	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	86,7%	89,4%	87,6%	2,9	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	1	36,9%	31,9%	39,4%	15,3	1,00
Sorting_CBL	0,98; 1,08; 1,19	4	51,6%	53,0%	53,0%	45,6	4,00
Waste_processing	0,25; 0,28; 0,31	3	63,6%	63,2%	62,9%	26,5	3,00

Design 1 – Split waste and packaging

Table G- 7: Required hours - Design 1 - Scenario 1

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	53,7%	55,2%	56,9%	10,7	
Workers2_1	1,3	2	61,3%	61,2%	61,0%	9,3	
Workers2_2	1,3	2	63,1%	60,8%	62,9%	9,1	
Workers2_3	1,3	2	63,7%	61,9%	63,6%	8,9	
Workers2_4	1,3	2	63,2%	63,9%	60,3%	9,0	
Workers2_5	1,3	2	63,7%	64,0%	63,4%	8,7	
Workers2_6	1,3	2	63,2%	63,0%	61,4%	9,0	
Workers2_7	1,3	2	64,2%	64,4%	64,1%	8,6	
Workers2_8	1,3	2	65,3%	64,0%	65,3%	8,4	
CBL Worker	1,3	4	57,5%	57,2%	57,2%	10,2	
Pallet_EPT1	1,2	10	53,6%	52,4%	52,7%	11,3	
Pallet_EPT2	1,2	10	55,9%	58,4%	56,6%	10,3	
Pallet_EPT3	1,2	10	58,4%	61,5%	62,1%	9,4	
Pallet_EPT4	1,2	10	65,7%	65,4%	66,6%	8,2	
Reach1	1,5	1	55,0%	54,3%	57,6%	10,6	
Reach2	1,5	1	57,6%	57,7%	57,5%	10,2	
Reach3	1,5	1	58,8%	58,0%	58,9%	9,9	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	1	62,8%	63,8%	62,3%	8,9	1,00
Dock2	0,17; 0,19; 0,21	2	72,2%	72,9%	72,3%	13,2	2,00
Dock3	0,17; 0,19; 0,21	1	63,5%	63,6%	62,7%	8,8	1,00
Dock4	0,17; 0,19; 0,21	1	64,1%	62,8%	63,1%	8,8	1,00
InfeedCBL	0,81; 0,9; 0,99	1	44,0%	45,2%	45,1%	13,3	1,00
InfeedRC1	0,68; 0,75; 0,83	1	62,8%	62,6%	61,5%	9,0	1,00
InfeedRC2	0,68; 0,75; 0,83	1	60,0%	62,5%	60,9%	9,3	1,00
InfeedRC3	0,68; 0,75; 0,83	1	61,7%	61,8%	61,0%	9,2	1,00
InfeedRC4	0,68; 0,75; 0,83	1	61,2%	61,0%	60,2%	9,4	1,00
InfeedRC5	0,68; 0,75; 0,83	1	50,6%	53,0%	53,0%	11,5	1,00
InfeedRC6	0,68; 0,75; 0,83	1	51,9%	52,8%	51,5%	11,5	1,00
InfeedT1	0,6; 0,67; 0,73	1	74,4%	74,1%	74,8%	6,1	1,00
InfeedT2	0,6; 0,67; 0,73	1	75,5%	75,2%	75,4%	5,9	1,00
PalletSort	2,7; 3; 3,3	1	67,9%	64,4%	69,0%	7,9	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	87,0%	87,9%	87,5%	3,0	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	1	33,7%	38,5%	34,1%	15,5	1,00
Sorting_CBL	0,98; 1,08; 1,19	4	52,7%	52,8%	52,5%	45,4	4,00
Waste_processing	0,23; 0,252; 0,28	3	64,5%	66,2%	65,3%	25,0	3,00

Design 2 – Carousel

Table G- 8: Required hours - Design 2 - Scenario 1

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	52,8%	54,2%	52,4%	11,2	
Workers2_1	1,3	2	57,8%	59,8%	57,3%	10,0	
Workers2_2	1,3	2	57,7%	58,6%	58,8%	10,0	
Workers2_3	1,3	2	59,0%	57,7%	58,7%	10,0	
Workers2_4	1,3	2	58,3%	58,6%	59,0%	9,9	
Workers2_5	1,3	2	60,0%	59,6%	60,1%	9,6	
Workers2_6	1,3	2	59,8%	59,5%	60,8%	9,6	
Workers2_7	1,3	2	59,1%	60,9%	60,6%	9,5	
Workers2_8	1,3	2	60,3%	61,7%	59,9%	9,5	
CBL Worker	1,3	4	49,5%	50,3%	48,9%	12,1	
Pallet_EPT1	1,2	10	90,9%	95,1%	91,3%	1,8	
Pallet_EPT2	1,2	10	92,3%	85,6%	91,9%	2,4	
Pallet_EPT3	1,2	10	91,3%	96,2%	92,0%	1,6	
Pallet_EPT4	1,2	10	95,6%	96,5%	95,2%	1,0	
Reach1	1,5	1	56,8%	56,5%	55,7%	10,5	
Reach2	1,5	1	57,4%	58,3%	56,3%	10,3	
Reach3	1,5	1	58,0%	58,8%	56,8%	10,1	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	1	61,1%	61,7%	60,8%	9,3	1,00
Dock2	0,17; 0,19; 0,21	2	70,4%	70,3%	68,1%	14,6	2,00
Dock3	0,17; 0,19; 0,21	1	62,8%	62,5%	61,4%	9,1	1,00
Dock4	0,17; 0,19; 0,21	1	62,5%	62,2%	61,1%	9,1	1,00
InfeedCBL	0,81; 0,9; 0,99	1	43,2%	44,7%	43,5%	13,5	1,00
InfeedRC1	0,68; 0,75; 0,83	1	60,2%	61,1%	59,9%	9,5	1,00
InfeedRC2	0,68; 0,75; 0,83	1	59,3%	61,1%	60,5%	9,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	59,6%	59,9%	61,0%	9,6	1,00
InfeedRC4	0,68; 0,75; 0,83	1	59,8%	61,3%	61,0%	9,4	1,00
InfeedRC5	0,68; 0,75; 0,83	1	50,1%	51,7%	51,1%	11,8	1,00
InfeedRC6	0,68; 0,75; 0,83	1	51,6%	52,3%	50,6%	11,6	1,00
InfeedT1	0,6; 0,67; 0,73	1	75,4%	75,9%	76,6%	5,8	1,00
InfeedT2	0,6; 0,67; 0,73	1	74,4%	75,0%	75,1%	6,0	1,00
PalletSort	2,7; 3; 3,3	1	69,3%	66,7%	66,4%	7,8	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	87,5%	87,9%	87,6%	3,0	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	1	31,7%	40,7%	37,7%	15,2	1,00
Sorting_CBL	0,98; 1,08; 1,19	4	51,9%	52,3%	52,9%	45,7	4,00
Waste_processing	0,23; 0,252; 0,28	3	63,1%	63,4%	63,6%	26,4	3,00

Design 3a – Completely automated (manual beer sorting)

Table G- 9: Required hours - Design 3a - Scenario 1

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	63,4%	69,3%	63,4%	8,3	
Workers2_1	1,3	2	72,3%	74,4%	72,4%	6,5	
Workers2_2	1,3	2	74,9%	76,8%	74,6%	5,9	
Workers2_3	1,3	2	78,0%	80,5%	78,6%	5,0	
Workers2_4	1,3	2	80,5%	83,1%	81,1%	4,4	
Workers2_5	1,3	2	84,1%	86,3%	84,7%	3,6	
Workers2_6	1,3	2	87,3%	89,4%	87,1%	2,9	
Workers2_7	1,3	2	90,1%	92,1%	89,6%	2,3	
Workers2_8	1,3	2	91,7%	94,3%	91,0%	1,8	
Pallet_EPT1	1,2	10	96,0%	95,4%	96,0%	1,0	
Pallet_EPT2	1,2	10	98,0%	97,7%	98,0%	0,5	
Pallet_EPT3	1,2	10	98,0%	97,7%	98,0%	0,5	
Pallet_EPT4	1,2	10	98,0%	97,7%	98,0%	0,5	
Reach1	1,5	1	64,8%	66,5%	65,4%	8,3	
Reach2	1,5	1	68,2%	66,8%	68,0%	7,8	
Reach3	1,5	1	68,8%	69,4%	68,1%	7,5	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,075; 0,083; 0,092	1	81,0%	82,1%	80,6%	*automated*	1,00
Dock2	0,075; 0,083; 0,092	1	80,7%	82,6%	80,5%	*automated*	1,00
Dock3	0,075; 0,083; 0,092	1	81,4%	82,6%	81,0%	*automated*	1,00
Dock4	0,075; 0,083; 0,092	1	82,5%	82,5%	81,8%	*automated*	1,00
EnterAGV	0,12; 0,17; 0,22	4	82,5%	82,5%	81,8%	17,0	4,00
EnterBeer	0,075; 0,083; 0,092	1	97,6%	97,4%	97,5%	0,6	1,00
EnterCBL	0,075; 0,083; 0,092	1	88,2%	88,4%	88,0%	2,8	1,00
InfeedCBL	0,81; 0,9; 0,99	1	36,1%	36,7%	33,6%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	53,4%	55,3%	53,6%	11,0	1,00
InfeedRC2	0,68; 0,75; 0,83	1	52,8%	54,0%	53,1%	11,2	1,00
InfeedRC3	0,68; 0,75; 0,83	1	52,8%	54,0%	53,5%	11,2	1,00
InfeedRC4	0,68; 0,75; 0,83	1	52,9%	54,8%	53,1%	11,1	1,00
InfeedRC5	0,68; 0,75; 0,83	1	61,6%	61,9%	62,7%	9,1	1,00
InfeedRC6	0,68; 0,75; 0,83	1	61,0%	61,6%	62,5%	9,2	1,00
InfeedT1	0,6; 0,67; 0,73	1	61,6%	61,9%	62,7%	9,1	1,00
InfeedT2	0,6; 0,67; 0,73	1	74,6%	75,1%	75,5%	6,0	1,00
PalletSort	2,7; 3; 3,3	1	67,4%	66,9%	66,6%	7,9	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	88,4%	87,7%	87,7%	2,9	1,00
Sorting_Beer_SM	1,8; 2; 2,2	1	69,0%	66,8%	69,9%	7,5	1,00
Sorting_CBL	0,09	1	87,9%	88,1%	87,7%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	71,6%	73,2%	72,7%	13,2	2,00

Design 3b – Completely automated

Table G- 10: Required hours - Design 3b - Scenario 1

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1	1,3	2	66,1%	64,3%	65,5%	8,3	
Workers2_1	1,3	2	72,2%	74,4%	72,0%	6,5	
Workers2_2	1,3	2	75,0%	77,0%	74,6%	5,9	
Workers2_3	1,3	2	78,4%	79,2%	78,0%	5,2	
Workers2_4	1,3	2	81,6%	82,7%	80,8%	4,4	
Workers2_5	1,3	2	84,7%	85,5%	84,4%	3,6	
Workers2_6	1,3	2	87,6%	88,1%	86,5%	3,0	
Workers2_7	1,3	2	90,5%	91,1%	88,3%	2,4	
Workers2_8	1,3	2	91,9%	93,4%	90,0%	2,0	
Pallet_EPT1	1,2	10	96,0%	96,0%	96,6%	0,9	
Pallet_EPT2	1,2	10	98,0%	98,0%	98,3%	0,5	
Pallet_EPT3	1,2	10	98,0%	98,0%	98,3%	0,5	
Pallet_EPT4	1,2	10	98,0%	98,0%	98,3%	0,5	
Reach1	1,5	1	68,0%	69,8%	73,8%	7,1	
Reach2	1,5	1	69,1%	72,8%	74,9%	6,7	
Reach3	1,5	1	69,3%	75,0%	74,8%	6,5	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,075; 0,083; 0,092	1	81,3%	82,2%	80,2%	*automated*	1,00
Dock2	0,075; 0,083; 0,092	1	81,6%	81,9%	80,0%	*automated*	1,00
Dock3	0,075; 0,083; 0,092	1	81,3%	82,1%	80,8%	*automated*	1,00
Dock4	0,075; 0,083; 0,092	1	81,0%	82,6%	81,4%	*automated*	1,00
EnterAGV	0,12; 0,17; 0,22	4	81,0%	82,6%	81,4%	17,6	4,00
EnterBeer	0,075; 0,083; 0,092	1	97,6%	97,6%	97,4%	0,6	1,00
EnterCBL	0,075; 0,083; 0,092	1	88,4%	88,3%	88,6%	2,8	1,00
InfeedCBL	0,81; 0,9; 0,99	1	36,4%	36,3%	36,6%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	53,7%	55,1%	56,2%	10,8	1,00
InfeedRC2	0,68; 0,75; 0,83	1	53,0%	53,6%	53,2%	11,2	1,00
InfeedRC3	0,68; 0,75; 0,83	1	53,6%	54,3%	53,3%	11,1	1,00
InfeedRC4	0,68; 0,75; 0,83	1	53,4%	54,5%	53,1%	11,1	1,00
InfeedRC5	0,68; 0,75; 0,83	1	60,7%	61,4%	61,0%	9,4	1,00
InfeedRC6	0,68; 0,75; 0,83	1	62,3%	61,7%	62,7%	9,1	1,00
InfeedT1	0,6; 0,67; 0,73	1	60,7%	61,4%	61,0%	9,4	1,00
InfeedT2	0,6; 0,67; 0,73	1	74,1%	74,8%	74,1%	6,2	1,00
PalletSort	2,7; 3; 3,3	1	59,9%	66,8%	70,9%	8,2	1,00
Sorting_Beer	0,05	1	98,6%	98,6%	98,4%	*automated*	1,00
Sorting_CBL	0,09	1	88,1%	88,0%	88,2%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	72,1%	72,6%	72,4%	13,2	2,00

G.3 Scenario 2

Orange: transport + loading time; blue: unloading time; grey: processing time

Current layout

Table G- 11: Required hours - Current layout - Scenario 2

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	51,3%	52,9%	50,0%	11,7	
Worker1_2	1,3	2	52,5%	52,3%	50,1%	11,6	
Workers2_1	1,3	2	53,5%	55,3%	52,8%	11,1	
Workers2_2	1,3	2	59,0%	55,7%	55,4%	10,4	
Workers2_3	1,3	2	54,7%	53,1%	53,3%	11,1	
Workers2_4	1,3	2	55,6%	55,8%	53,5%	10,8	
Workers2_5	1,3	2	56,6%	57,3%	54,0%	10,6	
Workers2_6	1,3	2	54,5%	55,9%	55,4%	10,7	
Workers2_7	1,3	2	54,9%	55,0%	54,2%	10,9	
Workers2_8	1,3	2	56,6%	58,0%	54,8%	10,4	
Workers2_9	1,3	2	57,8%	55,9%	55,9%	10,4	
Workers2_10	1,3	2	57,7%	55,0%	55,2%	10,6	
CBL Worker1	1,3	4	47,0%	47,7%	46,6%	12,7	
CBL Worker2	1,3	4	47,1%	48,6%	47,4%	12,6	
Pallet_EPT1	1,2	10	47,6%	47,2%	46,3%	12,7	
Pallet_EPT2	1,2	10	48,3%	50,3%	47,9%	12,3	
Pallet_EPT3	1,2	10	49,0%	50,2%	49,5%	12,1	
Pallet_EPT4	1,2	10	50,3%	52,1%	50,8%	11,7	
Pallet_EPT5	1,2	10	52,7%	52,3%	52,2%	11,4	
Reach1	1,5	1	54,4%	55,4%	56,3%	10,7	
Reach2	1,5	1	56,4%	56,4%	56,7%	10,4	
Reach3	1,5	1	58,7%	58,2%	58,0%	10,0	
Reach4	1,5	1	58,4%	58,7%	58,9%	9,9	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	2	58,9%	59,8%	55,2%	20,2	2,00
Dock2	0,17; 0,19; 0,21	2	58,7%	59,2%	55,5%	20,3	2,00
Dock3	0,17; 0,19; 0,21	2	59,1%	59,9%	56,3%	20,0	2,00
Dock4	0,17; 0,19; 0,21	1	47,6%	48,6%	46,7%	12,6	1,00
InfeedCBL	0,81; 0,9; 0,99	2	47,6%	48,6%	46,7%	25,1	2,00
InfeedRC1	0,68; 0,75; 0,83	1	47,6%	47,9%	47,7%	12,5	1,00
InfeedRC2	0,68; 0,75; 0,83	1	48,7%	49,3%	46,3%	12,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	47,7%	48,7%	48,4%	12,4	1,00
InfeedRC4	0,68; 0,75; 0,83	1	47,7%	47,6%	48,2%	12,5	1,00
InfeedRC5	0,68; 0,75; 0,83	1	52,9%	51,8%	51,8%	11,5	1,00
InfeedRC6	0,68; 0,75; 0,83	1	50,8%	54,2%	51,7%	11,5	1,00
InfeedT1	0,6; 0,67; 0,73	1	52,9%	51,8%	51,8%	11,5	1,00
InfeedT2	0,6; 0,67; 0,73	1	65,2%	65,5%	64,1%	8,4	1,00
PalletSort	2,7; 3; 3,3	2	67,8%	66,7%	70,0%	15,3	2,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	82,2%	84,2%	84,5%	3,9	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	2	52,5%	51,7%	53,1%	22,8	2,00
Sorting_CBL	0,98; 1,08; 1,19	5	47,5%	48,9%	48,0%	62,3	5,00
Waste_processing	0,25; 0,28; 0,31	4	57,2%	57,8%	56,7%	41,1	4,00

Design 1 – Split waste and packaging

Table G- 12: Required hours - Design 1 - Scenario 2

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	54,5%	55,3%	55,0%	10,8	
Worker1_2	1,3	2	55,2%	55,9%	55,7%	10,7	
Workers2_1	1,3	2	60,2%	58,0%	57,8%	9,9	
Workers2_2	1,3	2	64,6%	62,7%	61,0%	8,9	
Workers2_3	1,3	2	58,2%	63,5%	58,2%	9,6	
Workers2_4	1,3	2	60,9%	62,3%	59,6%	9,4	
Workers2_5	1,3	2	60,0%	60,6%	58,3%	9,7	
Workers2_6	1,3	2	62,5%	58,7%	56,1%	9,8	
Workers2_7	1,3	2	60,6%	60,5%	58,0%	9,7	
Workers2_8	1,3	2	64,0%	58,5%	58,1%	9,6	
Workers2_9	1,3	2	63,4%	61,1%	60,0%	9,2	
Workers2_10	1,3	2	63,3%	64,3%	59,1%	9,1	
CBL Worker1	1,3	4	59,4%	59,1%	57,2%	9,9	
CBL Worker2	1,3	4	61,3%	59,7%	57,9%	9,7	
Pallet_EPT1	1,2	10	49,3%	50,4%	50,3%	12,0	
Pallet_EPT2	1,2	10	52,1%	52,6%	52,4%	11,4	
Pallet_EPT3	1,2	10	54,4%	55,6%	55,0%	10,8	
Pallet_EPT4	1,2	10	56,7%	58,0%	58,0%	10,2	
Pallet_EPT5	1,2	10	61,4%	61,8%	61,3%	9,2	
Reach1	1,5	1	55,7%	56,8%	58,6%	10,3	
Reach2	1,5	1	58,7%	58,6%	60,5%	9,8	
Reach3	1,5	1	58,7%	60,4%	62,6%	9,5	
Reach4	1,5	1	58,8%	61,1%	63,4%	9,3	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	2	64,3%	64,6%	61,7%	17,5	2,00
Dock2	0,17; 0,19; 0,21	2	64,3%	64,6%	60,7%	17,7	2,00
Dock3	0,17; 0,19; 0,21	2	64,7%	64,8%	60,7%	17,6	2,00
Dock4	0,17; 0,19; 0,21	1	48,8%	50,7%	49,1%	12,1	1,00
InfeedCBL	0,81; 0,9; 0,99	2	59,1%	63,7%	61,0%	18,6	2,00
InfeedRC1	0,68; 0,75; 0,83	1	51,9%	52,2%	52,8%	11,4	1,00
InfeedRC2	0,68; 0,75; 0,83	1	51,3%	52,2%	52,4%	11,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	51,9%	52,6%	52,5%	11,4	1,00
InfeedRC4	0,68; 0,75; 0,83	1	51,1%	52,6%	52,8%	11,5	1,00
InfeedRC5	0,68; 0,75; 0,83	1	40,0%	44,3%	42,6%	13,8	1,00
InfeedRC6	0,68; 0,75; 0,83	1	38,3%	43,7%	40,9%	14,2	1,00
InfeedT1	0,6; 0,67; 0,73	1	63,9%	65,9%	66,2%	8,3	1,00
InfeedT2	0,6; 0,67; 0,73	1	67,9%	65,1%	65,4%	8,1	1,00
PalletSort	2,7; 3; 3,3	2	65,7%	67,9%	69,6%	15,5	2,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	82,9%	82,9%	82,7%	4,1	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	2	54,1%	54,8%	57,1%	21,4	2,00
Sorting_CBL	0,98; 1,08; 1,19	5	47,7%	49,2%	48,9%	61,6	5,00
Waste_processing	0,23; 0,252; 0,28	4	59,3%	60,1%	60,4%	38,5	4,00

Design 2 – Carousel

Table G- 13: Required hours - Design 2 - Scenario 2

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	54,5%	54,5%	54,2%	10,9	
Worker1_2	1,3	2	54,6%	55,7%	54,4%	10,8	
Workers2_1	1,3	2	57,1%	57,9%	58,5%	10,1	
Workers2_2	1,3	2	60,8%	62,0%	60,3%	9,4	
Workers2_3	1,3	2	58,0%	59,6%	57,9%	10,0	
Workers2_4	1,3	2	59,0%	60,3%	57,1%	9,9	
Workers2_5	1,3	2	57,4%	59,9%	57,9%	10,0	
Workers2_6	1,3	2	58,5%	62,4%	57,7%	9,7	
Workers2_7	1,3	2	59,2%	60,3%	57,8%	9,8	
Workers2_8	1,3	2	59,6%	60,4%	59,7%	9,6	
Workers2_9	1,3	2	60,1%	62,2%	60,0%	9,4	
Workers2_10	1,3	2	60,8%	59,1%	60,4%	9,6	
CBL Worker1	1,3	4	52,5%	54,3%	53,3%	11,2	
CBL Worker2	1,3	4	52,8%	54,3%	53,3%	11,2	
Pallet_EPT1	1,2	10	84,3%	87,1%	89,7%	3,1	
Pallet_EPT2	1,2	10	93,7%	94,0%	87,9%	2,0	
Pallet_EPT3	1,2	10	95,9%	91,0%	95,0%	1,4	
Pallet_EPT4	1,2	10	93,8%	94,4%	96,6%	1,2	
Pallet_EPT5	1,2	10	96,2%	95,6%	94,0%	1,1	
Reach1	1,5	1	53,6%	54,0%	53,0%	11,1	
Reach2	1,5	1	54,0%	54,1%	53,3%	11,1	
Reach3	1,5	1	54,6%	55,4%	54,4%	10,8	
Reach4	1,5	1	55,2%	56,2%	55,9%	10,6	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	2	64,4%	64,6%	64,5%	17,0	2,00
Dock2	0,17; 0,19; 0,21	2	63,6%	64,7%	63,8%	17,3	2,00
Dock3	0,17; 0,19; 0,21	2	64,3%	64,9%	64,8%	17,0	2,00
Dock4	0,17; 0,19; 0,21	1	50,0%	51,8%	50,4%	11,8	1,00
InfeedCBL	0,81; 0,9; 0,99	2	57,2%	60,9%	57,1%	20,0	2,00
InfeedRC1	0,68; 0,75; 0,83	1	53,4%	53,8%	52,7%	11,2	1,00
InfeedRC2	0,68; 0,75; 0,83	1	51,7%	54,2%	52,7%	11,3	1,00
InfeedRC3	0,68; 0,75; 0,83	1	52,7%	53,3%	53,3%	11,3	1,00
InfeedRC4	0,68; 0,75; 0,83	1	53,1%	52,8%	53,5%	11,2	1,00
InfeedRC5	0,68; 0,75; 0,83	1	39,9%	40,2%	39,9%	14,4	1,00
InfeedRC6	0,68; 0,75; 0,83	1	39,0%	42,8%	41,5%	14,1	1,00
InfeedT1	0,6; 0,67; 0,73	1	66,6%	66,1%	66,0%	8,1	1,00
InfeedT2	0,6; 0,67; 0,73	1	65,8%	66,6%	65,9%	8,1	1,00
PalletSort	2,7; 3; 3,3	2	68,2%	68,2%	66,6%	15,5	2,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	81,9%	83,7%	84,3%	4,0	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	2	55,3%	53,6%	56,6%	21,5	2,00
Sorting_CBL	0,98; 1,08; 1,19	5	48,2%	50,2%	49,5%	60,9	5,00
Waste_processing	0,23; 0,252; 0,28	4	57,6%	58,9%	57,7%	40,3	4,00

Design 3a – Completely automated (manual beer sorting)

Table G- 14: Required hours - Design 3a - Scenario 2

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	78,0%	76,2%	75,5%	5,6	
Worker1_2	1,3	2	78,9%	76,8%	75,7%	5,5	
Workers2_1	1,3	2	52,7%	55,1%	54,7%	11,0	
Workers2_2	1,3	2	55,7%	58,9%	57,9%	10,2	
Workers2_3	1,3	2	53,1%	56,3%	55,9%	10,8	
Workers2_4	1,3	2	54,0%	56,6%	55,1%	10,7	
Workers2_5	1,3	2	53,8%	57,2%	56,7%	10,6	
Workers2_6	1,3	2	54,6%	57,9%	56,5%	10,5	
Workers2_7	1,3	2	54,8%	58,2%	57,1%	10,4	
Workers2_8	1,3	2	55,2%	58,8%	57,6%	10,3	
Workers2_9	1,3	2	55,4%	58,8%	57,9%	10,2	
Workers2_10	1,3	2	55,7%	59,0%	57,9%	10,2	
Pallet_EPT1	1,2	10	98,3%	98,3%	98,6%	0,4	
Pallet_EPT2	1,2	10	98,3%	98,3%	98,6%	0,4	
Pallet_EPT3	1,2	10	98,3%	98,3%	98,6%	0,4	
Pallet_EPT4	1,2	10	98,3%	98,3%	98,6%	0,4	
Pallet_EPT5	1,2	10	98,3%	98,3%	98,6%	0,4	
Reach1	1,5	1	65,7%	64,3%	64,8%	8,4	
Reach2	1,5	1	66,3%	65,1%	67,7%	8,1	
Reach3	1,5	1	68,2%	68,3%	68,2%	7,6	
Reach4	1,5	1	68,2%	66,8%	68,5%	7,7	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,075; 0,083; 0,092	1	54,0%	57,0%	56,0%	*automated*	1,00
Dock2	0,075; 0,083; 0,092	1	54,6%	57,0%	56,4%	*automated*	1,00
Dock3	0,075; 0,083; 0,092	1	55,4%	57,5%	57,9%	*automated*	1,00
Dock4	0,075; 0,083; 0,092	1	55,8%	57,9%	56,5%	*automated*	1,00
EnterAGV	0,12; 0,17; 0,22	4	55,8%	57,9%	56,5%	41,5	4,00
EnterBeer	0,075; 0,083; 0,092	1	96,6%	96,8%	96,7%	0,8	1,00
EnterCBL	0,075; 0,083; 0,092	1	84,5%	84,8%	84,5%	3,7	1,00
InfeedCBL	0,81; 0,9; 0,99	1	16,4%	16,7%	12,3%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	41,9%	45,5%	42,9%	13,6	1,00
InfeedRC2	0,68; 0,75; 0,83	1	42,7%	44,9%	43,4%	13,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	42,6%	43,4%	42,5%	13,7	1,00
InfeedRC4	0,68; 0,75; 0,83	1	42,8%	43,8%	43,4%	13,6	1,00
InfeedRC5	0,68; 0,75; 0,83	1	52,3%	55,6%	53,4%	11,1	1,00
InfeedRC6	0,68; 0,75; 0,83	1	54,3%	55,6%	54,8%	10,8	1,00
InfeedT1	0,6; 0,67; 0,73	1	52,3%	55,6%	53,4%	11,1	1,00
InfeedT2	0,6; 0,67; 0,73	1	66,4%	66,9%	66,8%	8,0	1,00
PalletSort	2,7; 3; 3,3	1	67,9%	66,2%	68,8%	7,8	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	82,0%	83,6%	82,9%	4,1	1,00
Sorting_Beer_SM	1,8; 2; 2,2	2	71,9%	72,5%	72,7%	13,3	2,00
Sorting_CBL	0,09	1	84,1%	84,3%	84,1%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	66,5%	68,0%	67,3%	15,7	2,00

Design 3b – Completely automated

Table G- 15: Required hours - Design 3b - Scenario 2

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	76,2%	76,1%	76,8%	5,7	
Worker1_2	1,3	2	77,0%	76,6%	77,6%	5,5	
Workers2_1	1,3	2	52,4%	54,7%	52,7%	11,2	
Workers2_2	1,3	2	55,3%	58,3%	56,0%	10,4	
Workers2_3	1,3	2	53,0%	55,2%	53,9%	11,0	
Workers2_4	1,3	2	53,6%	55,8%	54,5%	10,9	
Workers2_5	1,3	2	54,2%	56,7%	55,0%	10,7	
Workers2_6	1,3	2	54,7%	57,0%	55,0%	10,7	
Workers2_7	1,3	2	55,0%	57,6%	55,7%	10,5	
Workers2_8	1,3	2	54,9%	57,9%	55,6%	10,5	
Workers2_9	1,3	2	55,2%	58,2%	56,1%	10,4	
Workers2_10	1,3	2	55,3%	58,2%	56,2%	10,4	
Pallet_EPT1	1,2	10	98,3%	98,3%	98,3%	0,4	
Pallet_EPT2	1,2	10	98,3%	98,3%	98,3%	0,4	
Pallet_EPT3	1,2	10	98,3%	98,3%	98,3%	0,4	
Pallet_EPT4	1,2	10	98,3%	98,3%	98,3%	0,4	
Pallet_EPT5	1,2	10	98,3%	98,3%	98,3%	0,4	
Reach1	1,5	1	70,6%	70,4%	67,2%	7,3	
Reach2	1,5	1	72,6%	72,9%	71,2%	6,7	
Reach3	1,5	1	74,1%	72,9%	71,2%	6,6	
Reach4	1,5	1	74,1%	73,1%	72,5%	6,4	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,075; 0,083; 0,092	1	54,0%	56,0%	54,5%	*automated*	1,00
Dock2	0,075; 0,083; 0,092	1	55,4%	56,4%	54,7%	*automated*	1,00
Dock3	0,075; 0,083; 0,092	1	55,9%	58,5%	56,5%	*automated*	1,00
Dock4	0,075; 0,083; 0,092	1	54,0%	58,7%	55,1%	*automated*	1,00
EnterAGV	0,12; 0,17; 0,22	4	54,0%	58,7%	55,1%	42,3	4,00
EnterBeer	0,075; 0,083; 0,092	1	96,6%	96,9%	96,7%	0,8	1,00
EnterCBL	0,075; 0,083; 0,092	1	84,1%	84,6%	84,4%	3,8	1,00
InfeedCBL	0,81; 0,9; 0,99	1	15,0%	17,1%	17,3%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	41,8%	43,4%	43,2%	13,7	1,00
InfeedRC2	0,68; 0,75; 0,83	1	43,1%	43,3%	43,6%	13,6	1,00
InfeedRC3	0,68; 0,75; 0,83	1	42,2%	44,0%	42,2%	13,7	1,00
InfeedRC4	0,68; 0,75; 0,83	1	42,2%	44,9%	43,1%	13,6	1,00
InfeedRC5	0,68; 0,75; 0,83	1	54,2%	54,9%	54,7%	10,9	1,00
InfeedRC6	0,68; 0,75; 0,83	1	53,1%	55,0%	53,7%	11,1	1,00
InfeedT1	0,6; 0,67; 0,73	1	54,2%	54,9%	54,7%	10,9	1,00
InfeedT2	0,6; 0,67; 0,73	1	66,9%	67,1%	66,9%	7,9	1,00
PalletSort	2,7; 3; 3,3	1	70,5%	66,3%	63,7%	8,0	1,00
Sorting_Beer	0,05	1	98,0%	98,1%	98,0%	*automated*	1,00
Sorting_CBL	0,09	1	83,6%	84,2%	84,0%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	66,6%	67,3%	66,6%	15,9	2,00

G.4 Scenario 3

Orange: transport + loading time; blue: unloading time; grey: processing time

Current layout

Table G- 16: Required hours - Current layout - Scenario 3

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	47,3%	51,2%	49,1%	12,2	
Worker1_2	1,3	2	48,6%	51,1%	50,2%	12,0	
Workers2_1	1,3	2	49,6%	52,9%	51,0%	11,7	
Workers2_2	1,3	2	52,0%	53,0%	53,7%	11,3	
Workers2_3	1,3	2	52,4%	53,7%	53,6%	11,2	
Workers2_4	1,3	2	51,6%	53,9%	54,3%	11,2	
Workers2_5	1,3	2	52,4%	54,0%	52,3%	11,3	
Workers2_6	1,3	2	50,1%	52,8%	52,5%	11,6	
Workers2_7	1,3	2	50,6%	53,7%	52,6%	11,5	
Workers2_8	1,3	2	51,3%	52,7%	52,2%	11,5	
Workers2_9	1,3	2	50,6%	52,6%	54,0%	11,4	
Workers2_10	1,3	2	50,1%	53,1%	52,1%	11,6	
Workers2_8	1,3	2	51,9%	53,7%	53,1%	11,3	
Workers2_9	1,3	2	51,1%	52,6%	53,6%	11,4	
Workers2_10	1,3	2	51,1%	54,0%	52,9%	11,4	
CBL Worker1	1,3	4	33,2%	35,9%	35,6%	15,6	
CBL Worker2	1,3	4	33,2%	36,9%	35,8%	15,5	
Pallet_EPT1	1,2	10	40,8%	40,9%	41,2%	14,2	
Pallet_EPT2	1,2	10	41,2%	41,9%	42,2%	14,0	
Pallet_EPT3	1,2	10	41,5%	42,6%	42,9%	13,8	
Pallet_EPT4	1,2	10	42,0%	43,7%	43,5%	13,7	
Pallet_EPT5	1,2	10	43,4%	45,0%	44,5%	13,4	
Pallet_EPT6	1,2	10	44,6%	45,2%	46,7%	13,1	
Reach1	1,5	1	53,9%	54,0%	53,0%	11,1	
Reach2	1,5	1	55,5%	58,0%	55,0%	10,5	
Reach3	1,5	1	56,4%	57,9%	56,2%	10,4	
Reach4	1,5	1	56,9%	58,1%	56,9%	10,2	
Reach5	1,5	1	57,8%	59,6%	58,1%	10,0	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	2	50,2%	52,7%	51,9%	23,2	2,00
Dock2	0,17; 0,19; 0,21	2	50,5%	52,7%	52,0%	23,2	2,00
Dock3	0,17; 0,19; 0,21	2	51,2%	53,1%	52,9%	22,8	2,00
Dock4	0,17; 0,19; 0,21	2	50,5%	53,1%	52,7%	23,0	2,00
InfeedCBL	0,81; 0,9; 0,99	2	50,5%	53,1%	52,7%	23,0	2,00
InfeedRC1	0,68; 0,75; 0,83	1	35,0%	37,4%	35,6%	15,4	1,00
InfeedRC2	0,68; 0,75; 0,83	1	33,1%	36,5%	36,6%	15,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	35,0%	37,2%	36,8%	15,3	1,00
InfeedRC4	0,68; 0,75; 0,83	1	34,0%	36,6%	37,5%	15,4	1,00
InfeedRC5	0,68; 0,75; 0,83	1	43,0%	42,6%	41,7%	13,8	1,00
InfeedRC6	0,68; 0,75; 0,83	1	39,7%	41,9%	40,3%	14,3	1,00
InfeedT1	0,6; 0,67; 0,73	1	43,0%	42,6%	41,7%	13,8	1,00
InfeedT2	0,6; 0,67; 0,73	1	56,8%	60,8%	58,4%	9,9	1,00

PalletSort	2,7; 3; 3,3	2	63,1%	60,1%	60,4%	18,6	2,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	76,3%	78,5%	78,4%	5,3	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	2	41,9%	48,5%	42,2%	26,8	2,00
Sorting_CBL	0,98; 1,08; 1,19	7	47,1%	49,1%	48,6%	86,9	7,00
Waste_processing	0,25; 0,28; 0,31	5	53,9%	55,1%	55,2%	54,3	5,00

Design 1 – Split waste and packaging

Table G- 17: Required hours - Design 1 - Scenario 3

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	52,0%	52,2%	52,3%	11,5	
Worker1_2	1,3	2	52,7%	52,8%	53,8%	11,3	
Workers2_1	1,3	2	54,3%	55,4%	53,3%	11,0	
Workers2_2	1,3	2	57,5%	57,8%	56,7%	10,2	
Workers2_3	1,3	2	56,7%	57,7%	58,3%	10,2	
Workers2_4	1,3	2	54,9%	57,9%	57,8%	10,3	
Workers2_5	1,3	2	57,7%	58,1%	58,4%	10,1	
Workers2_6	1,3	2	55,6%	54,7%	55,8%	10,7	
Workers2_7	1,3	2	56,0%	55,2%	56,8%	10,6	
Workers2_8	1,3	2	55,1%	54,8%	53,6%	10,9	
Workers2_9	1,3	2	55,6%	56,1%	55,4%	10,6	
Workers2_10	1,3	2	53,7%	57,1%	55,9%	10,7	
Workers2_11	1,3	2	55,1%	55,3%	57,2%	10,6	
Workers2_12	1,3	2	58,2%	57,4%	57,7%	10,1	
Workers2_13	1,3	2	57,9%	57,5%	57,3%	10,2	
CBL Worker1	1,3	4	50,5%	52,9%	52,1%	11,6	
CBL Worker2	1,3	4	53,2%	53,7%	53,2%	11,2	
Pallet_EPT1	1,2	10	44,0%	44,1%	41,8%	13,6	
Pallet_EPT2	1,2	10	44,0%	46,1%	43,4%	13,3	
Pallet_EPT3	1,2	10	44,5%	47,0%	44,9%	13,1	
Pallet_EPT4	1,2	10	46,5%	48,2%	45,0%	12,8	
Pallet_EPT5	1,2	10	46,5%	48,9%	46,3%	12,7	
Pallet_EPT6	1,2	10	47,8%	50,0%	47,4%	12,4	
Reach1	1,5	1	57,2%	59,7%	57,5%	10,0	
Reach2	1,5	1	58,9%	61,8%	59,9%	9,6	
Reach3	1,5	1	62,3%	64,4%	61,4%	8,9	
Reach4	1,5	1	62,2%	64,9%	61,3%	8,9	
Reach5	1,5	1	62,2%	65,5%	62,9%	8,8	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	2	54,9%	54,8%	55,1%	21,7	2,00
Dock2	0,17; 0,19; 0,21	2	54,2%	55,3%	55,4%	21,6	2,00
Dock3	0,17; 0,19; 0,21	2	54,5%	55,4%	55,8%	21,5	2,00
Dock4	0,17; 0,19; 0,21	2	54,1%	54,5%	55,0%	21,8	2,00
InfeedCBL	0,81; 0,9; 0,99	2	48,4%	52,6%	52,1%	23,5	2,00
InfeedRC1	0,68; 0,75; 0,83	1	42,6%	45,5%	43,0%	13,5	1,00
InfeedRC2	0,68; 0,75; 0,83	1	42,6%	45,7%	42,9%	13,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	42,7%	45,9%	43,3%	13,5	1,00

InfeedRC4	0,68; 0,75; 0,83	1	43,0%	46,0%	42,9%	13,4	1,00
InfeedRC5	0,68; 0,75; 0,83	1	24,5%	28,6%	26,7%	17,6	1,00
InfeedRC6	0,68; 0,75; 0,83	1	24,4%	25,5%	24,7%	18,0	1,00
InfeedT1	0,6; 0,67; 0,73	1	55,5%	59,0%	57,3%	10,3	1,00
InfeedT2	0,6; 0,67; 0,73	1	55,6%	59,4%	57,6%	10,2	1,00
PalletSort	2,7; 3; 3,3	2	58,3%	62,2%	59,3%	19,2	2,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	79,1%	79,9%	79,1%	4,9	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	2	47,6%	45,6%	45,0%	25,9	2,00
Sorting_CBL	0,98; 1,08; 1,19	7	48,4%	49,3%	48,8%	85,9	7,00
Waste_processing	0,23; 0,252; 0,28	5	57,6%	58,9%	58,4%	50,1	5,00

Design 2 – Carousel

Table G- 18: Required hours - Design 2 - Scenario 3

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	54,4%	54,4%	50,4%	11,3	
Worker1_2	1,3	2	54,1%	54,8%	51,8%	11,1	
Workers2_1	1,3	2	54,7%	55,3%	52,1%	11,0	
Workers2_2	1,3	2	57,0%	58,7%	55,1%	10,3	
Workers2_3	1,3	2	57,1%	59,2%	53,9%	10,4	
Workers2_4	1,3	2	56,1%	59,4%	53,9%	10,5	
Workers2_5	1,3	2	55,3%	59,7%	54,7%	10,4	
Workers2_6	1,3	2	55,2%	55,3%	52,6%	11,0	
Workers2_7	1,3	2	57,4%	55,9%	53,3%	10,7	
Workers2_8	1,3	2	54,7%	58,7%	53,3%	10,7	
Workers2_9	1,3	2	55,7%	57,3%	51,8%	10,8	
Workers2_10	1,3	2	56,5%	56,8%	54,8%	10,6	
Workers2_11	1,3	2	56,9%	57,3%	54,7%	10,5	
Workers2_12	1,3	2	56,4%	58,2%	54,7%	10,5	
Workers2_13	1,3	2	56,1%	57,9%	54,0%	10,6	
CBL Worker1	1,3	4	50,8%	52,2%	49,3%	11,8	
CBL Worker2	1,3	4	51,2%	52,5%	49,1%	11,8	
Pallet_EPT1	1,2	10	82,9%	86,4%	82,5%	3,9	
Pallet_EPT2	1,2	10	89,5%	89,6%	92,0%	2,3	
Pallet_EPT3	1,2	10	94,8%	91,9%	93,0%	1,6	
Pallet_EPT4	1,2	10	94,6%	93,8%	95,4%	1,3	
Pallet_EPT5	1,2	10	96,3%	95,9%	94,1%	1,1	
Pallet_EPT6	1,2	10	96,5%	94,5%	93,6%	1,2	
Reach1	1,5	1	54,2%	55,4%	54,7%	10,9	
Reach2	1,5	1	56,4%	55,9%	56,6%	10,5	
Reach3	1,5	1	57,0%	56,3%	56,7%	10,4	
Reach4	1,5	1	57,4%	57,3%	56,7%	10,3	
Reach5	1,5	1	57,8%	58,0%	57,8%	10,1	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	2	55,1%	57,3%	53,0%	21,5	2,00
Dock2	0,17; 0,19; 0,21	2	55,2%	57,7%	52,9%	21,5	2,00
Dock3	0,17; 0,19; 0,21	2	56,1%	57,7%	53,4%	21,3	2,00

Dock4	0,17; 0,19; 0,21	2	54,7%	56,7%	52,5%	21,8	2,00
InfeedCBL	0,81; 0,9; 0,99	2	55,0%	53,9%	49,9%	22,6	2,00
InfeedRC1	0,68; 0,75; 0,83	1	42,9%	44,9%	43,6%	13,5	1,00
InfeedRC2	0,68; 0,75; 0,83	1	42,9%	45,0%	43,5%	13,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	43,0%	45,2%	43,6%	13,5	1,00
InfeedRC4	0,68; 0,75; 0,83	1	43,0%	44,9%	43,8%	13,5	1,00
InfeedRC5	0,68; 0,75; 0,83	1	28,9%	28,6%	25,8%	17,3	1,00
InfeedRC6	0,68; 0,75; 0,83	1	26,2%	29,8%	25,4%	17,5	1,00
InfeedT1	0,6; 0,67; 0,73	1	55,9%	57,3%	55,1%	10,5	1,00
InfeedT2	0,6; 0,67; 0,73	1	57,5%	58,3%	57,3%	10,1	1,00
PalletSort	2,7; 3; 3,3	2	66,0%	62,4%	61,5%	17,6	2,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	78,5%	78,3%	78,5%	5,2	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	2	47,2%	49,1%	42,7%	25,8	2,00
Sorting_CBL	0,98; 1,08; 1,19	7	49,3%	49,8%	48,3%	85,4	7,00
Waste_processing	0,23; 0,252; 0,28	5	55,7%	56,8%	55,4%	52,8	5,00

Design 3a – Completely automated (manual beer sorting)

Table G- 19: Required hours - Design 3a - Scenario 3

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	73,1%	73,5%	73,0%	6,4	
Worker1_2	1,3	2	73,6%	74,3%	73,7%	6,3	
Workers2_1	1,3	2	41,9%	42,7%	41,3%	13,9	
Workers2_2	1,3	2	44,8%	44,9%	44,0%	13,3	
Workers2_3	1,3	2	44,9%	45,1%	44,0%	13,3	
Workers2_4	1,3	2	44,8%	45,0%	44,0%	13,3	
Workers2_5	1,3	2	44,9%	45,0%	44,1%	13,3	
Workers2_6	1,3	2	42,0%	42,7%	42,0%	13,9	
Workers2_7	1,3	2	42,7%	43,3%	42,4%	13,7	
Workers2_8	1,3	2	43,0%	43,5%	42,6%	13,7	
Workers2_9	1,3	2	43,5%	43,7%	42,6%	13,6	
Workers2_10	1,3	2	44,4%	44,3%	43,2%	13,4	
Workers2_11	1,3	2	44,2%	44,6%	43,6%	13,4	
Workers2_12	1,3	2	44,6%	44,9%	43,7%	13,3	
Workers2_13	1,3	2	44,4%	45,0%	43,9%	13,3	
Pallet_EPT1	1,2	10	97,7%	97,7%	98,0%	0,5	
Pallet_EPT2	1,2	10	97,7%	97,7%	98,0%	0,5	
Pallet_EPT3	1,2	10	97,7%	97,7%	98,0%	0,5	
Pallet_EPT4	1,2	10	97,7%	97,7%	98,0%	0,5	
Pallet_EPT5	1,2	10	97,7%	97,7%	98,0%	0,5	
Pallet_EPT6	1,2	10	100,0%	100,0%	100,0%	0,0	
Reach1	1,5	1	64,7%	65,0%	64,7%	8,4	
Reach2	1,5	1	65,4%	66,3%	65,6%	8,2	
Reach3	1,5	1	67,6%	66,7%	66,2%	8,0	
Reach4	1,5	1	67,7%	67,9%	67,8%	7,7	
Reach5	1,5	1	68,0%	69,0%	68,8%	7,5	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	**: Average amount of servers*

Dock1	0,075; 0,083; 0,092	1	42,2%	43,3%	42,4%	*automated*	1,00
Dock2	0,075; 0,083; 0,092	1	43,2%	44,4%	42,2%	*automated*	1,00
Dock3	0,075; 0,083; 0,092	1	45,8%	45,2%	43,2%	*automated*	1,00
Dock4	0,075; 0,083; 0,092	1	44,2%	43,6%	43,1%	*automated*	1,00
EnterAGV	0,12; 0,17; 0,22	4	44,2%	43,6%	43,1%	54,1	4,00
EnterBeer	0,075; 0,083; 0,092	1	95,8%	95,9%	95,8%	1,0	1,00
EnterCBL	0,075; 0,083; 0,092	1	80,8%	80,9%	80,5%	4,6	1,00
InfeedCBL	0,81; 0,9; 0,99	1	1,4%	2,0%	2,1%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	31,4%	32,4%	31,1%	16,4	1,00
InfeedRC2	0,68; 0,75; 0,83	1	30,6%	31,3%	32,2%	16,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	30,6%	31,6%	30,7%	16,6	1,00
InfeedRC4	0,68; 0,75; 0,83	1	31,1%	31,0%	30,8%	16,6	1,00
InfeedRC5	0,68; 0,75; 0,83	1	42,6%	44,9%	43,9%	13,5	1,00
InfeedRC6	0,68; 0,75; 0,83	1	42,7%	43,9%	42,9%	13,6	1,00
InfeedT1	0,6; 0,67; 0,73	1	42,6%	44,9%	43,9%	13,5	1,00
InfeedT2	0,6; 0,67; 0,73	1	57,3%	56,3%	55,9%	10,4	1,00
PalletSort	2,7; 3; 3,3	1	63,0%	62,8%	63,3%	8,9	1,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	78,2%	78,7%	79,4%	5,1	1,00
Sorting_Beer_SM	1,8; 2; 2,2	2	65,1%	66,1%	63,9%	16,8	2,00
Sorting_CBL	0,09	1	80,2%	80,4%	79,9%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	58,7%	59,8%	59,9%	19,5	2,00

Design 3b – Completely automated

Table G- 20: Required hours - Design 3b - Scenario 3

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*
Worker1_1	1,3	2	69,0%	71,0%	72,1%	7,0
Worker1_2	1,3	2	70,0%	72,2%	73,5%	6,7
Workers2_1	1,3	2	40,4%	43,1%	42,0%	14,0
Workers2_2	1,3	2	43,0%	45,4%	44,5%	13,4
Workers2_3	1,3	2	43,2%	45,4%	44,6%	13,3
Workers2_4	1,3	2	43,1%	45,4%	44,6%	13,4
Workers2_5	1,3	2	43,1%	45,4%	44,8%	13,3
Workers2_6	1,3	2	40,7%	42,9%	42,7%	13,9
Workers2_7	1,3	2	40,9%	43,7%	42,9%	13,8
Workers2_8	1,3	2	41,6%	44,1%	43,5%	13,7
Workers2_9	1,3	2	41,9%	44,1%	43,7%	13,6
Workers2_10	1,3	2	42,1%	44,4%	44,3%	13,5
Workers2_11	1,3	2	42,3%	44,9%	44,4%	13,5
Workers2_12	1,3	2	43,0%	45,3%	44,6%	13,4
Workers2_13	1,3	2	43,0%	44,9%	44,7%	13,4
Pallet_EPT1	1,2	10	97,7%	98,0%	98,0%	0,5
Pallet_EPT2	1,2	10	97,7%	98,0%	98,0%	0,5
Pallet_EPT3	1,2	10	97,7%	98,0%	98,0%	0,5
Pallet_EPT4	1,2	10	97,7%	98,0%	98,0%	0,5

Pallet_EPT5	1,2	10	97,7%	98,0%	98,0%	0,5	
Pallet_EPT6	1,2	10	100,0%	100,0%	100,0%	0,0	
Reach1	1,5	1	68,2%	69,7%	70,5%	7,3	
Reach2	1,5	1	72,5%	69,4%	70,8%	7,0	
Reach3	1,5	1	72,0%	72,8%	72,4%	6,6	
Reach4	1,5	1	74,4%	74,2%	74,0%	6,2	
Reach5	1,5	1	74,9%	75,1%	74,2%	6,1	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,075; 0,083; 0,092	1	41,4%	43,6%	42,6%	*automated*	1,00
Dock2	0,075; 0,083; 0,092	1	41,3%	44,6%	43,5%	*automated*	1,00
Dock3	0,075; 0,083; 0,092	1	41,8%	45,3%	43,6%	*automated*	1,00
Dock4	0,075; 0,083; 0,092	1	42,4%	44,0%	43,6%	*automated*	1,00
EnterAGV	0,12; 0,17; 0,22	4	42,4%	44,0%	43,6%	54,4	4,00
EnterBeer	0,075; 0,083; 0,092	1	95,7%	95,7%	95,7%	1,0	1,00
EnterCBL	0,075; 0,083; 0,092	1	81,2%	81,2%	80,7%	4,6	1,00
InfeedCBL	0,81; 0,9; 0,99	1	2,2%	1,9%	2,3%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	29,4%	32,0%	30,6%	16,6	1,00
InfeedRC2	0,68; 0,75; 0,83	1	30,7%	31,9%	31,0%	16,5	1,00
InfeedRC3	0,68; 0,75; 0,83	1	30,4%	32,3%	31,6%	16,5	1,00
InfeedRC4	0,68; 0,75; 0,83	1	30,7%	32,0%	32,5%	16,4	1,00
InfeedRC5	0,68; 0,75; 0,83	1	42,4%	44,8%	42,8%	13,6	1,00
InfeedRC6	0,68; 0,75; 0,83	1	42,5%	45,5%	43,3%	13,5	1,00
InfeedT1	0,6; 0,67; 0,73	1	42,4%	44,8%	42,8%	13,6	1,00
InfeedT2	0,6; 0,67; 0,73	1	58,1%	59,8%	56,8%	10,0	1,00
PalletSort	2,7; 3; 3,3	1	61,6%	59,8%	61,5%	9,4	1,00
Sorting_Beer	0,05	1	97,4%	97,4%	97,4%	*automated*	1,00
Sorting_CBL	0,09	1	80,7%	80,7%	80,2%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	58,4%	59,6%	58,8%	19,7	2,00

H. Simulation Results – Queue length

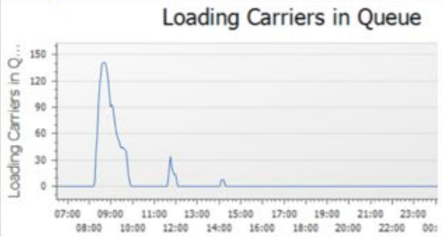
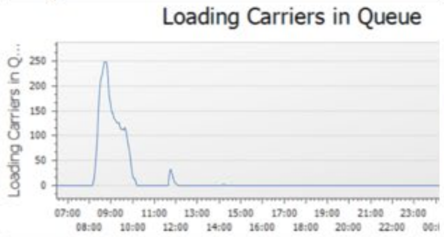
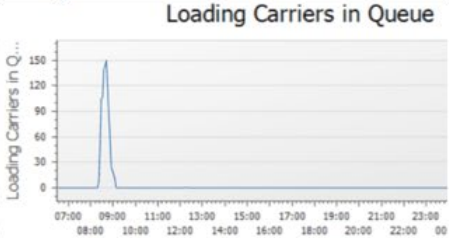
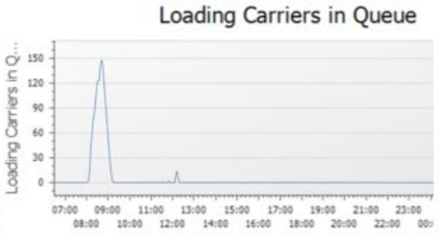
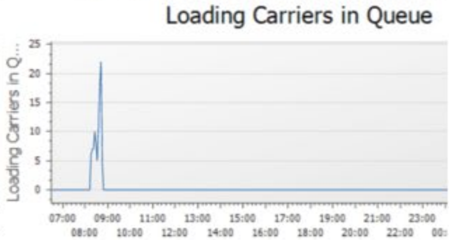
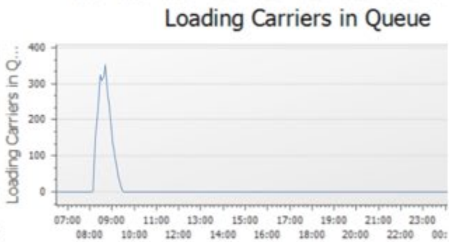
Sc.	Arr.	Current layout	Design 1	Design 2	Design 3a and 3b
1	1				
1	2				
1	3				

Figure H- 1: Queue length on inbound docks per design - Scenario 1

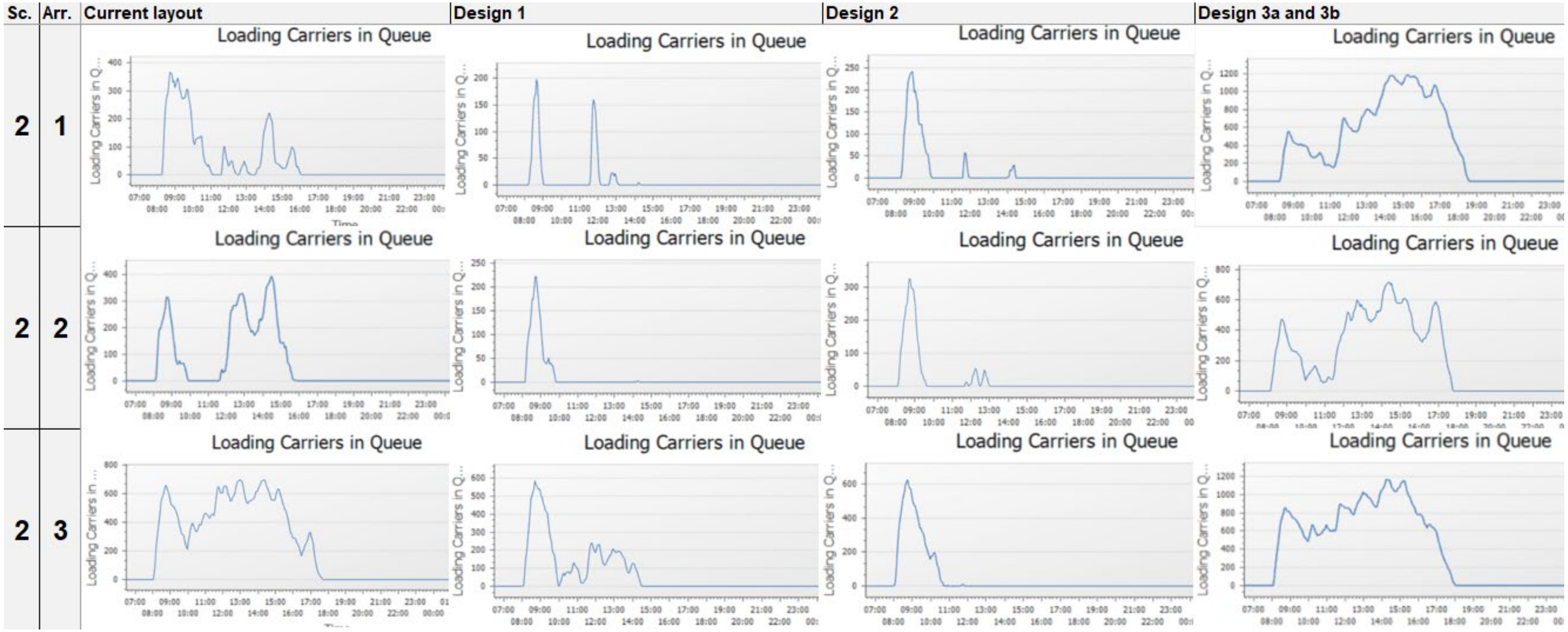


Figure H- 2: Queue length on inbound docks per design - Scenario 2

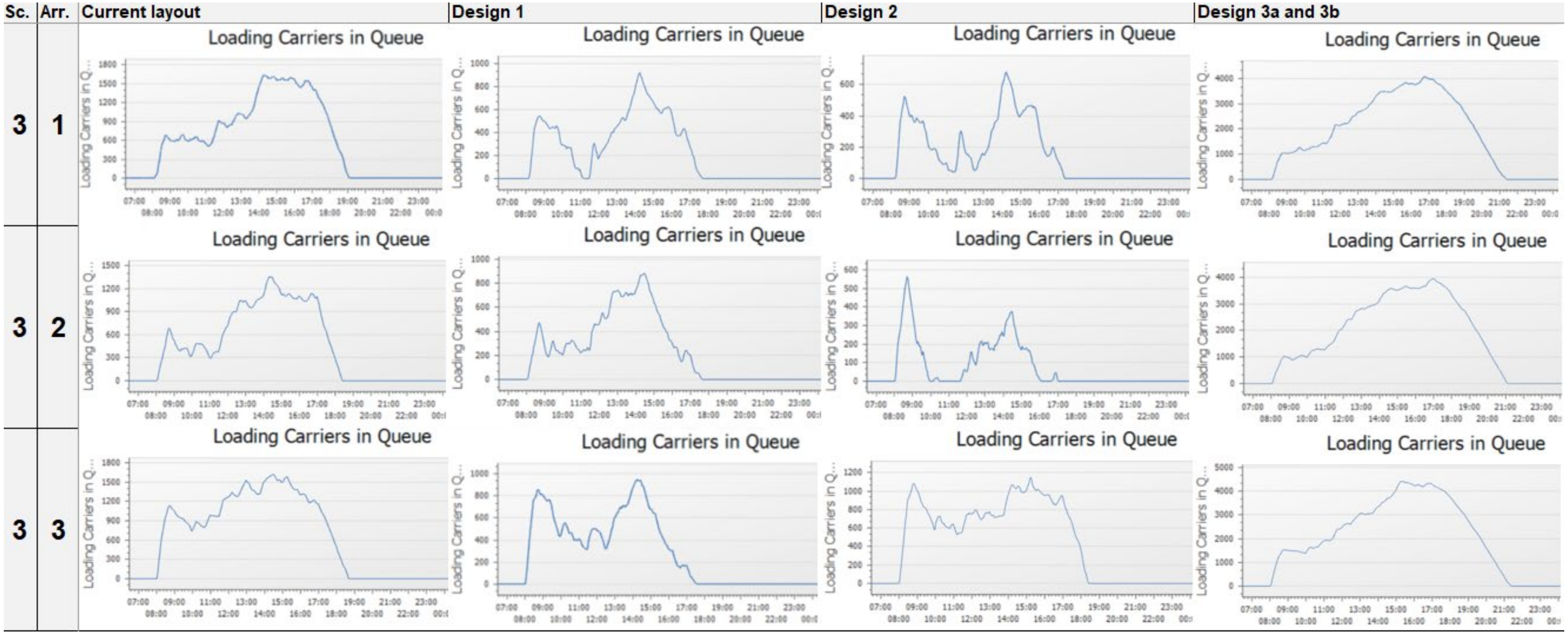


Figure H- 3: Queue length on inbound docks per design - Scenario 3

I. Simulation results – Improved designs

I.1 Required hours improved designs

Orange: transport + loading time; blue: unloading time; grey: processing time

Improved design 2

Table I- 1: Required hours - Adjusted design 2 - Scenario 3

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Worker1_1	1,3	2	70,9%	70,1%	67,5%	7,3	
Worker1_2	1,3	2	69,7%	71,0%	70,3%	7,1	
Workers2_1	1,3	2	70,0%	71,4%	69,6%	7,1	
Workers2_2	1,3	2	84,3%	87,9%	87,0%	3,3	
Workers2_3	1,3	2	73,3%	72,6%	71,9%	6,6	
Workers2_4	1,3	2	74,6%	75,6%	73,3%	6,1	
Workers2_5	1,3	2	76,6%	76,7%	74,7%	5,8	
Workers2_6	1,3	2	78,0%	79,4%	74,5%	5,4	
Workers2_7	1,3	2	80,0%	79,6%	79,7%	4,9	
Workers2_8	1,3	2	79,8%	79,3%	79,3%	4,9	
Workers2_9	1,3	2	82,6%	83,9%	81,9%	4,1	
Workers2_10	1,3	2	84,8%	83,3%	84,4%	3,8	
CBL Worker1	1,3	4	61,7%	63,5%	63,0%	8,9	
CBL Worker2	1,3	4	62,7%	64,4%	63,7%	8,7	
WorkerLD_1	1,3	2	54,0%	53,6%	52,2%	11,2	
WorkerLD_2	1,3	2	54,7%	54,9%	53,1%	11,0	
WorkerLD_3	1,3	2	54,5%	55,3%	53,1%	11,0	
Pallet_EPT1	1,2	10	65,3%	65,5%	64,6%	8,4	
Pallet_EPT2	1,2	10	68,0%	70,3%	68,0%	7,5	
Pallet_EPT3	1,2	10	70,0%	73,5%	71,2%	6,8	
Pallet_EPT4	1,2	10	74,3%	76,3%	76,7%	5,8	
Pallet_EPT5	1,2	10	79,1%	81,4%	80,7%	4,7	
Pallet_EPT6	1,2	10	81,1%	81,7%	81,6%	4,5	
Reach1	1,5	1	50,0%	51,3%	52,2%	11,7	
Reach2	1,5	1	50,2%	52,5%	54,0%	11,5	
Reach3	1,5	1	51,3%	53,9%	53,1%	11,3	
Reach4	1,5	1	52,0%	53,3%	55,0%	11,2	
Reach5	1,5	1	52,5%	54,7%	55,2%	11,0	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	*: Average amount of servers
Dock1	0,17; 0,19; 0,21	2	62,2%	63,1%	62,8%	17,9	2,00
Dock2	0,17; 0,19; 0,21	2	62,3%	63,5%	62,9%	17,8	2,00
Dock3	0,17; 0,19; 0,21	2	62,6%	63,6%	63,4%	17,7	2,00
Dock4	0,17; 0,19; 0,21	2	62,2%	63,2%	62,9%	17,9	2,00
EnterOther	0,75; 0,83; 0,92	2	63,9%	64,5%	65,2%	17,0	2,00
InfeedCBL	0,81; 0,9; 0,99	2	49,0%	52,5%	53,1%	23,3	2,00
InfeedRC1	0,68; 0,75; 0,83	1	43,5%	44,7%	44,6%	13,4	1,00
InfeedRC2	0,68; 0,75; 0,83	1	43,4%	45,4%	44,8%	13,3	1,00
InfeedRC3	0,68; 0,75; 0,83	1	43,5%	45,0%	44,6%	13,4	1,00
InfeedRC4	0,68; 0,75; 0,83	1	43,6%	45,4%	44,5%	13,3	1,00
InfeedRC5	0,68; 0,75; 0,83	1	43,5%	45,1%	45,3%	13,3	1,00

InfeedRC6	0,68; 0,75; 0,83	1	43,6%	45,1%	44,6%	13,3	1,00
InfeedT1	0,6; 0,67; 0,73	1	59,5%	57,5%	58,4%	10,0	1,00
InfeedT2	0,6; 0,67; 0,73	1	58,0%	58,5%	59,1%	9,9	1,00
PalletSort	2,7; 3; 3,3	2	61,1%	63,3%	64,4%	17,8	2,00
Sorting_Beer_FM	0,75; 0,83; 0,92	1	78,7%	80,0%	79,9%	4,9	1,00
Sorting_Beer_SM	3,7; 4,1; 4,5	2	44,8%	42,3%	50,9%	25,9	2,00
Sorting_CBL	0,98; 1,08; 1,19	7	48,8%	49,1%	49,0%	85,8	7,00
Waste_processing	0,23; 0,252; 0,28	5	55,4%	55,9%	56,1%	53,0	5,00

Improved design 3b

Table I- 2: Required hours - Improved design 3b - Scenario 3

Type	Processing time	Units per time	TimeIdle 1st run	TimeIdle 2nd run	TimeIdle 3rd run	Required hours	
Worker / vehicles	*meter / second*	*entities*	*%*	*%*	*%*	*hour*	
Workers2_1	1,3	2	55,4%	55,9%	55,4%	10,7	
Workers2_2	1,3	2	59,0%	60,4%	58,9%	9,7	
Workers2_3	1,3	2	59,2%	60,3%	59,3%	9,7	
Workers2_4	1,3	2	59,1%	60,5%	59,3%	9,7	
Workers2_5	1,3	2	59,3%	60,6%	59,3%	9,7	
Workers2_6	1,3	2	55,6%	56,2%	55,3%	10,6	
Workers2_7	1,3	2	56,1%	57,8%	56,9%	10,3	
Workers2_8	1,3	2	57,0%	57,9%	57,1%	10,2	
Workers2_9	1,3	2	58,0%	58,7%	58,2%	10,0	
Workers2_10	1,3	2	58,9%	59,6%	58,6%	9,8	
Workers2_11	1,3	2	58,5%	59,8%	59,1%	9,8	
Workers2_12	1,3	2	58,8%	60,1%	59,2%	9,7	
Workers2_13	1,3	2	59,2%	60,4%	59,2%	9,7	
WorkerLD_1	1,3	2	51,7%	52,7%	51,8%	11,5	
WorkerLD_2	1,3	2	52,2%	53,8%	52,9%	11,3	
WorkerLD_3	1,3	2	53,2%	54,4%	53,5%	11,1	
Pallet_EPT1	1,2	10	94,9%	95,5%	95,0%	1,2	
Pallet_EPT2	1,2	10	95,8%	95,8%	95,7%	1,0	
Pallet_EPT3	1,2	10	93,9%	93,9%	94,5%	1,4	
Pallet_EPT4	1,2	10	93,9%	93,8%	94,5%	1,4	
Pallet_EPT5	1,2	10	91,9%	92,2%	93,2%	1,8	
Pallet_EPT6	1,2	10	97,8%	95,1%	95,4%	0,9	
Reach1	1,5	1	69,9%	70,8%	70,5%	7,1	
Reach2	1,5	1	71,6%	73,6%	71,7%	6,6	
Reach3	1,5	1	72,0%	74,8%	72,9%	6,4	
Reach4	1,5	1	73,6%	73,3%	73,8%	6,4	
Reach5	1,5	1	75,1%	74,9%	73,6%	6,1	
Servers	*Random triangular (low, mode, high) minutes*	*servers*	*%*	*%*	*%*	*hour*	**: Average amount of servers*
Dock1	0,17; 0,19; 0,21	2	59,8%	60,7%	59,7%	19,2	2,00
Dock2	0,17; 0,19; 0,21	2	59,9%	61,5%	60,0%	19,0	2,00
Dock3	0,17; 0,19; 0,21	2	61,8%	63,9%	62,4%	17,9	2,00
Dock4	0,17; 0,19; 0,21	2	60,1%	62,1%	61,7%	18,6	2,00
EnterAGV	0,12; 0,17; 0,22	8	60,1%	62,1%	61,7%	74,3	8,00

EnterBeer	0,075; 0,083; 0,092	1	95,5%	96,0%	95,4%	1,1	1,00
EnterCBL	0,075; 0,083; 0,092	1	81,2%	80,9%	81,1%	4,5	1,00
InfeedCBL	0,81; 0,9; 0,99	1	48,4%	47,1%	47,8%	*automated*	1,00
InfeedRC1	0,68; 0,75; 0,83	1	34,6%	35,1%	34,5%	15,7	1,00
InfeedRC2	0,68; 0,75; 0,83	1	34,8%	35,2%	33,5%	15,7	1,00
InfeedRC3	0,68; 0,75; 0,83	1	34,7%	35,4%	34,0%	15,7	1,00
InfeedRC4	0,68; 0,75; 0,83	1	34,9%	35,3%	34,1%	15,7	1,00
InfeedRC5	0,68; 0,75; 0,83	1	35,0%	36,4%	35,0%	15,5	1,00
InfeedRC6	0,68; 0,75; 0,83	1	34,0%	35,7%	34,8%	15,6	1,00
InfeedT1	0,6; 0,67; 0,73	1	35,0%	36,4%	35,0%	15,5	1,00
InfeedT2	0,6; 0,67; 0,73	1	56,4%	56,8%	55,7%	10,5	1,00
PalletSort	2,7; 3; 3,3	1	61,5%	61,5%	61,9%	9,2	1,00
Sorting_Beer	0,05	1	97,3%	97,6%	97,2%	*automated*	1,00
Sorting_CBL	0,09	1	80,6%	80,4%	80,6%	*automated*	1,00
Waste_processing	0,12; 0,17; 0,22	2	32,4%	33,5%	32,4%	32,3	2,00

I.2 Buffer zone for loading carriers in improved design 2

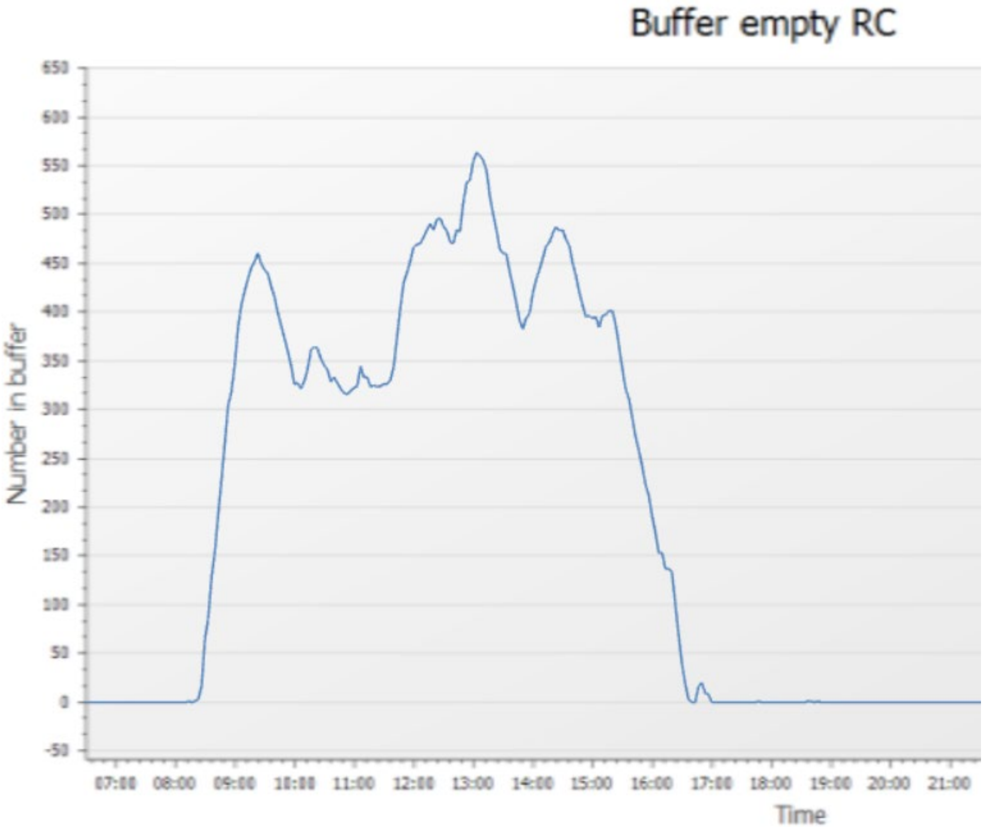


Figure I- 1: Amount of roll containers on buffer floor - Scenario 2

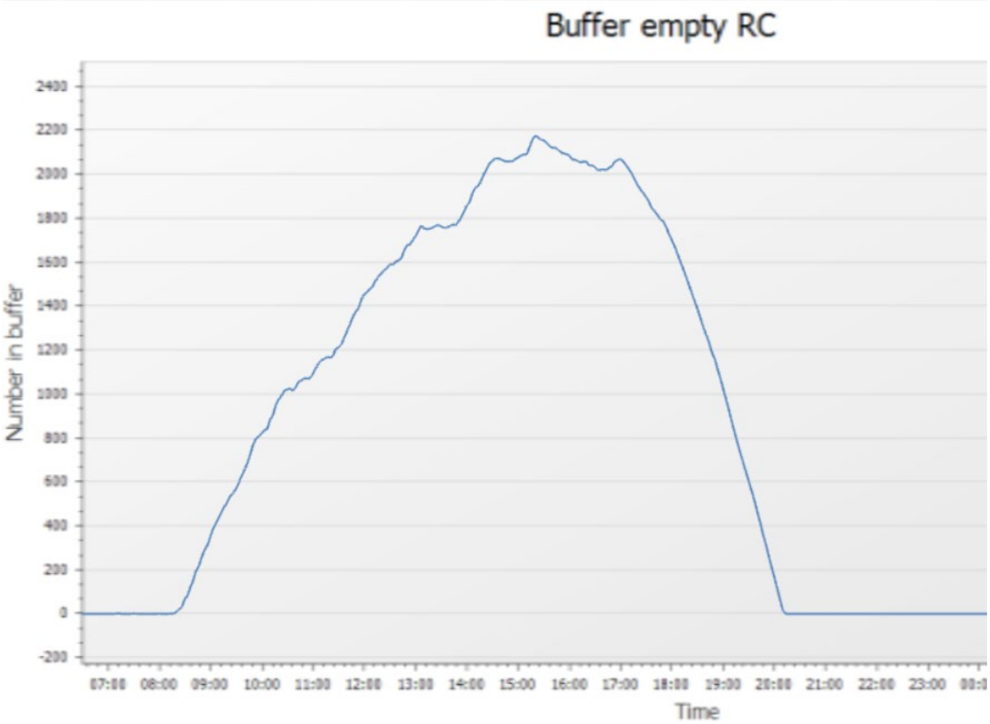


Figure I- 2: Amount of roll containers on buffer floor - Scenario 3

I.3 Buffer zone for loading carriers in improved design 3b

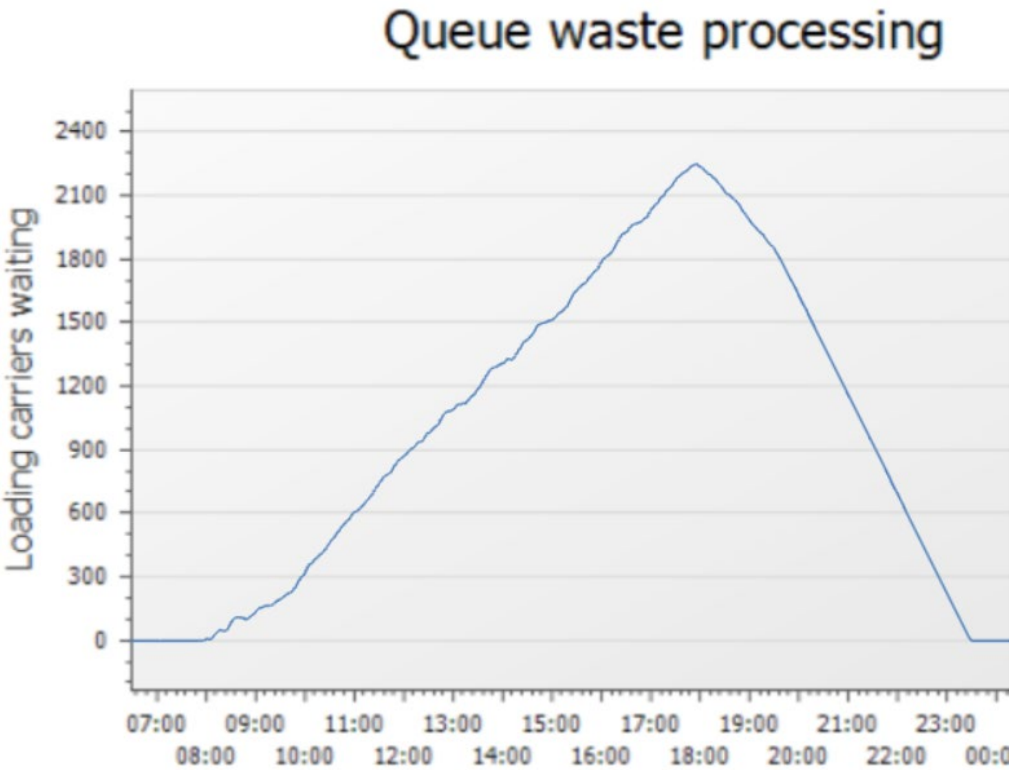


Figure I- 3: Output queue (temporary storage) loading carriers - improved design 3

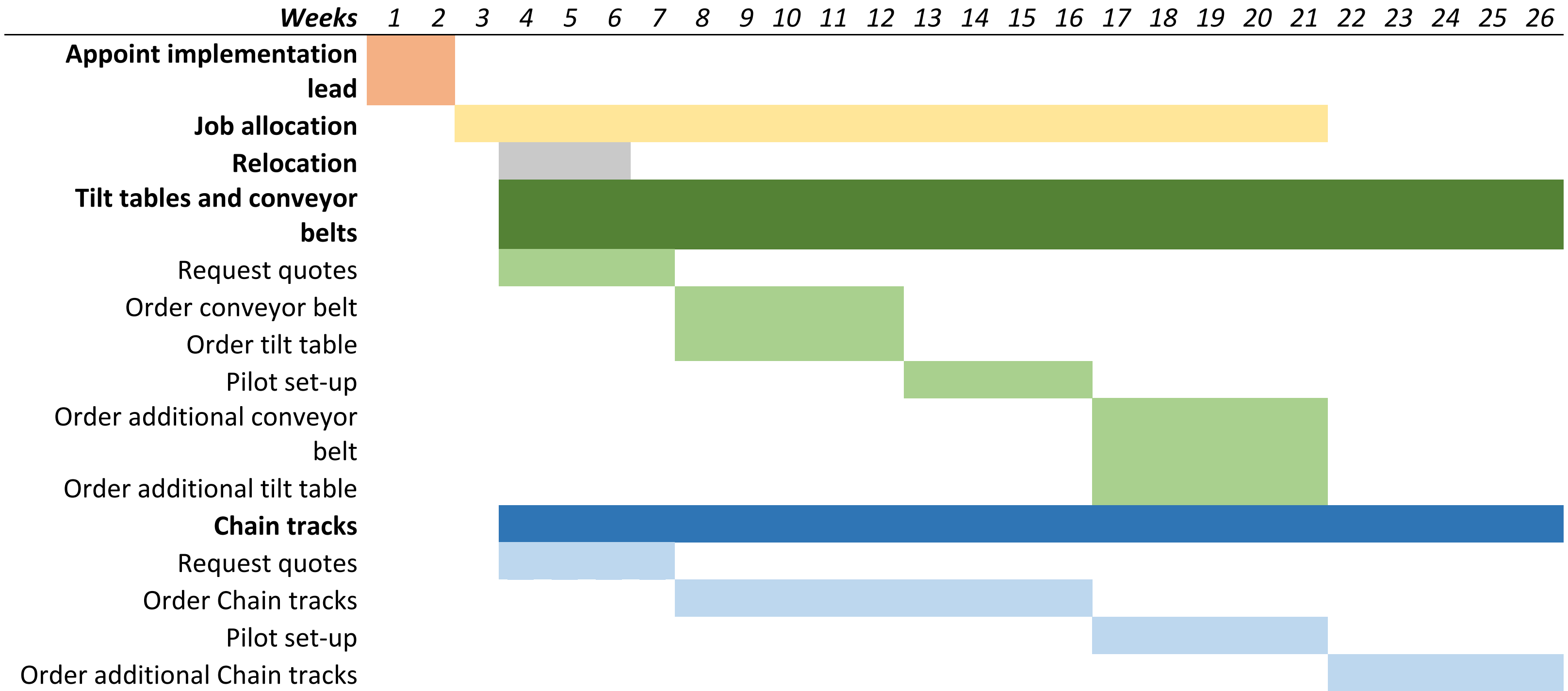
I.4 Quantities per solution and additional investment costs improved designs

Table I- 3: Quantities per solutions and investment costs per improved design - scenario 3

Scenario 3	Current layout	Design 2	Imp. Design 2	Design 3b	Imp. Design 3b	
Joloda Moving Floor	0	0	0	4	0	Amount of Joloda Moving Floors
Conveyor belt	0	100	37,5	0	0	Conveyor belt meters
Pallet EPT	3	3	3	3	3	Additional amount of Pallet EPT's
Reach EPT	3	3	3	3	3	Additional amount of Reach EPT's
AGV Tugger	0	0	0	15	15	Amount of AGV Tuggers
Chain track	0	75	200	100	100	Chain track meters
CBL crates sorter	0	0	0	1	1	Amount of CBL crate sorters
CBL stacker	0	0	0	2	2	Amount of CBL stackers
Beer crates sorter	0	0	0	1	1	Amount of Beer crate sorters
Tilt table	0	5	5	7	7	Amount of tilt tables
Additional floor	0	0	800	800	800	Amount of square meters
	€ 56.400	**€ 117.250**	**€ 312.850**	**€ 4.456.200**	**€ 4.356.200**	**Total investment costs (difference with current layout)**

I.5 Implementation timeline

Table I- 4: Implementation timeline



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