Warehouse design for a wholesale company in the packaging industry

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Management summary

Cause of investigation

Straatsma is situated at the Cargadoorweg in Nijmegen. Besides office space, the building offers a warehousing space of approximately 1100 pallet locations. The total capacity that Straatsma needs in order to be able to serve its customers far exceeds 1100. In order to solve this storage shortage, Straatsma makes use of De Klok, a third party logistics provider which is situated near the Cargadoorweg. Because the renting contract of the building at the Cargadoorweg will expire by the end of 2009, it was necessary for Straatsma to think about alternative means of storage. By the end of 2008, Straatsma decided to move its entire operation to Binderskampweg 40. It is not clear however, how this warehouse can best be designed.

Research goal

The goal of this research is to design the warehouse in such a way that it corresponds to the design objectives that are relevant to Straatsma.

Working method

In order to design the warehouse in such a way that it corresponds to the design objectives that are relevant to Straatsma, three consecutive phases have been executed:

- Before starting with the design of the warehouse, it had to be clear what matters to Straatsma. Both the current situation and the new warehouse have been analyzed in order to determine the extent to which certain design objectives are relevant.
- Once there was clarity with regard to the warehouse objectives, it was necessary to find a model to structure the warehouse design process.
- The last phase of this investigation was to design the new warehouse based on both the model for warehouse design and the design objectives that are relevant to Straatsma.

Conclusions

Based on the slow moving nature of the SKUs that Straatsma wholesales, the insufficient storage capacity of the new warehouse and the fact that the usage period of the new building is only three to five years, it became clear that cost minimization and space utilization are the two main design objectives. After selecting an appropriate warehouse design model, the new warehouse of Straatsma could actually be designed.

It must be noted that almost the entire warehouse design process was executed. Topics ranging from the required level of automation to a detailed interior layout of the new warehouse have all received attention. The fact that the decision to move into the new warehouse was made without extensive calculations with regard to the storage capacity, severely complicated the design process. Although space utilization played an important role throughout the warehouse design process, there are two initiatives that were executed in order to cope with the insufficient storage capacity that need to be mentioned specifically:

- In regular warehouse designs, it is customary to place one single SKU on a location. This was however not an option for Straatsma. A new method was developed to incorporate the fact that two SKUs can be stored on a single location into the warehouse design process.
- It was analyzed when Straatsma can make use of the storage capacity of its main suppliers in order to reduce the inventory levels of certain SKUs.

Recommendations

Despite the emphasis on space utilization and the initiatives described above, the storage capacity of the new warehouse is not large enough to store all the SKUs. In order to reduce the storage requirements that Straatsma will have by the end of 2009, when it will no longer be able to use both the old warehouse and the new warehouse, Straatsma will have to refuse keeping SKUs on stock that have a very high sojourn time. These products take up space while they do not generate much money.

There are also measures that are not linked to the storage capacity, that need to be taken into consideration in order to successfully exploit the new warehouse:

- Deliveries from suppliers will have to be scheduled properly, such that the size of the expedition area will not pose a problem.
- When moving products towards the new building a sound preparation can create enormous benefits with regard to material handling.

Preface

With this report I conclude the graduation project that I executed at Straatsma Verpakkingen in Nijmegen from the period of March 2008 to May 2009. The graduation project is the final stage of the track 'Production and Logistic Management'. This track is part of the master studies 'Industrial Engineering & Management', which is offered to me by the University of Twente. This project could not have taken place without the assistance of a number of people. I would like to thank a few of them specifically.

First of all I would like to thank Harold Regter, the head of purchasing of Straatsma Verpakkingen. He has provided valuable input with regard to the specific characteristics of the company from the day that I entered the building of Straatsma to the day that I finished my graduation project.

I would also like to extend my gratitude to Bert Kwakernaak, who is currently the strategic business unit manager of Straatsma. Although he was not present at the beginning of this research, his supervision played an important role during the last couple of months.

From the University of Twente, I would like to say thank you to Peter Schuur en Stephan Maathuis. Peter Schuur, who was my first supervisor, helped me with quite a number of difficult issues for which I am very grateful. His adequate responses have definitely contributed to this investigation. I would like to thank Stephan Maathuis, my second supervisor, especially for his input with regard to the structure of this research.

Luuk van der Weijst, a senior consultant at Districon, also needs to be mentioned in this preface. Not only did I have a number of interesting discussions with him with regard to warehouse design, he also provided certain templates that made it possible to present matters in a clarifying way.

Besides Harald Regter and Bert Kwakernaak, I would also like to show my gratitude to all other colleagues. Not only was everyone very helpful with regard to obtaining the right information, they also made the time that I stayed at Straatsma Verpakkingen a pleasant one.

Although Marti Pluygers was not active at Straatsma Verpakkingen during the last months of this research I would still like to render my thanks to her. As the former strategic business unit manager of Straatsma, she was the one that accepted my application for the graduation project. Although many things have changed since then, this whole project would not have existed without her. In a similar manner I would also like to thank Bert Beek, since he introduced me to Marti Pluygers.

The last person that I would like to thank is my mother, Tonnie Veldman-Assendorp. She has been a great support for me not only during this project, but also in the many years before. Without her mental (and financial) support, I would never have graduated from the University of Twente.

Arnhem, 23th of May 2009
Frank Veldman

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List of abbreviations

AB = Ambachtsbakker
BBY = Back Beko Ijsselstreek
BHS = Backershuys
BZ = Beko Zuid
COI = Cube Order Index
EB = Echte Bakker
ERP = Enterprise Resource Package
FTE = Full-time Equivalent
KPI = Key Performance Indicator
PW = Public warehouse
RWA = Rook- en Warmte Afvoerinstallatie
SKU = Stock Keeping Unit
SLAP = Storage Location Assignment Problem
TNO = Nederlandse organisatie voor Toegepast Natuurwetenschappelijk Onderzoek
WI = Weba-Inco

1) Introduction

With this report I conclude the graduation project that I executed at Straatsma Verpakkingen in Nijmegen from the period of March 2008 to May 2009. The graduation project is the final stage of the track ‘Production and Logistic Management’. This track is part of the master studies ‘Industrial Engineering & Management’, which is offered to me by the University of Twente.

1.1) Cause of investigation

Straatsma is situated at the Cargadoorweg in Nijmegen. Besides office space, the building offers a warehousing space of approximately 1100 pallet locations. The total capacity that Straatsma needs in order to be able to serve its customers far exceeds 1100. In order to solve this storage shortage, Straatsma makes use of De Klok, a third party logistics provider which is situated near the Cargadoorweg. Because the rent of the building at the Cargadoorweg ends in 2009, it was necessary for Straatsma to think about alternative means of storage. At the end of 2008, Straatsma decided to move its entire operation to Binderskampweg 40. It is not clear however how this warehouse can best be designed.

1.2) Structure of investigation

The structure of this research will be as follows. In chapter two Straatsma is introduced. Beko, of which Straatsma is a full subsidiary company, and the different customers that can be distinguished will also receive attention. The problem statement, the research goal, the scope of the research, the research questions and the research approach will be elaborated on next.

Chapter three will start with an overview of the relevant logistical flows. After this, the functions that the warehouses of De Klok and Straatsma serve will be discussed. The processes that are executed within the warehouse of Straatsma will also be elaborated on. In order to understand the way Straatsma does business, it is necessary to explain how the software system is used. The last step is to profile the warehouse activities that Straatsma performs.

The new building that Straatsma has in mind for conducting its warehouse business will be described in chapter four. Very important of course are the dimensions of the areas that are available for warehousing activities. Other subjects like the location of the docks and the strength of the floor are also discussed. A capacity check is also performed in order to determine whether the new building offers enough storage space.

In order to evaluate possible warehouse configurations, it must be clear what matters are especially important to Straatsma. Chapter five will start with an overview of objectives that are often mentioned in literature. The relative importance of the objectives that are mentioned will receive attention next.

When designing a warehouse it is wise to use a framework. Chapter six will therefore start with an explanation of a few frameworks that are available in literature. The next step is of course to select the framework that is most appropriate for the warehouse design process. This framework will be used in the remainder of the investigation, and will therefore be partly responsible for the contents of the following three chapters.

In chapter seven, some major strategic decisions will be made with regard to the interior of the new warehouse. Subjects which need to be investigated are the required level of automation, the need for a forward area, and the need for multiple storage systems. The decision whether or not to batch items and execute zone picking will also receive attention in this chapter.

Once the strategic decisions are made, it is time to focus on the tactical questions that need to be answered. What is possible at this stage is of course heavily dependent on the decisions that are made at the previous stage. Topics that will be discussed in chapter eight are the storage policy, the different kind of trucks that Straatsma needs, and the rack layout.

Chapter nine will deal with the last set of issues. Highly relevant is the decision with regard to the pallet rack configurations.

The conclusions of this investigation will be summarized in chapter ten. Recommendations with regard to warehouse operations will also be mentioned in the last chapter.

A reading chart is drafted in order to get a good overview about the structure of the investigation.

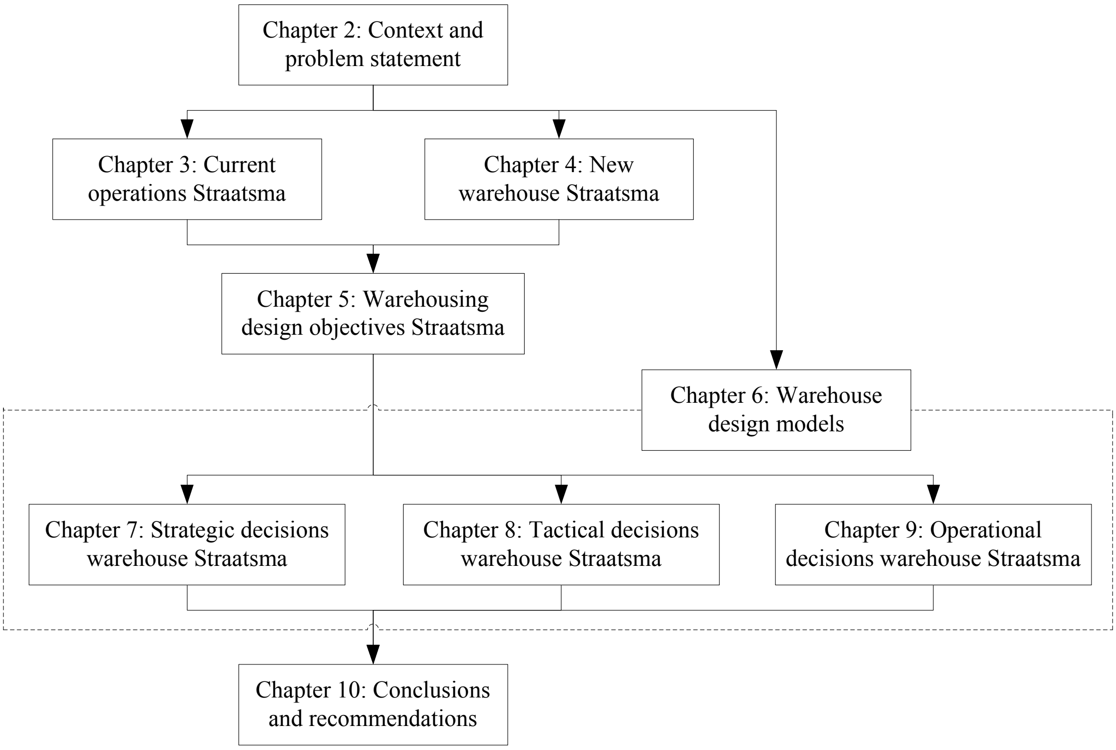


Figure 1: Reading chart

2) Context and problem statement

Multiple subjects will receive attention in this chapter. A short description about Straatsma Verpakkingen b.v. will be given in section 2.1.Relevant items are the history of Straatsma, the organization of Straatsma with regard to personnel and the ways one can differentiate between various products that Straatsma orders and distributes. In section 2.2 Beko Benelux U.A. will be introduced. This is a collaboration of purchase associations of which Straatsma is a full subsidiary company. Once the introduction of Beko Benelux U.A. is concluded, it is possible to elaborate on the various customers of Straatsma in section 2.3. After introducing Straatsma, its mother company and its customers, the problem statement will be mentioned in section 2.4. In section 2.5 the research goal will receive attention. Since the research goal involves various related topics it is necessary to restrict the scope of the research in section 2.6. The research questions that need to be answered in order to be able to fulfill the research goal will receive attention in section 2.7. The research approach, consisting of the basic form of the report, the type of research and the research methodology are the last topics of this chapter.

2.1) Straatsma Verpakkingen b.v

Straatsma Verpakkingen b.v is a wholesale company in packaging materials for bakeries that was founded in 1957 in Nijmegen. After having operated independently for many years, a change of course took place in 1993. The owner of that time, Marcel Straatsma, decided to sell his company to Beko, a full service purchase association of bakeries which will be elaborated on in the next section. Because of this takeover, Straatsma was able to bundle volumes in order to gain a purchase advantage.

Straatsma acquired her position in the market by specializing in packaging materials for handcrafted bread and banquet bakeries. Packaging materials are often purchased in large quantities in order to sell them in smaller quantities afterwards. With a turnover over 14 million in 2007 (Resultaten t/m 4e kwartaal 2007), Straatsma can be called market leader in the Netherlands.

At this point in time Straatsma is employing 20 people, summing up to 17.9 FTE (Lonenadministratie 08-07-2008). Straatsma uses a functional structure with divisional aspects. The functional structure becomes clear when looking at the organizational chart that is depicted on the next page. One can speak of divisional aspects because the main customer groups are appointed a contact person of the account management.

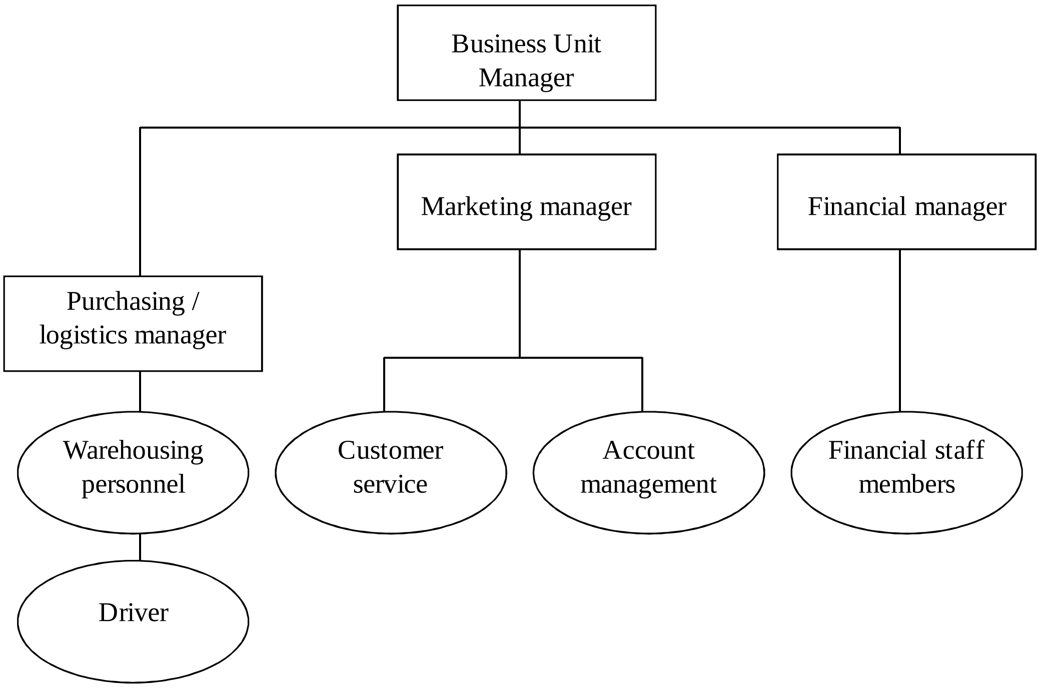


Figure 2: Organizational chart Straatsma

It is possible to differentiate between the various products that Straatsma sells. One differentiation that is often used is the following:

Neutral packaging materials
These packaging materials are neutral. They do not have a special color, nor are they linked to a specific bakery or guild. They can be ordered by everyone.

Neutrally printed packaging materials
These packaging materials have a certain design without a bakery specific nature. It is possible that the design can be ordered by various clients, but it is also possible that certain neutrally printed packaging materials are linked to a certain guild which makes it impossible for bakeries that are not a member of that specific guild to order them.

Customer specific packaging materials
These packaging materials can only be ordered by a specific bakery, because the name or the address of that specific bakery is on the packaging materials.

It is also possible to differentiate between various products based on when certain products can be ordered:

Regular packaging materials
Most products can be ordered throughout the year.

Seasonal packaging materials
Various products are only ordered during a specific period in a year. In this category one can think of packaging materials that are linked to specific holidays. It must be noted that seasonal products can also have a customer specific nature.

The last way to separate packaging materials is based on the distinction between products that are inventory driven, and products that are order driven:

Inventory driven packaging materials
These packaging materials are stored in a warehouse of Straatsma, waiting to be shipped to a customer. When the inventory level of such a product falls under a certain value, an order is placed with the corresponding supplier in order to regain an appropriate inventory level.

Order driven packaging materials
Order driven products are products that are not stored in a warehouse of Straatsma for longer periods of time. A customer order is in this case directly linked to an order that Straatsma places with one of its suppliers.

2.2) Purchase association Beko Benelux U.A.

Beko Benelux is a collaboration of regional, autonomously operating purchase associations for handcrafted bread and banquet bakeries. It was founded in 1965 when a number of bakeries decided to see whether it was possible to gain a purchase advantage when collaborating. Nowadays Beko is specialized in both basic food ingredients as well as auxiliary products. With a turnover over 350 million in 2007 Beko can be considered market leader.

The collaboration Beko currently consists out of five purchase associations, which all have their own warehouse: Back Beko IJsselstreek (Meppel), Het Backershuys (Utrecht), Beko Zuid (Veghel), Weba-Inco ('s- Gravenzande) en VecoIJs (Utrecht). It must be noted that Back Beko IJsselstreek and Het Backerhuys together form VOF Beko Nederland. In total more than 2250 bakeries are delivered from the various purchase associations. VecoIJs does not focus on bakeries and will therefore be left out of this thesis.

Bakeries can become a member of one of the purchase associations (depending on location) when they meet certain conditions. It is for instance not possible for an industrial bakery to become a member. Furthermore there is a certain fee that potential members have to pay. In return members not only get a purchase advantage on their ingredients.

Beko operates using a 'one-stop-shop' strategy, which means that bakeries are able to turn to Beko for almost all of their needs. In order to accomplish this, the various purchase associations, united in Beko Benelux U.A., have multiple subsidiary companies. Straatsma is one company that is incorporated executing the 'one-stop-shop' strategy. The organizational chart of Beko is depicted in figure 3.

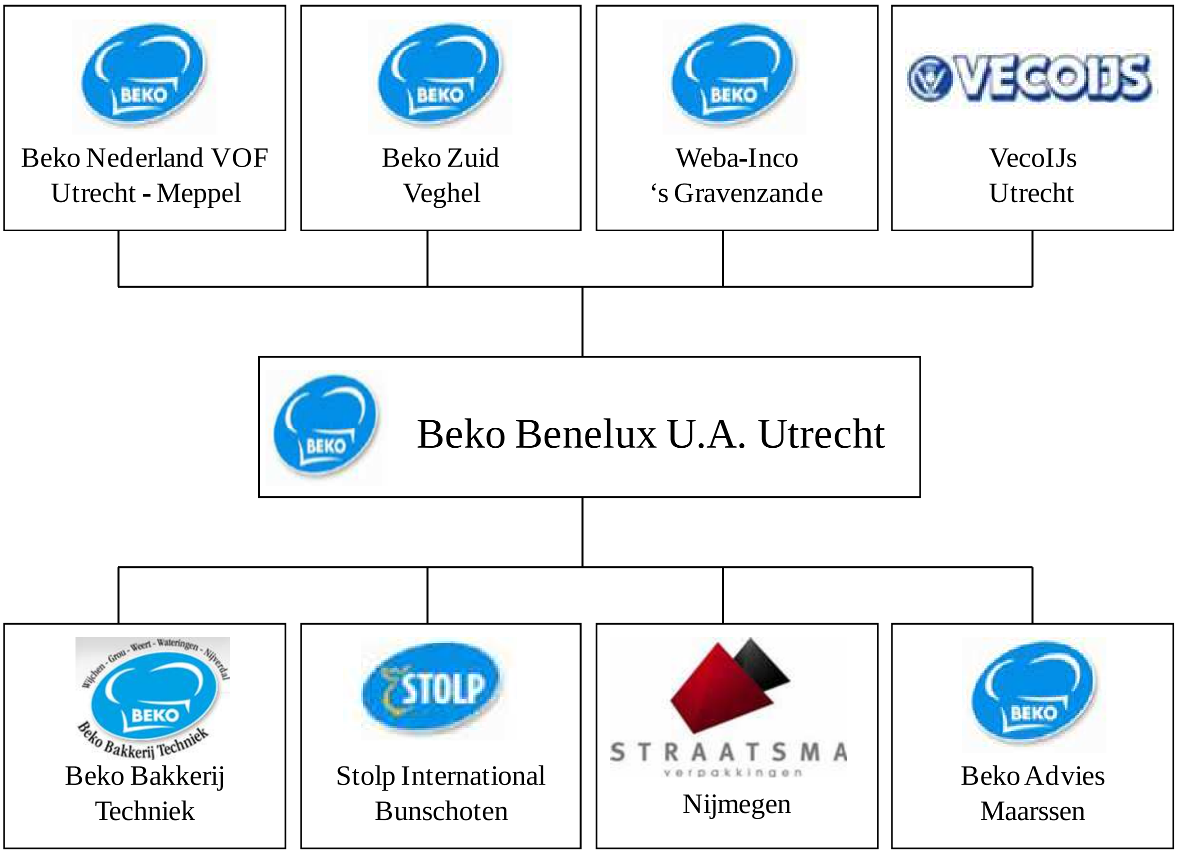


Figure 3: Organizational chart Beko

The subsidiary companies of Beko Benelux U.A. are: Beko Bakkerij Techniek, Stolp, Beko Advies and Straatsma. Beko Bakkerij Techniek gives technical support, Stolp purchases dried fruits and seeds and Beko Advies gives support with relation to the shop and marketing.
The board of Beko Benelux U.A. is formed by the chairmen of the purchase associations. These are elected by means of a meeting with members of the individual associations. The chairmen together appoint a general director that leads Beko Benelux U.A. The individual purchase associations operate autonomously to a large extent. Their policies are determined by the boards of the individual associations in close collaboration with their members. There is also a supervisory board to control whether the pre-specified policies are actually executed (Pluygers 2006; Beek 2007).

2.3) Customers of Straatsma

The customers of Straatsma can be divided into various groups. The most important distinction is that of internal customers and external customers. The internal customers consist of the Beko purchase associations. The external customers consist out of multiple groups of which the following groups are the most important:

- Het Echte Bakkersgilde
- De Ambachtsbakker
- Beko Zuid klanten
- Straatsma klanten
- Grobak
- Diversen

A few remarks need to be made when looking at the various external groups. First of all it must to be noted that it is not uncommon that bakeries which are a member of a certain guild are also connected to one of the purchase associations. Furthermore it seems strange that Beko

Zuid klanten are characterized as a separate external customers group while this is not the case for the other three purchase association. This is because various Beko Zuid klanten, that are not member of a specific bakery guild, do place their orders directly with Straatsma. This is not the case for (most) members of the other purchase associations. They place their order with their corresponding purchase association which directs (most) orders towards Straatsma. The reason for this arrangement is that Beko Zuid and Straatsma are located in the same region. Straatsma klanten are bakeries which have special arrangements, because they belonged to a certain craft guild in the past. Grobak is a direct competitor of Beko, which supplies Bakker Bart stores. While individual orders of Bakker Bart stores are delivered by Grobak, Straatsma makes sure that the inventory of Grobak with regard to packaging materials is adequate. The group Diversen shows a differentiated profile. There are individual bakeries which are not connected to either a bakery guild, or one of the four purchase associations. Besides bakeries, other sorts of companies like supermarkets, butchers and shoe stores also belong to this group.

2.4) Problem statement

Straatsma is situated at the Cargadoorweg in Nijmegen. Besides office space, the building offers a warehousing space of approximately 1100 pallet locations (Beek 2008). The total capacity that Straatsma needs in order to be able to serve its customers far exceeds 1100. In order to solve this storage shortage, Straatsma makes use of De Klok, a third party logistics provider which is situated near the Cargadoorweg. This relation lasts for more than 13 years.
Because the renting contract of the building at the Cargadoorweg will expire by the end of 2009, it was necessary for Straatsma to think about alternative means of storage.

It must be noted that the future with regard to warehouse operations is not entirely certain. Another subsidiary company of Beko Benelux U.A, Beko Bakkerijtechniek, will in the future also need a new building. It might be advantageous to use one building for both companies. This cannot be accomplished immediately however, since Beko Bakkerijtechniek has a renting contract that lasts until 2012. As a consequence the time window of the new warehouse situation for Straatsma is reasonably short (3-5 years).

After considering multiple options, Beko Benelux U.A. decided to move both the products that were traditionally warehoused at the Cargadoorweg and the products that have in recent years been warehoused by De Klok towards one building. The building that is situated at Binderskampweg 40 was selected for this purpose. It is not clear however whether the building offers enough storage capacity, and in what way the interior of the building can best be used for storage and retrieval of packaging materials. The problem statement consists of two sections:

> *Is the storage capacity of the warehouse situated at Binderskampweg 40 large enough to store all packaging materials?*
>
> *How can the interior of the warehouse be designed in order to store and retrieve packaging materials in an efficient manner?*

2.5) Research goal

The decision was already made to move into the new warehouse. In order to design the warehouse in a proper manner, the level of importance of different design objectives must be clear. There are often tradeoffs between various objectives. In order to determine the relative importance of space utilization, it is necessary to make an initial estimation whether the new warehouse offers enough storage capacity. In this sense, analyzing the storage capacity of the new warehouse is a means to an end, instead of a separate goal. Even if the storage requirements would exceed the storage capacity, the interior of the warehouse still needs to be designed.

The goal of this research is to design the warehouse in such a way that it corresponds to the design objectives that are relevant to Straatsma.

2.6) Scope of research

Moving into a new warehouse is a complex decision, which involves many problems. It is not possible to investigate everything within the pre specified amount of time:

- The order profile of Straatsma influences the optimal warehouse design. It will not be investigated whether, and how it is possible to alter the order profile.
- Whether the new building offers enough storage space, and how this space should be used, is outside the scope of this investigation.
- The total number of warehouse personnel that is needed in order to fulfill all warehouse tasks will not be determined.
- Assigning individual SKUs to specific storage locations is outside the scope of this investigation

2.7) Research questions

In order to fulfill the research goal, several research questions need to be answered. There are three main questions which consist of multiple sub questions.

1) *What design objectives are relevant to Straatsma?*
   a) *How can the current operations of Straatsma be described?*
   b) *What does the newly proposed building of Straatsma look like?*
   c) *Does the new warehouse offer enough storage capacity?*

2) *In what way can a warehouse design process be structured?*

3) *What is the best way to design the new warehouse of Straatsma?*
   a) *What is the best way to deal with the strategic decisions that need to be made?*
   b) *What is the best way to deal with the tactical decisions that need to be made?*
   c) *What is the best way to deal with the operational decisions that need to be made?*

How the questions mentioned correspond to the different chapters of this investigation was already depicted in figure 1.

2.8) Research approach

When discussing the research approach it is important to consider, the basic form of research, the research type, and the methods that are used.

It is possible to differentiate between several basic forms of research. Baarda & Goede (2001) recognize three basic forms of research: describing research, exploring research and testing research. Zwaan (2003) identifies explanatory research as a fourth basic type. The four basic forms of research differ from each other based on the extent to which hypotheses have been formulated:

- Describing research constitutes giving an accurate description of the features of a certain entity of investigation based on a predetermined method, without indicating certain relations or explanations.
- With exploratory research no well formulated hypothesis or theory is available either. The goal however is different in the sense that it aims to develop a certain theory.
- Explanatory research is about extracting a number of factors from theory in order to explain certain symptoms or relations.
- In case of testing research a pre specified hypothesis, which is derived from a certain theory, is tested to see whether it is in fact true. When theory and practice are combined to predict whether a certain action is suitable in a specific situation it can also be labeled testing research.

Although it is possible to argue about the amount of theory that is available with regard to integral warehouse design, this investigation can clearly be labeled testing research. Theory and practice will be combined in order to create a warehouse design that is suitable for Straatsma.

The research type is often a result of the basic form. This does not mean that there is a one on one relation however. Certain research types are common with regard to a specific basic form. There are six broad categories of research types:
- Laboratory experiment: Is about two identical entities in identical situations of which one is exposed to a certain factor. It is checked whether the two entities react in a different manner.
- Field experiment: Same as laboratory experiment, but executed in real life.
- Case study: Is about investigating a single entity.
- Comparative investigation: Is about collecting a large amount of data for exploratory or explanatory purposes.
- Evaluation: Is about evaluating whether an action has resulted in the expected outcome.
- Action investigation: The investigation takes place during an action.
- Simulation: In simulation a model of reality is created, in order to find out what effect certain actions would have in reality.

In case of testing research, the research types: laboratory experiment, field experiment and evaluation are most common. In this investigation however, the case study is applicable. The question about the amount of storage capacity and the design of the building is specific for Straatsma. It is definitely not possible to generalize these findings.

In order to fulfill the research goal, a lot of information is needed. The main methods that are used for acquiring this information are:
- Literature study
- Desk and field research

Literature is used in many occasions. It is first used to describe general warehouse functions and processes. It serves an even greater purpose in determining how to design a warehouse. Not only the sequence of steps that need to be taken in order to complete the warehouse design process, but also the general characteristics about when to use certain warehouse configurations, like batching and so on. While theory prescribes when certain warehouse configurations can offer significant benefits, it is still necessary to determine whether or not this is the case for Straatsma. Desk and field research takes place throughout the investigation, but plays a prominent role in activity profiling.

3) Current operations Straatsma

Not all customers receive their products out of the warehouses of Straatsma and De Klok. In section 3.1 an overview of the logistical flows within the supply chain will be presented. Once it is clear from which warehouse customers receive their products, it is time to discuss the functions that the warehouses of Straatsma and De Klok serve in section 3.2. The processes that involve warehouse personnel will be elaborated on in section 3.3. After elaborating on the processes that take place within the warehouse of Straatsma, the software system that Straatsma uses will receive attention in section 3.4. The final step is to profile the products and warehouse related activities of Straatsma. The outcomes serve as input for questions later in this thesis.

3.1) Major logistical flows

As is elaborated on in (Beek 2008), there are customers which receive their packaging materials in up to six different ways. It is not wise to chart the logistical flows in this much detail, because it would not give a good overview of the actual situation. In the figure below the most prominent logistical flows are charted. The size and point of the arrows give an indication of the amount of flow.

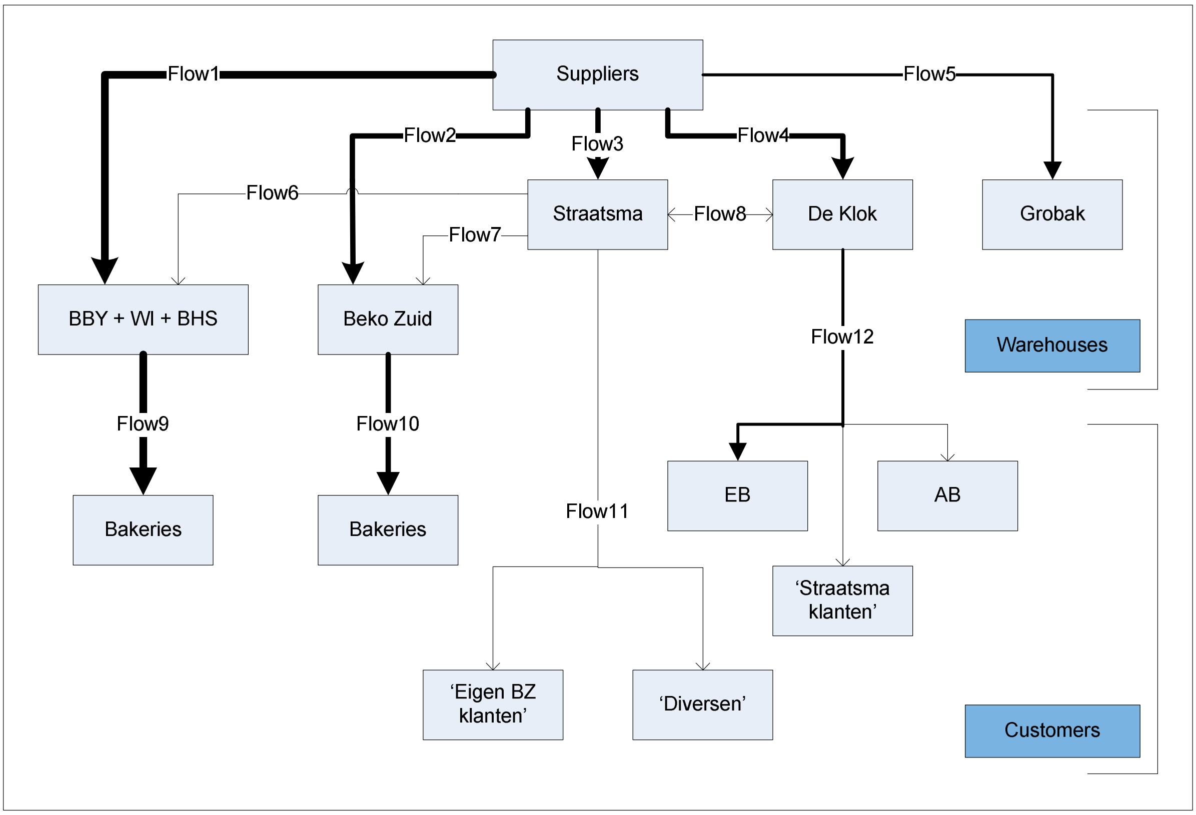


Figure 4: Major logistical flows

The flows are largely representative for both inventory driven and order driven products. Only order driven products that are directly delivered from the supplier to the final customer are not depicted in the figure. Furthermore it applies both to regular products and seasonal products. The only difference is that certain customer specific seasonal products are warehoused by Straatsma instead of De Klok.

It must be noted that some flows contain mainly neutral packaging materials, while other flows contain several types of packaging materials. In appendix 1, it is indicated which type of packaging materials are most common with regard to certain flows. The appendix also contains information with regard to transportation and delivery methods. It might be clear that the new warehouse will only be used for a fraction of all packaging materials that Straatsma wholesales. The majority of the packaging materials are transported directly to either the purchase organizations, Grobak or end customers.

3.2) Functions of warehouses Straatsma and De Klok

The fact that several customers are delivered from the warehouses of Straatsma en De Klok does not happen without a reason. Several books have been written about possible functions of warehouses. Lambert et al (1998) differentiate between 12 different functions that warehouses can have:

1) Achieve transportation economies
2) Achieve production economies
3) Take advantage of quantity purchase discounts and forward buys
4) Maintain a source of supply
5) Support the firm's customer service policies
6) Meet changing market conditions and uncertainties
7) Overcome the time and space differences that exist between producers and customers.
8) Accomplishing least total cost logistics commensurate with a desired level of customer service
9) Support the just-in-time programs of suppliers and customers
10) Provide customers with a mix of products instead of a single product on each order
11) Provide temporary storage for materials that are to be disposed or recycled
12) Provide a buffer location for trans-shipments

Coyle et al (2003) use a more narrow classification. They recognize warehouses can add value in the following ways:

i) Consolidation
ii) Product mixing
iii) Service
iv) Contingency protection
v) Smooth operation

The warehouses of Straatsma and De Klok serve several of the functions mentioned above. Among the most important ones are the following:

- Because customers receive a variety of products from multiple suppliers, Straatsma not only facilitates product mixing, but consolidation also results in transportation economies.
- When Straatsma decides to keep certain products on stock it facilitates a speedy delivery of products. It also makes it possible for bakeries to order only a few boxes. This is important, since bakeries often have limited storage capacity.
- As a wholesale company taking advantage of quantity purchase discounts and forward buys is one of the most important functions.
- The warehouse of Straatsma is also used for temporary storage in case of order driven packaging materials.

It might be clear that the warehouses of De Klok and Straatsma are distribution warehouses that play an essential role in conducting business for Straatsma.

3.3) Warehouse processes

Multiple authors, including Coyle et al (2003), Gu (2005) and Rouwenhorst et al (2000), stipulate there are four basic warehouse operations:

1) Receiving
2) Storage
3) Order picking
4) Shipping

Other authors like Le Duc (2005) and De Koster et al (2006) also recognize sorting and cross docking to be main warehousing activities. Naming the main warehousing activities does however not give a good impression of how people operate within the warehouse of Straatsma.

It is possible to distinguish four recurring processes involving the warehouse and warehouse personnel of Straatsma. These processes, which comprise of a succession of activities, are:

- Receiving and registering packaging materials
- Order picking and delivery
- Inventory check
- Handle 'haal en breng' items

An elaborate report on how the processes within Straatsma should be organized is written in Beek (2007). It appears however that not all processes are executed exactly the way it was intended. In appendix 2 high level flow charts are depicted of how the processes within the warehouse are currently executed. Certain actions, like the fact that orders are checked after picking, will need to be taken into account in the warehouse design process.

3.4) Exact

The way processes are organized is dependent on the information system that is used. Straatsma makes use of Exact, an Enterprise Resource Package (ERP) that is implemented in July 2007. Although a thorough explanation of this system is not in the scope of this research, it is important to mention the way Straatsma uses the field warehouse. Straatsma differentiates between actual warehouses, which are used for inventory driven products, and virtual warehouses, which are used for order driven products.

When entering an order into the ERP- system that concerns order driven products, Straatsma differentiates between the following virtual warehouses:

- 'Rechtstreekse Levering 10' (RL10): These are deliveries from the supplier directly to the warehouses of one of the purchase associations, where Straatsma receives a 10% fee for its services.
- 'Rechtstreekse Levering 20' (RL20): These are deliveries from the supplier directly to the warehouses of one of the purchase associations, where Straatsma receives a 20% fee for its services. The higher fee compared to RL10 is based on a higher involvement in the order.
- 'Cliënt Rechtstreekse Levering' (CRL): This 'warehouse' is used when it concerns order driven products for external customers. They can be delivered at the warehouse of Straatsma, but also at the exact location of the customer ordering the product. This depends on the specific arrangements between Straatsma and the specific supplier.

When inventory driven products are ordered, they can either be stored at the warehouse of De Klok, or at the warehouse of Straatsma. There are however various warehouses that can be selected when entering an order into Exact. Which options are available is visible in table 1.

Warehousecode	Name
1	Straatsma Verpakkingen bv
A	Straatsma Tijdelijk
EURO	EUROZAK BV
KLOK	KLOK PW
KLSV	KLOK – Straatsma
NW	Straatsma nieuw magazijn
OVER	Magazijn tbv TNO goedgekeurd

Table 1: Warehouse codes and corresponding names

Since Exact was installed, Straatsma originally made use of four of the warehouses mentioned in the table. Warehouse 1 was used for products that were actually stored at the warehouse of Straatsma. Warehouse EURO is used to conduct business for Eurozak BV. Eurozak is a financial construction which is of no importance in this research. Warehouse KLOK is used when items are stored at the main warehouse of De Klok. Warehouse KLSV was used to store items in a building opposite to the warehouse of Straatsma. Both the warehouses 1 and KLSV are no longer in use. At the 26th of January a fire destroyed part of the warehouse of De Klok. The warehouse of De Klok that was located opposite to the building of Straatsma (KLSV) burned down to the ground. Because of damage, predominantly as a result of smoke, it was no longer possible to use the warehouse of Straatsma either. In order to continue doing business Straatsma moved into the building of Tatung. Warehouse NW was created to register which products were delivered at the building of Tatung. There has been debate about which items that were stored at the warehouse of Straatsma could be used again, and which needed to be destroyed. After being tested by TNO, it appeared that quite some products were approved for reuse. These products were stored at the building of Tatung under the warehouse code OVER. The insurance company was of course only willing to pay for the building of Tatung for a limited period of time. After the warehouse of Straatsma was being cleaned, the products needed to move back to the warehouse at the Cargadoorweg. For administrative purposes, it was decided to use warehouse A for this purpose.

3.5) Activity profiling

Activity profiling can be defined as the analysis of historical sales transaction data for the purposes of projecting warehouse activity and determining storage mode, physical layout, work flow processes, and labor and equipment requirements (Schuur 2008). A first step is to collect information about the following topics:

- Items
- Orders
- Inventory

3.5.1) Items

Determining which items need to be stored in the new warehouse is not straightforward. First of all, the decision of customers to leave or join Straatsma influences which products need to be stored. Since these decisions are made regularly, the whole of items that needs to be stored also changes regularly. Another problem exists with products that are subject to a seasonal demand. In these situations it is not sensible to speak of an average inventory, since products are ordered and distributed only during short periods in a year.

In order to tackle the first problem, it was decided to use a fixed moment in time. All items that were stored at the 16th of July 2008 were initially incorporated in the investigation. Neutral items that were stored under warehouse code OVER were excluded from the investigation, when they had not been ordered in the time that Straatsma was operating in the building of Tatung. The reason for this was that there is hardly any demand for these products, which means they will not be stored in the new warehouse. Products of customers which have indicated that they will not receive their packaging materials from Straatsma in the future were also removed. It is not wise to design a warehouse based on items that will not be stored in the building in the future.

In order to deal with the second problem, it was decided to remove products that are subject to a strong seasonal demand. These products can be identified by Exact, because they are labeled 'feestartikelen'.

Some items that appeared on the list are related to taxes, and are not actually stored in one of the warehouses. These items are of course not taken into account when analyzing the number of SKUs for the new warehouse. After subtracting the various categories mentioned above, it appeared that there are 2739 products that need to be stored in the new warehouse. The table below indicates which pieces of information were collected of these products.

Product characteristics	
Itemcode	Material
Product description	Weight
Product group	Volume
Reorder level	Printing
Order size	Number of picks
Lead time	Total demand
Customer group	(Customer)

Table 2: Product characteristics

With regard to the volume of products no information could be found in Exact. Information was gathered by consulting some of the large suppliers, doing field research and making assumptions based on the previous two methods. The fact that the sales entity is sometimes a certain fraction of a box complicated the task vigorously. Exact does not register when the sales entity is only a fraction of a box. Information with regard to product characteristics can be found in the file SKUs-Straatsma.xls[1].

3.5.2) Orders

Besides the items that need to be stored in a warehouse it is also important to characterize orders that are delivered from the warehouses of Straatsma and De Klok. In order to obtain relevant information ,orders that have been delivered in the period from 01-07-2007 to 30-06-2008 were extracted from the system.

Some orders could not be used to analyze the order profile and were removed from the list. First of all it was necessary to remove all orders that were intended for Bakker Bart stores, since these items will be distributed by Grobak in the future (except Bart's retail). Orders of which the order quantity was set equal to zero were also removed. Orders as a result of direct sales were also removed since this will not occur in the future. It was also necessary to remove certain order lines within certain orders. Several matters like 'Rembours', 'Cliché', 'Vracht', 'Mn' and 'Goudbedrukte verpakking' do not provide a useful insight into the order profile, and were therefore removed from the list. Table 3 indicates what information was collected with regard to orders. Information with regard to orders can be found in the file Orders-Straatsma.xls[2]

[1] The file SKUs-Straatsma.xls can be found on the disc containing this report.
[2] The file Orders-Straatsma.xls can be found on the disc containing this report

Order characteristics
Order number
Customer number
Number of order lines
Number of products / order line

Table 3: Order characteristics

3.5.3) Inventory

The inventory position that was obtained on the 16th of July does not have much value. This is a snapshot which cannot be used to calculate the capacity that is needed. With respect to inventory the maximum inventory position and the average inventory position are relevant. Normally the following formulas can be used to calculate these inventory positions.

$$Maximum\ inventory\ level = reorderlevel - (demand / year) * lead\ time\ in\ years + ordersize$$
$$Average\ inventory\ level = reorderlevel - (demand / year) * lead\ time\ in\ years + ordersize / 2$$

Equation 1: Maximum and average inventory level (1)

Although the calculations are simple, complications arose when using the formulas mentioned above. One problem is that data fields are not always filled in correctly. For several items the lead times and the reorder points are not entered properly into the system. In order to overcome this problem a second formula was used to calculate the values for average and maximum inventory position. This formula is based on the fact that the reorder level is approximately the same as the demand during the lead time plus an additional two weeks.

$$Maximum\ inventory\ level = demand / year * (2/52) + ordersize$$
$$Average\ inventory\ level = demand / year * (2/52) + ordersize / 2$$

Equation 2: Maximum and average inventory level (2)

In some situations, the order size is not filled in correctly. When this is the case, both formulas mentioned above cannot be used. This is not always a problem. Sometimes one product has two product numbers because the item is sold in two different sales entities. Tape for instance is sold in full boxes, but also in packs of twelve roles. It might be clear that only full boxes can be ordered with suppliers. There are also situations in which a purchase size equal to one does pose problems. It concerns products, where it is not entirely clear about how much to order. It was decided to incorporate these products with their current inventory levels. It is not realistic to ignore these products all together, while predicting an average and maximum inventory level does not make sense either.

Another problem concerns products that are stored both at the warehouses of De Klok and Straatsma. In most cases this concerns boxes which are not completely full, which cannot be stored at the De Klok. There are however also products which are stored at both warehouses in large quantities. In these cases purchasing is consulted about the expected inventory levels. Table 4 indicates which inventory characteristics have been collected. Information with regard to inventory characteristics can be found in the file SKUs-Straatsma.xls[1].

Inventory characteristics
Maximum inventory position
Average inventory position

Table 4: Inventory characteristics

[1] The file SKUs-Straatsma.xls can be found on the disc containing this report.

3.5.4) Charts and graphs

Solely collecting and consolidating all data is not sufficient. It is also necessary to analyze the data, and to present in a clarifying manner. Many different matters have been analyzed. Not all matters are equally important however. The major outcomes of activity profiling are based on the following three topics.

Number of orders

In the period from 01-07-2007 until 30-06-2008, 8598 customer orders were placed that needed delivery from the warehouses of de Klok or Straatsma. These orders were filed in 261 working days. In the figure below, it is indicated in what way the number of orders is distributed over the number of days.

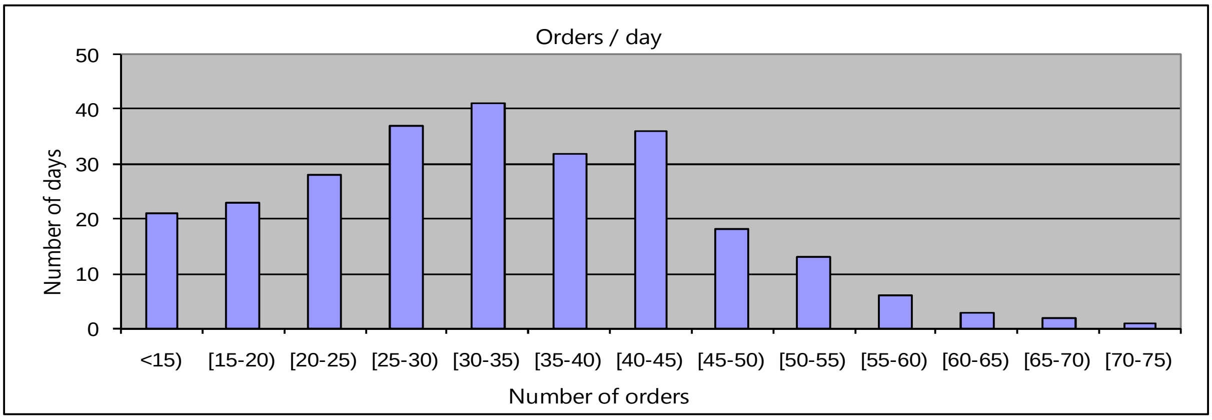


Figure 5: Orders per day

During a regular day, between 25 and 45 orders are entered into the system. There are days however in which the number of orders more than doubles the average number of orders.

Order lines per order

In the figure below it is indicated how many orders have a pre specified number of order lines.

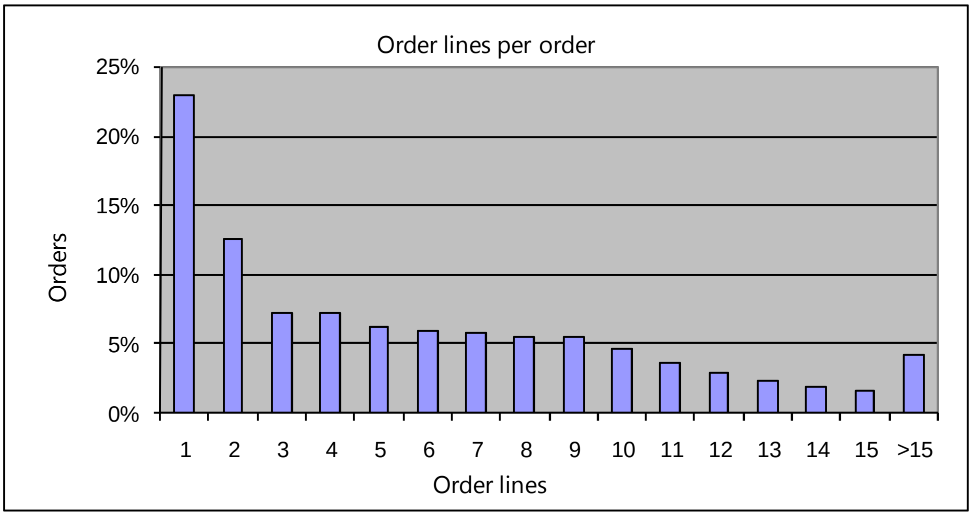


Figure 6: Order lines per order

The average number of order lines per order is 5.81. This does however not give a complete overview of the situation. The largest category of orders are orders which consist of one single order line. Orders with only two order lines are the next most frequent.

Sojourn time
In order to characterize whether a warehouse is slow moving or fast moving it is sensible to analyze the average stay of an item in the warehouse. This is also called the sojourn time. In the figure below the sojourn times of SKUs are depicted.

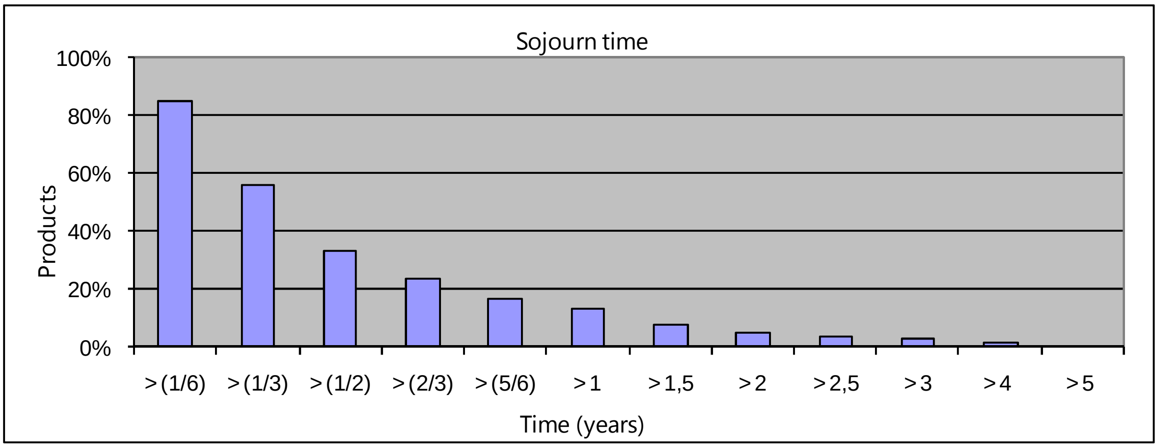


Figure 7: Sojourn time

The slow moving character of the SKUs that Straatsma has in storage becomes very clear when analyzing the figure above. Almost 40% of the SKUs have a sojourn time that is longer than one half year.

The three figures above are displayed, because they indicate that the new warehouse is rather slow moving. Not only does an analysis of sojourn times of SKUs reveal that items stay on average a substantial amount of time in the warehouse. Based on the combination of the number of orders and the number of order lines it is also possible to deduct that the total number of order lines that has to be picked each day is quite low. Besides the slow moving nature of the warehouse, the weight and the volume also need to be mentioned. Boxes are both fairly big and heavy. An elaborate discussion of all findings can be found in appendix 3.

3.6 Conclusions

In this chapter, the logistical flows, processes and activities have been analyzed. With regard to the logistical flows an important conclusion is that the new warehouse will only be used for a fraction of all packaging materials that Straatsma wholesales. The majority of the packaging materials are transported directly to either the purchase organizations, Grobak or end customers.

Straatsma makes use of warehouses for different purposes. It appears that product mixing, consolidation, facilitating a speedy delivery and quantity purchase discounts are the most important reasons for Straatsma to store packaging materials.

After elaborating on the information system and the processes that Straatsma executes information was gathered with respect to items, orders and inventory in order to be able to profile the activities that Straatsma performs. A very important conclusion is that the warehouse of Straatsma is rather slow moving. Besides the fact that SKUs have relatively long sojourn times, the total number of order lines that has to be picked is also quite low. These, and other findings from activity profiling ,will have to be taken into account when designing the warehouse.

4) New warehouse Straatsma

The new warehouse that will have to replace both the own warehouse and De Klok is located at Binderskampweg 40 in Nijmegen. In order to obtain insight into the structure, a map of the ground floor of the building will be presented in section 4.1. A number of remarks will be made in order to interpret the map in a correct manner. In the floor plan it can be seen that the new warehouse of Straatsma consists of a number of different areas. Each of the areas will be elaborated on in section 4.2. Besides the functionality of the areas, additional matters of interest will also receive attention. Once the building is properly described the capacity will be investigated in section 4.3. In a concluding section, the most important findings will be summarized.

4.1) Floor plan Binderskampweg 40

A part of the building consists of two floors. Although it will be indicated which section of the warehouse consists of two floors, it was decided not to display the floor plan of the second floor. The exact layout of the second floor is of no interest in this investigation, since it only houses office space. The floor plan of the ground floor of the new warehouse is depicted in the figure below.

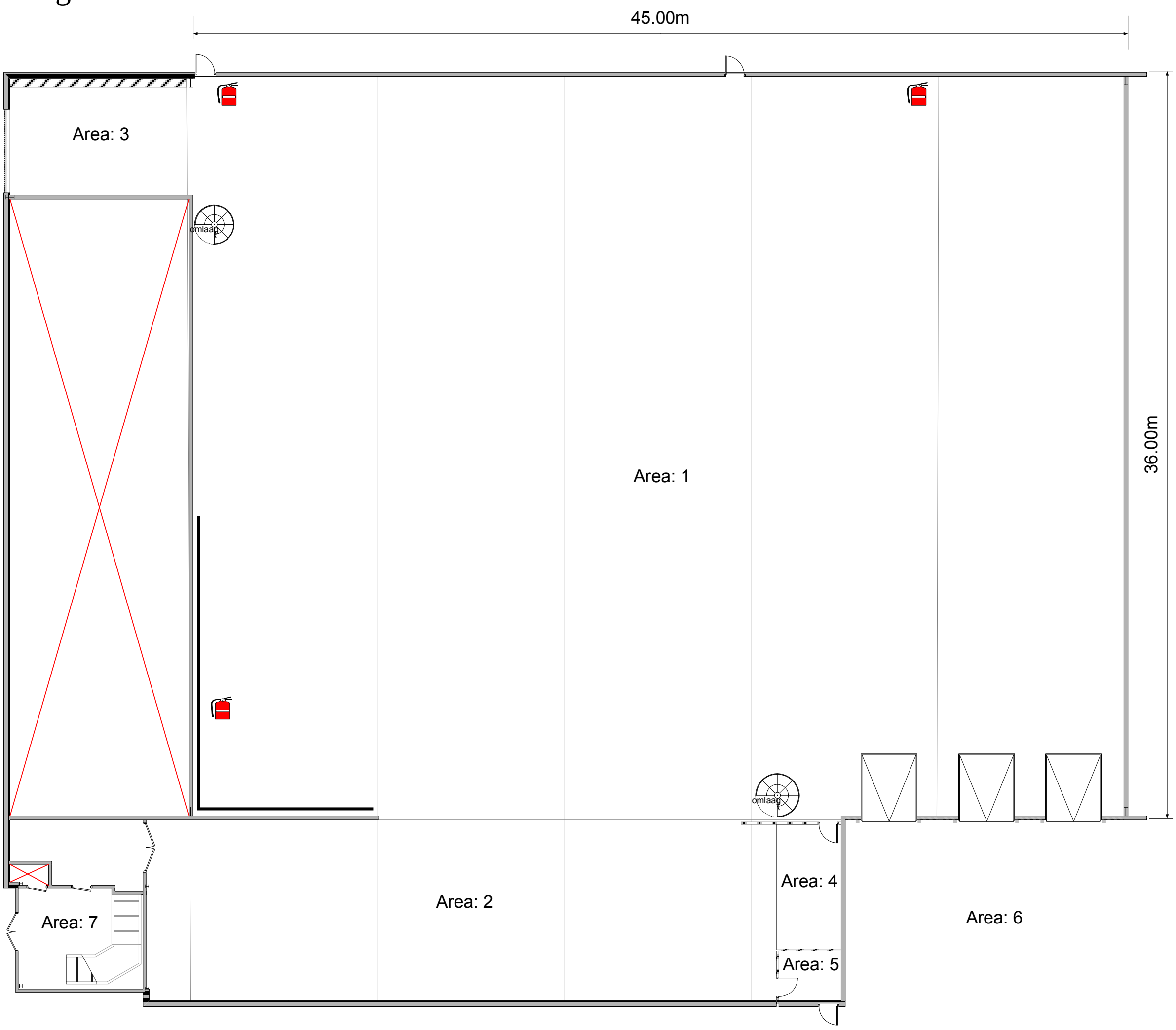


Figure 8: Floor plan new warehouse Straatsma

A number of remarks need to be made in order to fully understand the floor plan that is depicted in the figure above:

- The areas with a red cross are not accessible to Straatsma. The small area is a maintenance area, while the larger area is used by a different company.
- The soft lines in the floor plan indicate the support beams in the building.
- Objects that are located on the ground are also depicted in the floor plan. This is useful since they are important factors to take into account when the rack layout needs to be developed. It must be noted that the doors, the fire escapes, the pipe and the fire extinguishers are exemplified. Otherwise the objects would barely be visible. The dock levelers and the staircases are large enough to be displayed on scale.
- Only the large area (area 1) does not have a second floor. Offices are located above all other areas, including the docks.
- The different areas of the warehouse are numbered. The functionality of the numbers will become clear in the next section.

4.2) Different areas new building

In the following sections each of the areas that are visible in the floor plan from the previous section will receive additional attention. Besides the functionality of the area it is in some situations important to mention additional information like for instance the height of the building, or possible objects that need to be taken into account. It must be noted that the numbers in the headings of the following sections correspond to the numbers that are displayed in the floor plan. This way it is possible to determine the location of an area in the warehouse.

4.2.1) Area 1: Main warehousing area

Area 1 is the main warehousing area. It is approximately 45m x 36m large, and will be responsible for a large part of the storage capacity of the new building. There are a number of different matters in this area that need to be discussed.

Floor

The floor is constructed of 0.13 m of concrete on top of construction plastic. Each square meter is reinforced with 25 kilograms of steel fiber. This should not impose restrictions on the operations of Straatsma. It must be noted however that this is not investigated.

Support beams

Four identical support beams run across the main warehousing area. In the figure below, the dimensions of the beams have been depicted.

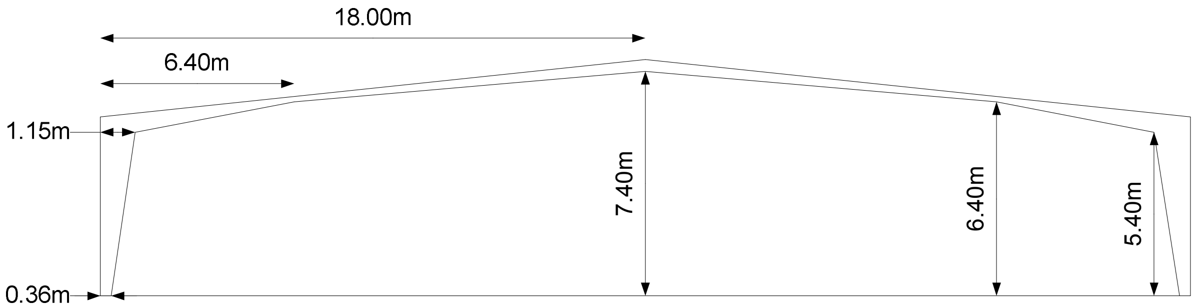


Figure 9: Support beams in main warehousing area

One big advantage of the structure is that there are no support columns in the middle of the area. The beams do jut out 1.15m on both sides of the building however. The support beams have a width of 0.29m.

Useable height
The general height of the building can largely be deducted from the figure about the support beams, since the roof of the building is positioned on top of the support beams, and the support beams are at most 0.50m high. The general height is not equal to the useable height however. The building does not have a sprinkler system. In the event of fire, both the warehouse docks and ten smoke hatches that are positioned in the roof of the main warehousing area are opened in order to make sure that heat and smoke can leave the building. This type of fire protection systems has consequences for the useable height. The 'Rook- and Warmte Afvoerinstallatie' (RWA) of the new building has recently been investigated. Based on this RWA-calculation, in combination with an analysis about the fire sensitivity of the products stored, it was determined that, in order for warehouse personnel to have a safe getaway, packaging material cannot be stacked above five meter (Rapportage F23819-rap01a, 2008).

Obstacles
Besides the main columns, there are a number of other 'obstacles' that need to be considered when designing for instance a rack layout:

- Staircases
- Fire escapes
- Fire extinguishers
- Pipes
- Dock levelers

The positions of the obstacles are visible in the floor plan. The warehouse is also equipped with a number of vans, two heaters and four series of neon tubes. These objects do not pose any restrictions with regard to the design of the warehouse however, and are therefore neglected in the remainder of this investigation.

4.2.2) Area 2: Secondary warehousing area

Area 2 is the secondary warehousing area. It is approximately 30m x 9m, and will also be used for storage purposes. Besides the functionality of the area it is important to elaborate on a number of additional matters:

- The floor in the area is similar to the one of the main warehousing area.
- The height of the area is completely different from the main warehousing area. The support beams have a different structure, because offices are located above the area. The beams do not jut out into the building, and the height under a beam is constant. The useable height in the area is normally approximately 3.5m. This number is decreased to almost 3m when located under one of the support beams.
- The south wall has a number of windows. A laser is placed parallel to the south wall in order to detect a possible burglary.
- There are doors located on both the west and the east wall that need to be considered when developing a design for the area.

4.2.3) Area 3: Second expedition area

The main expedition area is of course located behind the docks. Area 3, which is approximately 9m x 6m large, will have to serve as a second expedition area. Since there is only one leveled warehouse door, it is the only possible place where the Straatsma van can enter the building. The fact that the area is only 3.5m high, results in a rather space efficient expedition area. During the night, the expedition area can serve as parking lot for the van.

4.2.4) Area 4: Office
Warehouse personnel needs access to the information system. Area 4 will provide the space that is needed for this. It is also possible to receive drivers from suppliers in this area.

4.2.5) Area 5: Entrance lobby drivers
Area 5 is the entrance lobby for drivers that are about to make a delivery to the warehouse. A counter facilitates that it is possible to contact warehouse personnel without entering the secondary warehousing area.

4.2.6) Area 6: Docks
The new warehouse has three docks that can be used to load and unload trucks. The length and the angle of the docks should make it possible for a wide variety of trucks to access the building. This has not been investigated however.

4.2.7) Area 7: General entrance lobby
Area 7 is the general entrance hall of the building that is of no direct interest to warehouse operations. It will not only be used by Straatsma, but also by the other company. The stairs towards the offices on the second floor is also located in the entrance hall.

4.3) Capacity of warehouse
The decision to move into the new building was made without a thorough analysis of the capacity requirements that Straatsma has. This does definitely not mean that such a rough cut capacity check is obsolete at this point however. When discussing the capacity of a warehouse it is important to consider both the flow capacity and the storage capacity.

4.3.1) Flow capacity
The new warehouse has three docks, and a leveled warehouse door to accommodate the flow of SKUs in and out of the warehouse. When using two docks for the inflow of products and one dock for the outflow of products, it is unlikely that the flow capacity will pose a problem:

- The Straatsma van can always go to the warehouse door situated at the second expedition area. Because other vehicles do not make use of this door the flow capacity with regard to the Straatsma van is guaranteed.
- Reserving one dock for the remaining out flow is sufficient, since Straatsma only makes use of De Klok for its transportation needs (GLS packages are often delivered at the depot by the Straatsma van).
- Having two docks for incoming goods does not pose a problem. The number of suppliers that frequently deliver products is fairly low. Proper planning should definitely make it possible that trucks do not have to wait for one another.

4.3.2) Storage capacity
In appendix 4, an estimation of the total number of pallets that can be placed in the building is compared to an estimation of the number of pallet locations that Straatsma needs to store all its packaging materials (based on April 2008). The conclusion is rather straightforward. Even when taking into account that the number of storage locations that are needed to store the SKUs that are currently stored at De Klok can significantly be reduced, the storage capacity of the new warehouse does not suffice. An estimate of the total number of pallets that

Straatsma needs exceeds an optimistic estimation of the number of pallet locations that can be placed in the new building by almost 800.

As a consequence of the shortage in storage space Straatsma has to choose between reducing inventory (levels) or storing certain customer groups at an external location. Straatsma is very clear about this decision. It does not want to decide in advance to store certain customer groups at an external location. There are a number of reasons why Straatsma thinks that it is possible to decrease the total amount of inventory significantly compared to April 2008:

- Several products suffered from excessive inventory positions in April 2008. Various items that were stored at the Cargadoorweg during the fired were approved for sales (warehouse Over) while this was not expected.
- Inventory policies are changing at the moment. Straatsma wants to make more use of the storage capacities of its major suppliers. By using this capacity, Straatsma is able to benefit from low prices that are coupled with large production runs without having to suffer from high inventory levels.
- Straatsma officially has the policy to send off packaging materials to their corresponding customers when items are not sold one year after arrival in the warehouse. Analyzing the sojourn time of SKUs reveals that this policy has been neglected however.

The effects of inventory decreasing policies will have to be investigated in order to analyze whether the new warehouse offers enough storage capacity to store all remaining packaging materials in the long run. It is safe to say however that the shortage in storage space will not be solved when Straatsma enters the new building. The capacity shortage is quite substantial, while it takes time to execute the storage reducing policies.

Straatsma acknowledges that the storage capacity of the new warehouse is insufficient to store all packaging materials in the short term. In order to deal with this, management has made sure that Straatsma can make use of the warehouse situated at the Cargadoorweg for as long as is necessary in 2009. The general idea is that inventory reducing policies will have decreased the total storage requirements of Straatsma to such an extent, that it is possible to store all remaining packaging materials in the new warehouse by the end of 2009. Whether this is possible is highly questionable however.

4.4) Conclusions

In this chapter the new warehouse of Straatsma has been described. The building consists of a number of areas of which two are suitable for storage purposes:

- The main warehousing area is 36m x 45m. A positive feature is the fact that there are no columns in the middle of the area. A down side is the stackable height. Despite the fact that the building is almost 8m high in the top, Straatsma is not allowed to store packaging materials above 5m because of fire protection.
- The second warehousing area has the dimensions 30m x 9m. The stackable height in this area is approximately 3.50m. The column structure in this area is different from the main warehousing area, since it has a flat roof.

The capacity of the new warehouse was also analyzed. The fact that the new warehouse has three warehouse docks and one general warehouse door makes that the flow capacity of the building is not an issue. After comparing rough estimates of the total storage capacity of the new warehouse and the storage requirements of Straatsma, it became clear that Straatsma will suffer from a major shortage in storage capacity however.

Straatsma does not want to decide in advance to place certain cuatomer groups at an external location. In order to deal with the shortage of storage space in the long run, a number inventory reducing policies were introduced. To compensate for the definite shortage in storage space in the short run, Straatsma is able to use the warehouse situated at the Cargadoorweg until the end of 2009. Since it is questionable whether the new warehouse will offer enough storage capacity to store all remaining packaging materials at the end of 2009, space utilization will be of high importance during the design of the warehouse.

5) Warehousing design objectives Straatsma

When designing a warehouse there are multiple design objectives. In order to find out which design objectives are relevant to Straatsma, the following steps will be executed. Various authors have elaborated on design objectives. In section 5.1 several of these authors and their corresponding design objectives will be mentioned. The design objectives that are mentioned by different authors obviously overlap to a great extent. In section 5.2 one list with design objectives will be presented. The importance of a design factor depends on both the characteristics of a company, and the characteristics of the new warehouse. The importance of the different design factors that were distinguished in the second section will be determined for Straatsma in section 5.3. In section 5.4 the most important findings of this chapter will be summarized.

5.1) Literature review design objectives

There are a number of different authors that have written about design objectives. The theory of a number of these authors will be mentioned.

Gu (2005) recognizes there are five indicators of warehouse performance:

- Construction and maintenance costs
- Material handling costs
- Storage capacity
- Space utilization
- Equipment utilization

Goetschalckx & Ashayeri (1989) state that the objective of order picking systems is to maximize the service level subject to resource constraints, such as labor, machines and capital. The service level is composed of multiple factors, such as:

- Average order delivery time
- Variation of order delivery time
- Order integrity
- Accuracy

De Koster et al (2006) emphasize the importance of the objective function that is mentioned by Goetschalckx & Ashayeri (1989), but also recognize various other objectives:

- Minimizing throughput of an order
- Minimizing the overall throughput time (of a batch of orders)
- Maximize the use of space
- Maximize the use of equipment
- Maximize the use of labor
- Maximize the accessibility of all items

Because of the importance of delivery times, De Koster emphasizes the need to reduce traveling distance. Since various authors have indicated that traveling time is an increasing function of traveling distance, and order pickers spend a large proportion of their time traveling, reducing traveling distances can be very beneficial.

Coyle et al (2003) differentiate between general design objectives and material handling objectives. One interesting general design objective is protection. One guideline is that stacking or storing light or fragile items near other items that could cause them damage should be avoided.

With respect to material handling Coyle et al (2003) mention several objectives that are useful when designing an order picking system:

- Increase effective capacity of warehouse
- Minimizes aisle space
- Reduce the number of times a product is handled
- Develop effective working conditions
- Reduce movement involving manual labour
- Improve logistics services
- Reduce costs

Rouwenhorst et al (2000) stipulate that design objectives differ, depending on the kind of warehouse. Maximum throughput at minimum investment and operational cost is considered to be most important in case of distribution warehouses, while maximum storage capacity at minimum investment and operational cost is said to be the most prominent design objective in case of production warehouses.

5.2) General design objectives

A great deal of overlap exists when analyzing the warehousing objectives and performance indicators that are listed by the various authors. Before evaluating to what extent design objectives are relevant to Straatsma, it is first necessary to create one list. The list must cover the objectives mentioned above, without having much overlap. The following list of objectives satisfies this requirement:

Minimize total costs
While some authors have split costs in multiple components, it is also possible to create one design objective covering all expenditures.

Maximize space utilization
This is a clear cut design objective which is mentioned by almost all authors. Since space nowadays is rather expensive, it is crucial to use it in an optimal fashion.

Minimize order picking time
This objective relates to both the average order picking time as well as the variation in order picking time. It also includes accessibility of all items, since this directly affects the order picking time. Throughput related objectives can also be categorized under this heading.

Maximize order accuracy
The order picking time is not the only characteristic of an order that is important. It is also important that the right products arrive at the right customer in the right state.

Develop effective working conditions
Effective working conditions include multiple dimensions. One dimension includes the safety of order pickers. Effective working conditions also relates to the way an order picker picks items. Order picking might for instance be easier when items are stored on a pallet compared to deep drawers which are not easily accessible. Avoiding heavy manual labor and minimizing the number of times a product is handled are also important when considering effective working conditions.

Maximize flexibility
Although this last objective is not mentioned directly, it corresponds to a certain extent with multiple objectives mentioned in literature. Two components of flexibility are the ability to achieve a higher output for a short period of time, and to overcome problems such as machine failure or absence of personnel. It must be noted that other matters can also fall under this category.

Labor utilization and equipment utilization are not mentioned explicitly, because they are incorporated by the minimization of costs and the maximization of flexibility.

5.3) Design objectives Straatsma

Now that a list of design objectives is drawn up, it is possible to evaluate to what extent the specific objectives are relevant to Straatsma. Determining the importance of various design objectives is based on various matters. Not only activity profiling and the capacity check serve as input. Discussions with multiple members of the organization of Straatsma have also contributed.

Minimize total costs
There are two reasons why costs are especially important. Straatsma wants to move all its pick locations into one new warehouse, because it is expected that this saves money. When a company moves into a new warehouse to increase for instance its throughput, there is a lower emphasis on costs. The second reason why minimizing the total costs is especially important is because of the short time span. It is not sensible to make huge investments when the pay pack period is limited to three to five years. There is little time for the investments to pay out.

Maximize space utilization
The capacity check has made it abundantly clear that space utilization is crucial. By using space in an efficient manner, the shortage in storage capacity needs to be minimized as much as possible.

Minimize order picking time
Minimizing the order picking time is not a specific goal for Straatsma. This does however not mean that the order picking time can be neglected. Customers that have their products stored at De Klok that place their orders before 12.00pm are promised a delivery on the next day. It is also possible that orders that are delivered with the Straatsma van have to be picked within a few hours. This is the case when the area in which a certain customer is located is scheduled for delivery the next day. When analyzing the deadlines mentioned above, it is clear that the order picking time is a certain boundary condition. Although there is no need to optimize it, it is necessary to make sure that all customers receive their packaging materials in time. Accessibility of all items is therefore crucial.

Maximize order accuracy
Certain policies like zoning can increase the chance of order picking mistakes. Every company wants to prevent these kind of mistakes because of multiple reasons. First of all it affects customer satisfaction. Another reason is that action has to be undertaken to restore the wrong shipment. In this sense order accuracy is definitely important to Straatsma. Delivering the wrong products does however not result in huge penalty clauses.

Develop effective working conditions
Safety is very important in every warehouse. In this case the new warehouse of Straatsma is no exception. Avoiding heavy manual labor and minimizing the number of time a product is handled are also important to Straatsma, especially since there are quite a number of products that weigh more than 15 kg. The fact that the warehousing of Straatsma has a lot of SKUs with a low throughput reduces the necessity for effective working conditions. Since certain SKUs are only picked a few times per year, the ease of picking is not always the most important determinant.

Maximize flexibility
There are two reasons why flexibility is especially important for Straatsma. The first reason is that demand of products is not constant throughout the year. It is therefore a definite advantage when it is possible to increase the output of the warehouse temporarily.
The warehousing function of Straatsma is relatively small, compared to large third party logistics providers. This means that both warehousing staff and equipment will be minimal. As a result an order handling equipment failure or the absence of a warehouse employee will automatically lead to a high loss percentage wise. Flexibility, as in the ability to compensate for the absence of warehouse personnel or the failure of handling equipment, is therefore an important factor for Straatsma.

5.4) Conclusions

It was possible to extract a list of six warehouse design objectives from theory. The importance of the design objectives depend on the specific characteristics of Straatsma. In the table below the six design objectives are listed in combination with the factors that influence whether a certain objective is relevant to Straatsma. A final conclusion with regard to the importance has been noted in the last column of the table.

Design objective	Factors	Conclusion
- Minimize total cost	- Reason for relocation (↑)	Highly important
	- Short time span (↑)	
- Maximize space utilization	- Limited capacity new warehouse (↑)	Highly important
- Minimize order picking time	- Delivery agreements (↑)	Moderately important
	- Not a specific goal (↓)	
- Maximize order accuracy	- Involves customer satisfaction (↑)	Important
	- No large penalties involved (↓)	
- Effective working conditions	- Heavy SKUs (↑)	Moderately important
	- Slow moving SKUs (↓)	
- Maximize flexibility	- Relatively small crew (↑)	Important
	- Fluctuating demand (↑)	

Table 5: Importance of design objectives with regard to Straatsma

The minimization of the total cost and the maximization of space utilization are the most important. These have to be taking into account to make the whole relocation profitable.
The order picking time must be short enough to fulfill delivery agreements, but there is no reason to minimize this number as far as possible. The order accuracy is important although there are no severe penalties for wrong deliveries. The effective working conditions are not always an important determinant since there are a lot of slow moving SKUs. The flexibility is important for Straatsma because of the relatively small crew and the fluctuating demand.

6) Warehouse design models

Designing a warehouse is a complex process that involves many decisions and considerations. In order to execute the process in a proper manner, it is sensible to use a structured approach. In section 6.1 a number of frameworks for warehouse design that are eligible for use will be explained. In section 6.2 the model that will be used in the remainder of this investigation will be selected. A framework is a general model that is not concerned with specific instances. How to use the model when designing a warehouse for Straatsma will receive attention in section 6.3. In the last section the major findings of this chapter will be summarized.

6.1) Literature review and pre selection warehouse design models

Various authors state that research on warehouse decisions has mainly focused on isolated sub problems (Govindaraj et al 2000; Rouwenhorst et al 2000; De Koster et al 2006; Baker et al 2007). Multiple frameworks in which the steps that need to be performed when involved in the process of warehouse design are available in literature however. In chronological order Heskett et al (1973), Apple (1977), Firth et al (1988), Hatton (1990), Mulcahy (1994), Oxley (1994), Govindaraj et al (2000), Rouwenhorst et al (2000), Rowley (2000), Rushton et al (2000), Bodner et al (2002), Hassan (2002), Waters (2003), Rushton et al (2006), Gu (2005) and Baker et al (2007) have all presented models for systematic warehouse design.

It is not wise to elaborate on all the models described above. According to Baker, many of the frameworks that are mentioned above have a high commonality. Besides commonalities in the actual steps, authors also have similar thoughts with regard to the whole process:

- It is acknowledged that warehouse design is highly complex.
- Step by step approaches are used to tackle complexity.
- Steps are interrelated and a degree of iteration is needed.
- It may not be possible to identify the optimal solution because of the high number of possibilities.

Because of the large number of frameworks and their commonalities it was decided not to elaborate on each of the frameworks. Only frameworks that were published after the year 2000 of which the full text is available without purchasing costs will receive additional attention. There are five different frameworks that meet the criteria.

6.1.1) Govindaraj et al (2000) & Bodner et al (2002)

Govindaraj has developed a framework for designing a warehouse that consists of five phases:

- The first step is the assembly of relevant data.
- The second step is to formulate a number of functional requirements based on the data collected in the first step. Possible cost targets may also be formulated.
- The functional requirements can assist in making high level design decisions such as the decision to use a forward area, batch products or use automatic storage systems.
- The next step is to focus on detailed specifications in order to optimize the individual warehouse systems.
- After detailed specifications are set, the phase of data collection starts again.

The framework that Govindaraj has presented clearly incorporates the iterative nature of designing a warehouse. The process described above is visualized in figure 10.

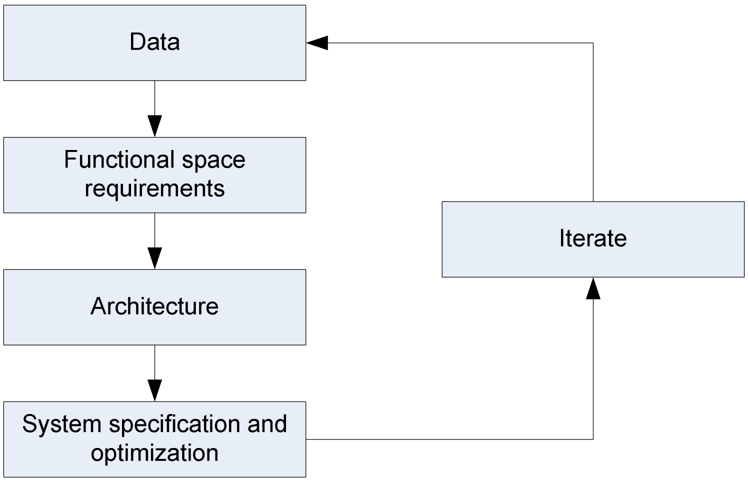


Figure 10: Warehousing design process (Govindaraj et al 2000)

The framework that is mentioned in Bodner et al (2002) is identical to the framework that has just been described.

6.1.2) Rouwenhorst et al (2000)

Rouwenhorst also recognizes that a number of steps need to be executed: concept, data acquisition, functional specification, technical specification, selection of means and equipment, layout and selection of planning and control policies. Instead of elaborating on the different steps however, a top down approach is created which clusters decisions at a similar design level. The goal is to reach an optimum, by optimizing several sub problems simultaneously. The design levels that are distinguished are strategic, tactical and operational. Decisions that are made on a higher design level impose restraints on decisions that need to be made at a lower level. Three figures have been created, indicating the decisions that need to be made in each of the design levels. In order to illustrate the type of decision, the figures consist out of three axes:

- Processes: The decisions that need to be taken are either related to receiving, storage, order picking or shipping.
- Warehouses resources: Resources comprise among other things storage conveyers, storage systems, pick equipment, but also personnel
- Organization: Organization refers to policies that a company has, in order to operate in an appropriate manner.

Strategic level

Decisions that are made at this level are long term, and often have a large impact on the capital investments that need to be made. The decisions mainly concern the process flow and the selection of the types of storage systems. An overview of the decisions that need to made can be seen in figure 11.

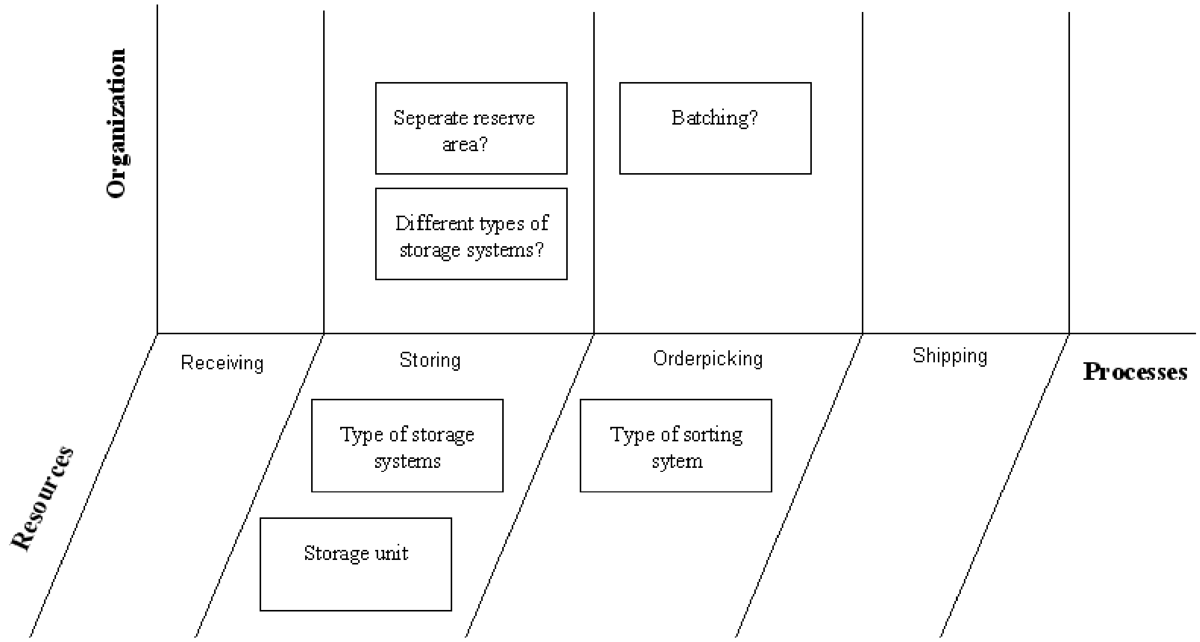


Figure 11: Decisions at strategic level (Rouwenhorst et al 2000)

Tactical level

Tactical decisions do not have the same long term impact. Problems that are dealt with in the tactical phase include the dimensions of resources and the design of a layout. An overview of the relevant decisions is depicted in the figure below.

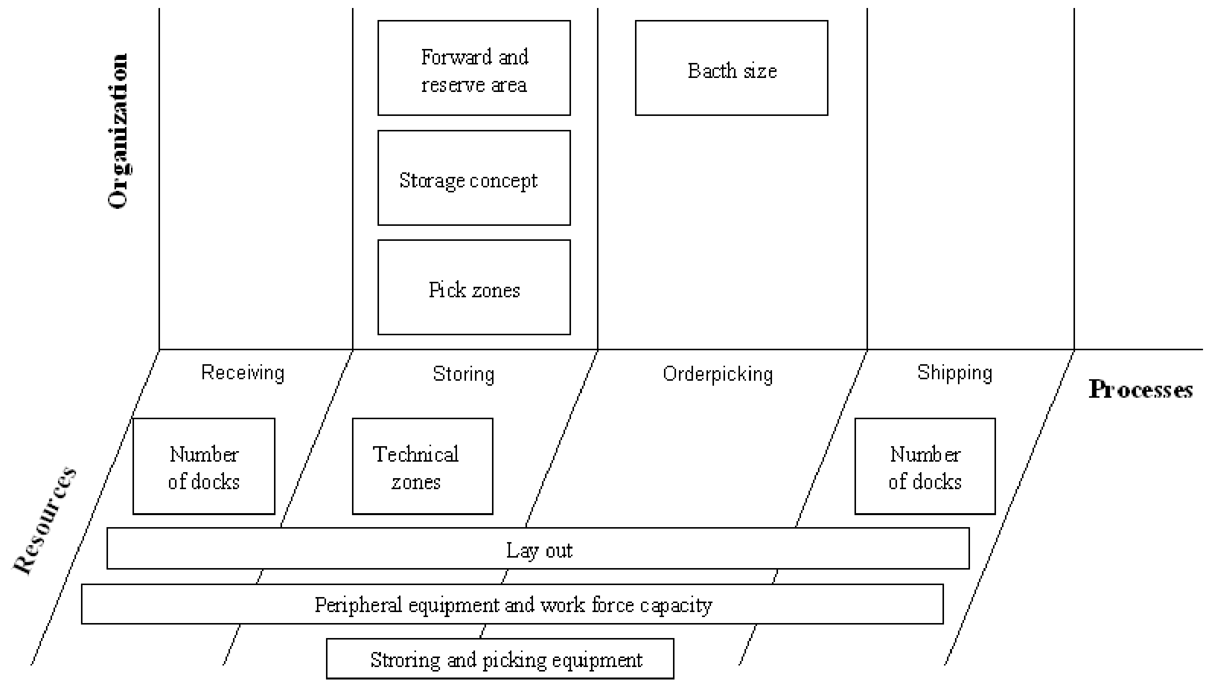


Figure 12: Decisions at tactical level (Rouwenhorst et al 2000)

Operational level
The time span of decisions that are made at this level is about one year. The decisions concern assignment and control problems of people and equipment. An overall picture of the relevant topics can be seen in the figure below.

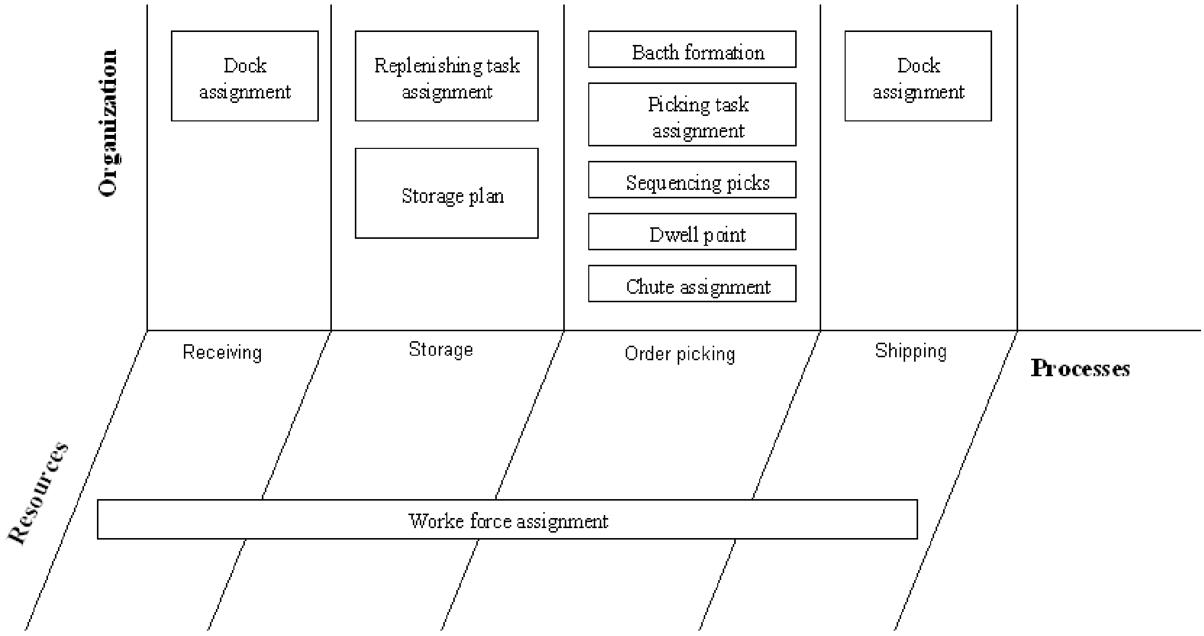


Figure 13: Decisions at operational level (Rouwenhorst et al 2000)

Clearly the model does not elaborate on all the stages of warehouse design. Both the stages concept and data acquisition are not included in one of the design levels.

6.1.3) Gu (2005)
According to Gu, the process of warehouse design constitutes out of two sections: warehouse decisions and warehouse operations. Within both sections a number of different categories can be distinguished, which are each linked to multiple decisions that need to be made. The exact decisions that need to be made in each of the two sections is illustrated in figure 14.

Design and Operation Problems			Decisions
Warehouse Design	Overall Structure		• Material flow • Department identification • Relative location of departments
	Sizing and Dimensioning		• Size of the warehouse • Size and dimension of departments
	Department Layout		• Pallet block-stacking pattern (for pallet storage) • Aisle orientation • Number, length, and width of aisles • Door locations
	Equipment Selection		• Level of automation • Storage equipment selection • Material handling equipment selection (order picking, sorting)
	Operation Strategy		• Storage rule selection • Order picking method selection
Warehouse Operation	Receiving & Shipping		• Truck-dock assignment • Order-truck assignment • Truck dispatch schedule
	Storage	SKU-Department Assignment	• Assignment of items to different warehouse departments • Space allocation
		Zoning	• Assignment of SKUs to zones • Assignment of pickers to zones
		Storage Location Assignment	• Storage location assignment • Specification of storage classes (for class-based storage)
	Order Picking	Batching	• Batch size • Order-batch assignment
		Routing & Sequencing	• Routing and sequencing of order picking tours • Dwell point selection (for AS/RS)
		Sortation	• Order-lane assignment

Figure 14: Decisions in warehousing design and warehousing operations (Gu 2005)

Gu has made a few important remarks in relation to the usage of the model described above:

- Gu realizes that design problems are interrelated. It is emphasized that it is not possible to solve matters independently.
- It is important to note that the process is not strictly sequential. One needs to take certain operating problems into account in the design phase. Having to alter matters afterwards can be very costly.
- The importance of performance evaluation is stipulated. It can not only be used to evaluate possible warehouse configurations, but also to narrow down the design space during the early design stages.

Based on the remarks made above, it is now possible to show a graphical representation of the entire model.

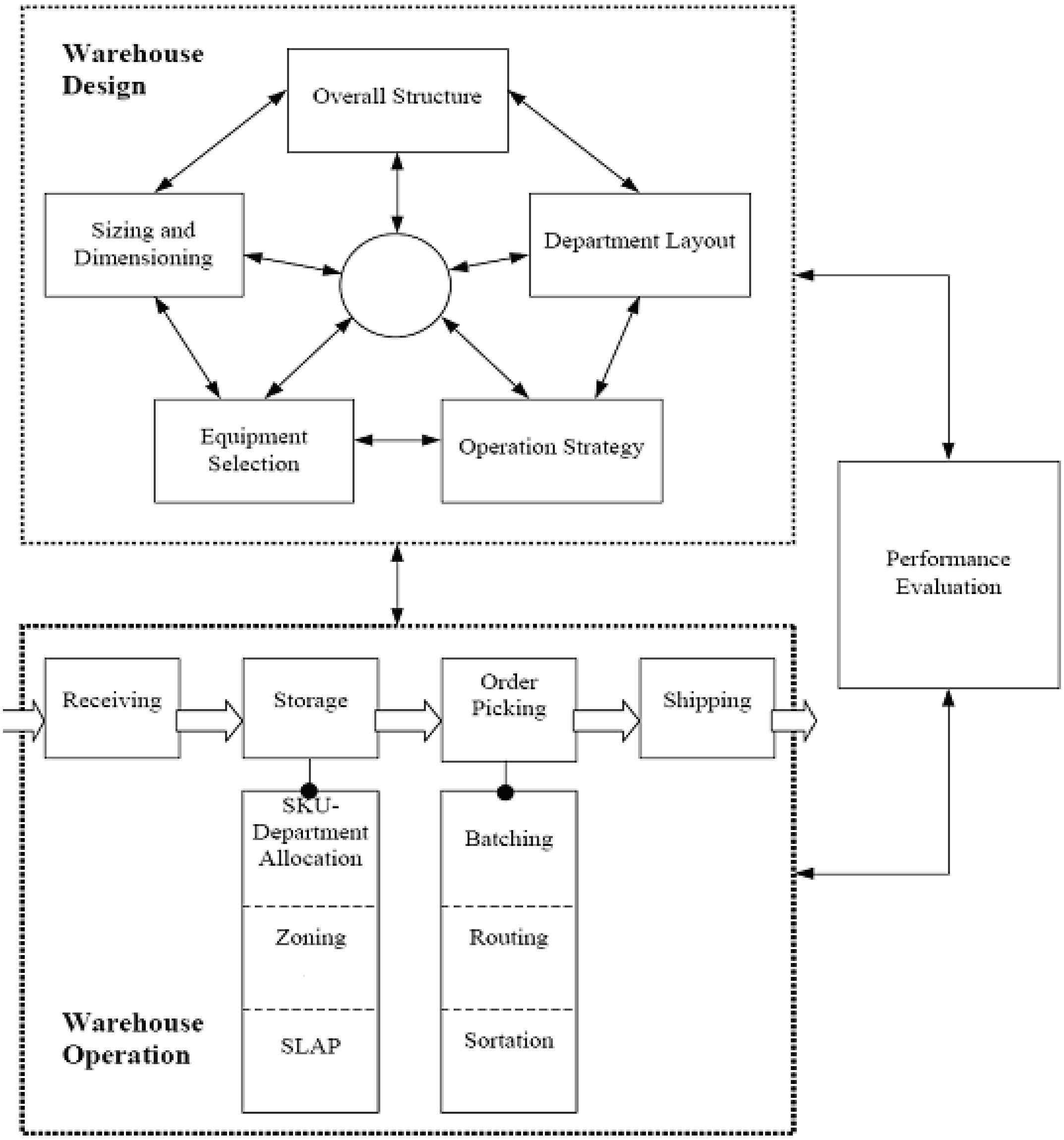


Figure 15: Graphical representation warehouse design model (Gu 2005)

6.1.4) Baker et al (2007)

In his article Baker compares both frameworks that have been mentioned by other authors, as well as those that are used by companies specialized in warehousing in order to come up with a general framework for warehouse design. According to the article, warehouse design consists of the following 12 steps:

1) Define system requirements: Refers to the requirements that are valued in the whole supply chain, and also includes matters like planning and environmental issues.
2) Define and obtain data.
3) Analyze data: Plain data needs to be analyzed in such a manner that it can support decision making.
4) Establish unit loads to be used.
5) Determine operating procedures and methods: This step refers to matters like batching, zoning and so on.
6) Consider possible equipment types and characteristics.
7) Calculate equipment capacities and quantities.
8) Define services and ancillary operations.

9) Prepare possible layouts.
10) Evaluate and assess.
11) Identify the preferred design.

6.2) Selection of warehouse design model

Now several warehouse models have been explained, it is time to select the model that can best be used to design the warehouse of Straatsma. After introducing three criteria that will be used to evaluate the warehouse design models, I will rate the models to see which warehouse design model can best be used.

Since formal criteria indicating which design model to use in which situation are nonexistent, a number of plausible criteria will have to be contrived. It was decided to rate the models based on the following criteria:

- Appropriate design levels: For the design of the warehouse of Straatsma it is necessary to make both strategic decisions, as well as operational decisions. It is very beneficial if this is incorporated into the design model.
- Adaptability: Certain decisions that are relevant in normal warehouse design processes might not be important in others. It is convenient when such changes do not disrupt the model to a great extent. The same thing can be said about decisions that are added.
- Prescriptiveness: The decision to search for a general warehouse model was made in order to have a good overview about the decisions that need to be made, and the order in which to make them. Whether models are prescriptive in this sense is the last criteria on which the models will be rated.

In the table below it can be seen how the models score on the different criteria that have just been introduced.

Model / Criteria	Appropriate design levels	Adaptability	Prescriptiveness
Govindaraj et al (2000)	+	+	--
Rouwenhorst et al (2000)	++	++	-
Gu (2005)	+	++	-
Baker et al (2007)	--	-	+

Table 6: Scoring warehouse design models

A short discussion will reveal why the models have obtained the scores that are depicted in the table above.

Govindaraj et al (2000)
A plus is scored on the criterion appropriate design levels because of the distinction between high level architecture and systems specification and optimization. The model scores a very narrow plus on adaptability because it commits to almost nothing. This mean there is liberty with how to proceed. The model of Govindaraj scores very badly on prescriptivenes. First of all, little is mentioned about the different subjects that have to be discussed. Secondly there no information about how to proceed in the stages architecture and system specification and optimization.

Gu (2005)
With regard to appropriate design levels the mode of Gu scores a plus because of the difference between high level warehouse decisions and low level warehouse operations. The model scores full points on adaptability. Decisions can easily be added to both the subjects that are distinguished in the section about warehouse decisions, as well as to the different processes that are mentioned under warehouse operations. A lower score is allocated on

prescriptiveness. The process does not have a clear starting or end point, while a clear explanation on how to incorporate performance analysis is also neglected.

Rouwenhorst et al (2000)
Because three different design levels have been distinguished, the model scores full points on the first criterion. The fact that it is very easy to either incorporate or remove decisions relating to both resources and organization regarding all warehouse processes results in the highest possible score on adaptability. The model scores lower on prescriptiveness. Although it provides a good overview about the different decisions that need to be made within a design stage, it is stated that the decisions have to be made simultaneously.

Baker et al (2007)
The model of Baker is assigned the lowest possible score on appropriate design levels. This is because the model is not equipped to make operational decisions. The model also scores bad on adaptability. Removing or adding a number of decisions clearly disrupts the model. The model is rated a plus on prescriptiveness. It indicates the different decisions that need to be made, and the order in which to make them reasonably well.

When looking at the table that indicates the scores of the various frameworks for warehouse design, it is clear that the model of Rouwenhorst is most suitable for usage in the remainder of this thesis. It scores higher or just as high on all criteria in comparison to the models of both Govindaraj and Gu, while the scores of the model that is presented by Baker on both appropriate design level and adaptability makes it impossible to select this model. This does not mean that the other models are completely disregarded. Because of the adaptability of the model of Rouwenhorst, it is possible to incorporate decisions from other warehousing design models.

6.3) Usage of framework for warehouse design

The remainder of this thesis will be based on the warehouse design model of Rouwenhorst et al (2000). Chapters seven to nine will each correspond to one of the design levels. The first section of each of these chapters is an introduction that is explanatory for how the model of Rouwenhorst is used to design the warehouse of Straatsma. It consists of three sections.

Overview of relevant decisions
The introductions will start with a chart similar to the ones that were introduced when explaining the model that depicts the relevant decisions that Straatsma has to make. Here it becomes clear that the model will not be used exactly as was described in the previous section. Certain decisions that were depicted on the charts corresponding to the design levels when introducing the model will not receive attention:

- When making decisions on warehouse subjects, other decisions may become obsolete. There is no need to consider several sorting systems when you are not going to batch orders.
- Most decisions that need to be made at the operational level will be disregarded because they fall outside the scope of this investigation.

On the other hand there are also decisions that are added compared to the charts presented earlier. The model was selected partly because of its adaptability. Decisions from other warehouse models can be added when this provides additional insight.

Flow diagram
According to the model of Rouwenhorst, the decisions at a certain design level need to be solved simultaneously. There seem to be differences among the various decisions that are mentioned at a certain design level however.

- Certain decisions can be made based on a combination of theory, the design objectives and the findings of activity profiling, without much emphasis on other decisions.
- There are also decisions that can only be made properly when other decisions at the same design level have already been discussed.
- In some situations decisions are in fact very much related. The consequences of one decision severely affect the other decision, but also the other way around.

A flow diagram will be presented in order to illustrate in what order to make the for Straatsma relevant decisions. It indicates which decisions can be made rather independently, and which are heavily dependent on others.

Confrontation matrix
In the third section of the introduction, a confrontation matrix will be presented that links the design objectives to the various decisions that need to be made. It will indicate which design objectives are especially important when making certain decisions. This is helpful in order to understand the remainder of the chapter.

When the introduction is ended the different decisions that need to be made will be worked out in the subsequent sections. The numbers in the flow diagrams will correspond to the sections in the chapters to provide a good overview. One last important remark is that the warehouse design model is a way to structure the decision process. It does not provide all the answers with regard to the decisions that need to be made.

6.4) Conclusions

This chapter started with a brief literature review on warehouse design models, after which four different models that could be extracted from literature were explained. When making a comparison based on appropriate design levels, adaptability and prescriptiveness, the model of Rouwenhorst et al (2000) proved to be the most appropriate option.

The model of Rouwenhorst divides the warehouse design process in three stages: strategic, tactical and operational. Each of the decisions at a certain design stage are supposed to be made simultaneously. The following chapters correspond to the design levels that are mentioned in the model. The model will not be used exactly as was described in theory. There are certain decisions that are not important for Straatsma, while other decisions can be added to provide additional insight. To use the framework each of the following chapters will start with an introduction that has three purposes:

- The different decisions that are important to Straatsma will be displayed.
- A flow diagram will indicate the order in which to make the various decisions.
- Which design objectives are crucial for Straatsma when making the necessary decisions will become clear by means of a confrontation matrix.

Once the confrontation matrix has been presented the different decisions that are important to Straatsma will be made in the subsequent sections.

7) Strategic decisions warehouse Straatsma

Section 7.1 will be an introduction about the different strategic decisions that Straatsma needs to make, as was discussed in section 6.3. In the subsequent sections each of the relevant strategic decisions will receive brief attention. Section 7. 6 will summarize the main findings of this chapter.

7.1) Introduction strategic decisions

The purpose of this introduction is to indicate in what way the model of Rouwenhorst et al (2000) is used in relation to strategic decision making. It will consist of an overview of the relevant decisions, a flow diagram and a confrontation matrix.

Overview strategic decisions

In the figure below I present an overview of the different strategic decision that Straatsma needs to make. The figure also indicates which of the major warehouse processes is involved, and whether it relates to resources, or organization.

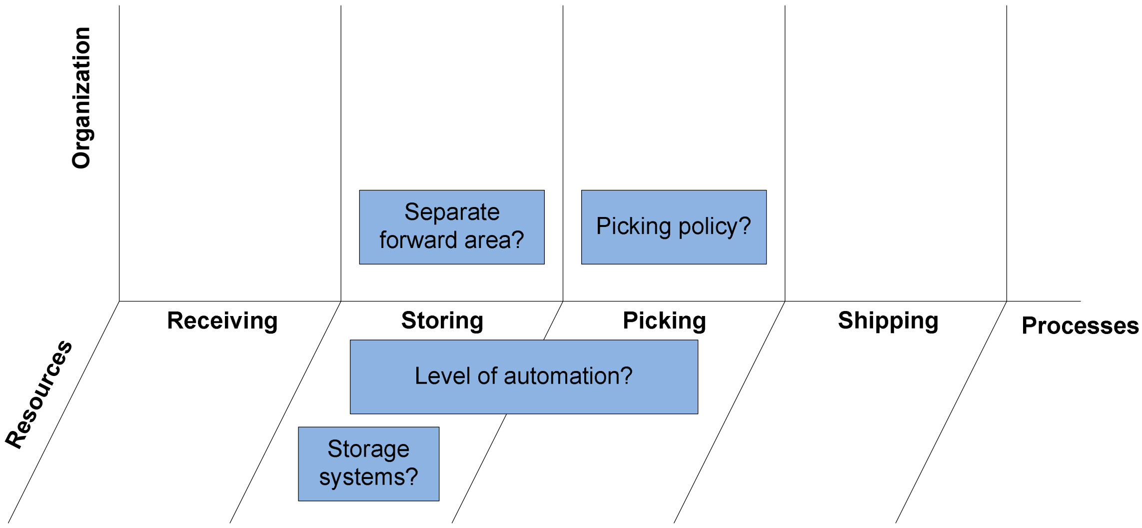


Figure 16: Overview strategic decisions

When comparing the overview that was just presented with the overview of relevant decisions that was displayed when introducing the theory of Rouwenhorst, there are two major differences:

- The decisions about the sorting system and the storage unit can be neglected. As will become clear in this chapter, Straatsma will not make use of batching in a structural manner, which makes a discussion about various sorter types redundant. The storage unit will also not be investigated. Suppliers of Straatsma deliver the products on both euro and block pallets. This will simply have to be taken into account in the design of the warehouse.
- The level of automation is a strategic decision that has been added. Although this decision was mentioned in the article of Rouwenhorst, it was not depicted in the overview that was presented.

Flow diagram strategic decisions

The flow diagram that I have displayed in the figure below indicates in which order the different strategic decisions will be made.

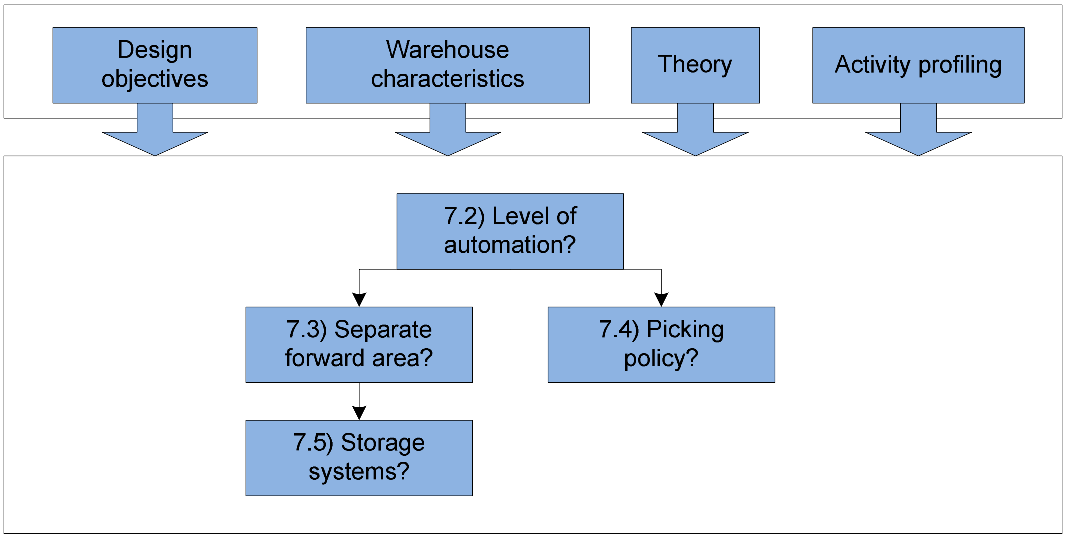


Figure 17: Flow diagram strategic decisions

It is clear that the level of automation is something that needs to be considered in the beginning of any warehouse design. It clearly affects almost any other decision that has to be made. After the most appropriate level of automation has been determined, decisions with regard to the picking policy and whether or not to have a fast pick area will be discussed. It is important to consider the storage types after the decision whether or not to have a fast pick area, since the storage type in a fast pick area can very well be different from the type that is used in the remaining warehouse.

Confrontation matrix

In the figure below I have indicated which design objectives are especially important with regard to the different strategic decisions that need to be made.

	Decisions			
Design objectives	Level of automation?	Seperate forward area?	Order picking policy?	Multiple storage systems?
Minimize total cost	x	x		x
Maximize space utilization		x		x
Minimize order picking time			x	x
Maximize order accuracy			x	
Effective working conditions				
Maximize flexibility				

Figure 18: Confrontation matrix strategic decisions

The figure above does not need any explanation. Why certain design factors are important will become clear in the remainder of this chapter.

7.2) Level of automation

A classification that was proposed by De Koster et al (2006) was used to decide on the level of automation, since it provides a good overview of the different possibilities. The classification is depicted in the figure below.

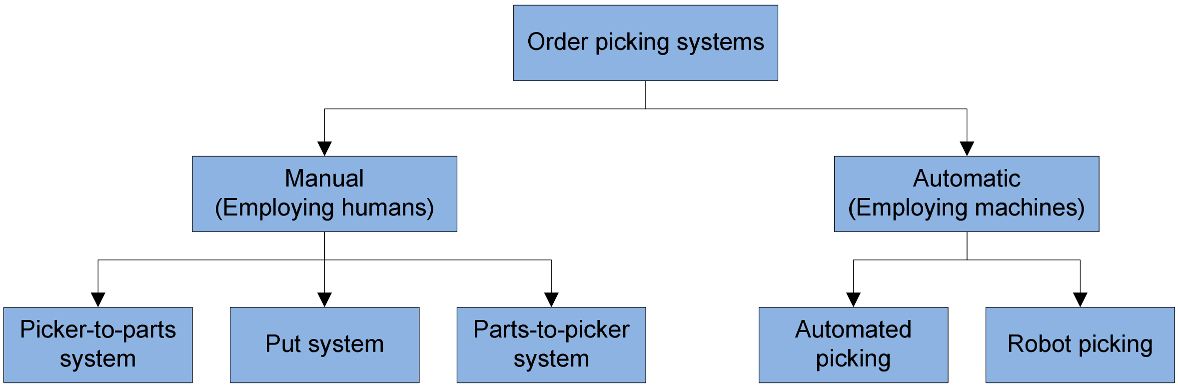


Figure 19: Classification of order picking systems (De Koster et al 2006)

To determine which level of automation is most suitable for Straatsma was rather straightforward. Automated picking operations are not an option, since they are considered only when dealing with relatively small, uniform sized valuable items (van den Berg & Zijm 1999; Le Duc 2005). 'Put systems' and 'Parts to picker systems' do not need to be considered either. These systems all require significant investments in technology, which cannot be justified when the time span is only three to five years. A 'picker to parts system' is the most appropriate order picking system for the new warehouse of Straatsma. This means that the level of automation will be low.

7.3) Separate forward area

Which types of forward areas can be appropriate depends on the pick size of the operation. (Bartholi & hackman 2007). Straatsma is a company that deals predominantly with case picks. With regard to case picks, there are two plausible forward area configurations:

- Picks are made from locations on the ground, while bulk pallets that are used for replenishing are stored in the pallet locations that are positioned directly above the pick location.
- Picks are made from a pallet flow rack onto a conveyer, that transports the items to a sorting area. Bulk pallets are stored in a reserve area.

To determine whether it is sensible to have a forward area, it was necessary to analyze whether the two plausible forward area configurations are suitable:

- It is not possible to reserve the pallet locations that are positioned directly above the pick location of a fast moving SKU solely for bulk pallets of this specific SKU. Doing this would result in empty pallet locations in situations when the number of bulk pallets of this specific SKU is limited. This is unacceptable when bearing in mind the shortage in storage capacity.
- Making picks from a pallet flown rack is also not an option. First of all it was decided to keep the level of automation low. A second reason, that will receive additional attention later in this thesis, is that a pallet flow rack is not suitable for the operations of Straatsma.

When analyzing the remarks above, it can be concluded that having a separated forward area in the new warehouse is not a sensible option.

7.4) Picking policy

Different picking policies can be distinguished. According to Tompkins (2003) the three major picking policies are discrete order picking, batch picking and zone picking. Wave picking is sometimes mentioned as a fourth distinctive policy. The picking policies are not multi exclusive. In the table below the different picking policies have been displayed.

Method	Pickers / order	Lines / pick	Periods / shift
1) Discrete	One	One	One
2) Zone	Multiple	One	One
3) Batch	One	Multiple	One
4)Wave	One	One	Multiple
5) Zone-batch	Multiple	Multiple	One
6) Zone-wave	Multiple	One	One
8) Zone-batch-wave	Multiple	Multiple	Multiple

Table 7: Order picking policies

To determine which picking policy is most appropriate for Straatsma two different methods were used:

- In the article of Piasecki (2001), a prescriptive theory was introduced that indicates when certain picking policies are encountered. It is indicated that when dealing with case picks, discrete order picking is often the most suitable policy. Other policies are only seen in certain special circumstances.
- Using only a prescriptive theory does not seem wise. In order to make a sound decision, it was investigated whether Straatsma can benefit from the theoretical advantages that zone picking, batch picking and wave picking offer. Possible drawbacks were of course also considered. The findings are presented in appendix 5. It appeared that there are several reasons why Straatsma cannot actually benefit from the general advantages of zone picking, batch picking and wave picking, while the policies do seem to have certain drawbacks.

Discrete order picking is the most suitable order picking policy for Straatsma. It is very important to note that this does not mean that it is not possible for warehouse personnel to collect two orders at the same time when they feel this is appropriate. There is no need to formalize this however. It is not necessary to investigate for instance batching policies to obtain combined picking lists.

7.5) Storage systems

There are a large number of different types of storage systems. A small explanation of various types of storage systems can be found in appendix 6. Not all storage systems are suitable for Straatsma however. Based on the articles of Brown et al (1996) and Parrot (1981), a list of factors that need to be taken into account when selecting a storage system was drawn up, in order to determine which storage system do not need any consideration. In the figure below, I have indicated which storage systems can be disregarded, and which factors are responsible for this. In appendix 7 it will be explained why certain storage systems do no longer need consideration as a result of the factors that are mentioned by Brown and Parrot.

Storage systems	Factors influencing storage system selection						
	Product characteristics	Material handling equipement	Throughput requirements	Layout considerations	Budget considerations	Fire protection system	Storage unit
Floor stacking	x						
Standard selective pallet rack							
Double deep rack			x				
Drive-in rack			x				
Drive-through rack			x				
Push back rack			x				
Pallet flow rack			x				
Carton flow rack	x		x		x		
Shelving							
Cantilever rack	x						
Movable rack					x		
Mezzanine	x				x	x	

Figure 20: Suitability different storage systems

After conducting the pre selection, it appeared that only the standard selective pallet rack and shelving are feasible alternatives for Straatsma. Analyzing the advantages and disadvantages of both systems showed that both systems can be used in the new warehouse, since they facilitate the storage of different types of products. Shelving can be used in the secondary warehousing area, while the standard selective pallet rack is an excellent storage system for the main warehousing area. An analysis of the specific advantages and disadvantages of the standard selective pallet rack and shelving can be found in appendix 8.

7.6) Conclusions strategic decision making

In this chapter several decisions of a strategic nature have received attention. Four topics have been discussed: level of automation, separate reserve area, picking policy and storage systems. It was decided that the new warehouse of Straatsma requires a low level of information. Systems with a high level of automation require high initial investments which cannot be justified when the time span is only three to five years.

After analyzing the pick size, it was possible to identify two forward area configurations that are appropriate according to literature. Neither of the two configurations appeared suitable for Straatsma however. In one configuration it is impossible to achieve high space utilization, while the other configuration requires high initial investments.

It is possible to distinguish multiple picking policies. In order for a company to determine which policy to select, it is necessary to analyze whether a company can benefit from batch picking, zone picking or ware picking. For Straatsma it is not sensible to adopt one of the strategies mentioned. While it is not possible to benefit from the general advantages, some of the strategies do have significant drawbacks. Discrete order picking, which is also called single order picking, is the most appropriate strategy for Straatsma. This coincides with a prescriptive theory that was also analyzed.

After introducing several types of storage systems, a pre selection was made based on a number of criteria. All two storage systems that survived the pre selection appeared to be suitable for Straatsma. The single selective pallet rack is the appropriate storage system in the main warehousing area, while shelves can be used in the secondary warehousing area.

8) Tactical decisions warehouse Straatsma

This chapter will start with an introduction about the tactical decisions that are relevant for Straatsma in section 8.1. The tactical decisions that need to be made will be discussed in the following sections. Section 8.5 will state the main conclusions of this chapter.

8.1) Introduction tactical decisions

This introduction will make clear in what way the model of Rouwenhorst et al (2000) is used in order to deal with decisions of a tactical nature. It will consist of an overview of the relevant decisions, a flow diagram and a confrontation matrix.

Overview tactical decisions

In the figure below it can be seen which decisions of a tactical nature will receive attention in this chapter.

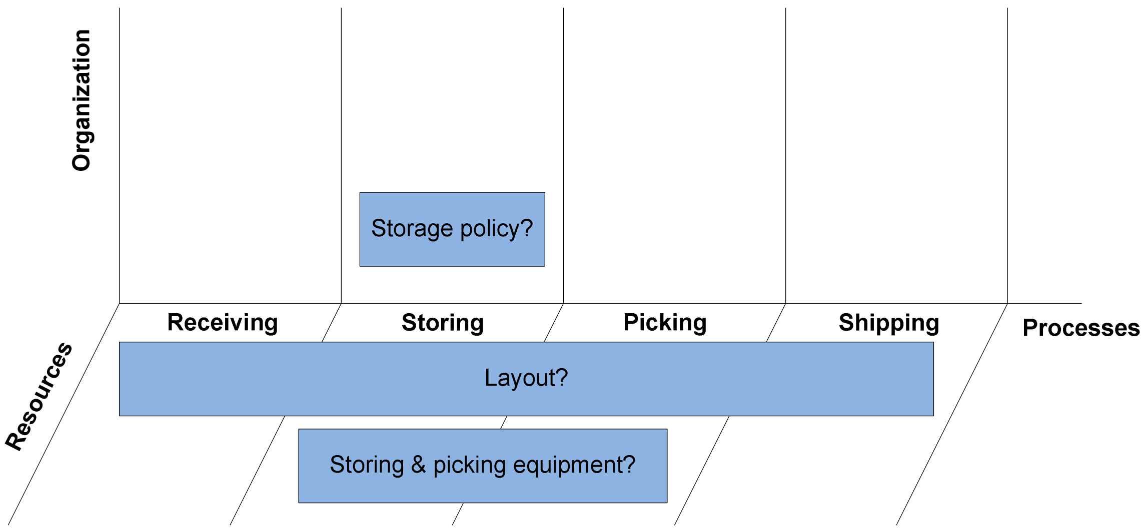


Figure 21: Overview tactical decisions

There are a number of differences when comparing the figure above, with the figure that was presented in the explanation of the model of Rouwenhorst:

- There is no need to discuss the batch size, pick zones, technical zones and the size of the forward area as a result of several strategic decisions that were made in the previous chapter.
- It is not necessary devote a separate paragraph to the docks. Since Straatsma deals with an existing building, the number of docks are a given. Which docks will be used for which purpose was already mentioned in the section about the flow capacity.
- The peripheral equipment and work force capacity is outside the scope of this thesis.

One last remark that needs to be make is that matters like routing and the picking method were not added as decisions. The layout that will be presented will make clear that routing is not an issue. Picking methods are not discussed because Straatsma is not considering to deviate from working with picking lists at this moment.

Flow diagram tactical decisions

The flow diagram that I depicted below indicates in which order the tactical decisions will be made.

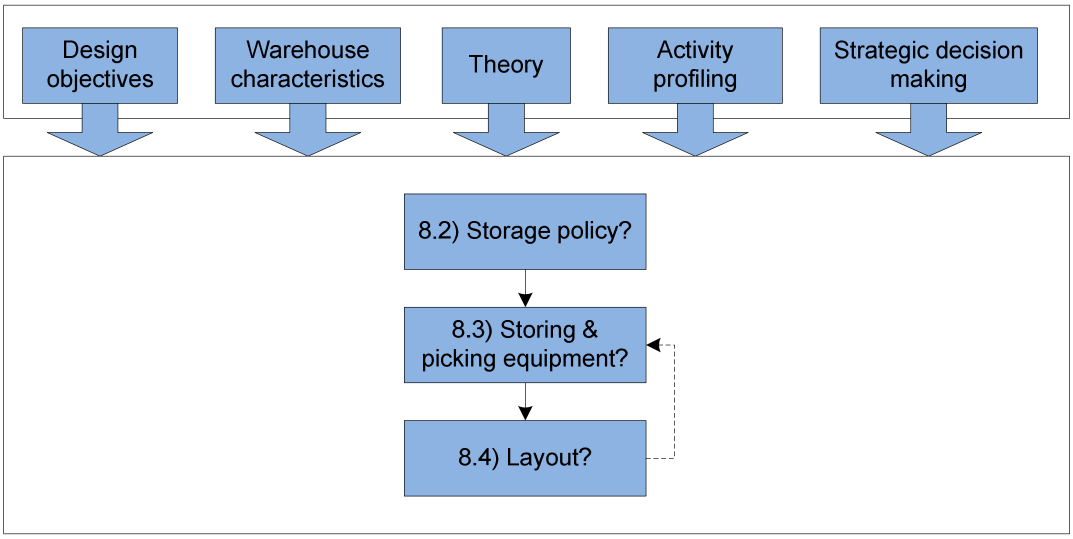


Figure 22: Flow diagram tactical decisions

The picking policy is the first tactical decision that will be discussed. The decision with regard to the warehouse trucks will be made next, since it is essential to know the required aisle width before designing the layout of the new warehouse. It must be noted however that it is impossible to treat the two decisions strictly sequential. The layout will also be a factor that needs to be taken into account when selecting warehouse trucks.

Confrontation matrix
In the confrontation matrix below I have indicated which design objectives are essential when making the various tactical decisions.

	Decisions		
Design objectives	Storage concept?	Layout?	Storage & picking equipment?
Minimize total cost			x
Maximize space utilization	x	x	x
Minimize order picking time	x	x	x
Maximize order accuracy			
Effective working conditions	x	x	x
Maximize flexibility			x

Figure 23: Confrontation matrix tactical decisions

In analogy with the previous chapter there is no need to elaborate on the matrix at this point. The remaining sections will make clear why certain design objectives are labeled as essential with regard to certain decisions.

8.2) Storage policy

When goods arrive at a warehouse, they have to be assigned to a certain storage location. The objectives of this so called storage location assignment problem (SLAP) are to reduce material handling costs and improve space utilization (Gu 2005). The SLAP will be dealt with in two design levels. In this section a storage policy is selected that indicates on what basis products are assigned to locations. The SLAP will also play a role in the operational stage in order to decide on where to locate which rack configuration.

The different storage policies that can be distinguished in literature have been investigated. It appeared that the level of detail is an important reason why there is no general consensus among authors. It is possible to argue that there are in fact only three storage policies: random storage, dedicated storage and class based storage. It must be noted that it is not necessary for a company to choose one storage policy. It is not uncommon that companies use multiple storage policies within one warehouse. An overview of which storage policies can be distinguished can be seen is appendix 9.

Companies that want to have an efficient order picking process without sacrificing the space utilization often have dedicated pick locations with random bulk locations. Since these objectives are also relevant to Straatsma, it has been investigated whether this is a sensible storage policy for the new warehouse. After analyzing possible benefits from correlated storage and full turnover storage, it became clear that having dedicated pick locations is very beneficial for Straatsma. Storing packaging materials of a single customer in close proximity to each other can significantly reduce the travel times of order pickers. A detailed discussion about the benefits of dedicated locations for Straatsma can be found in appendix 10. Because of the low number of bulk locations compared to the number of pick locations, the storage policy does not attain a space utilization that is sufficiently high.

One variant of full turnover storage, the Cube Order Index (Heskett 1963), will be used when designing the pallet rack configuration in section 9.4. The formula is therefore depicted below.

$$COI = \frac{\text{Re}\,quired\ storage\ locations}{Pick\ rate}$$

Equation 3: COI

In order to achieve a high space utilization it is necessary for Straatsma to store multiple SKUs on a single location. The essence of this deviant form of shared storage is that two or more SKUs share a certain storage location in order to minimize the amount of storage space that is required. This can be achieved by scheduling deliveries of SKUs that are stored together at different moments in time, thereby decreasing inventory peaks and spreading them over time. The figure below illustrates the effect described.

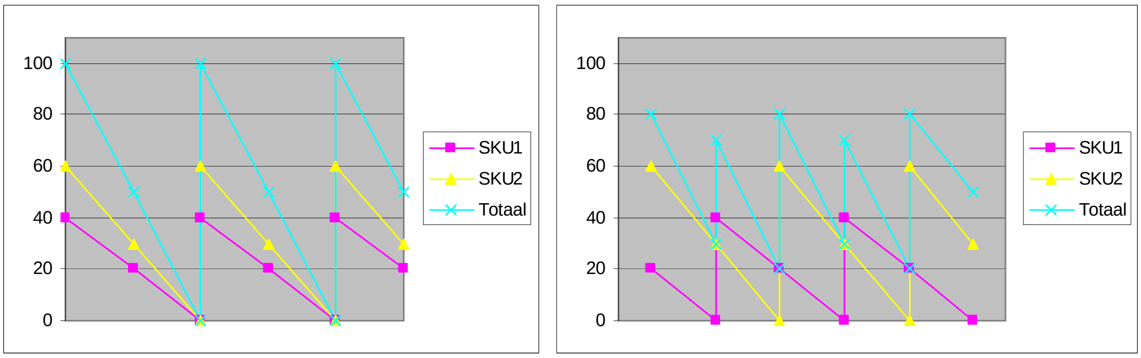


Figure 24: Decreased inventory peaks by spreading orders over time

No existing literature could be found with regard to storing multiple SKUs on a single storage location. A new method was developed to incorporate this policy into warehouse design. The new method enables to determine the effect that storing multiple SKUs on a single location has on the total storage capacity that is needed.

When applying this deviant form of shared storage, SKUs are first assigned to a single location, in order to subtract the number of instances in which two SKUs can share a single location. Determining when two SKUs can share a storage location is only possible when there is insight into the maximum space that is needed to store the SKUs. The formula that is used for this purpose is depicted in the figure below (Hall 1987).

$$Q_{\max} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{i} D_i * D_j}{\sum_{i=1}^{m} D_i} * T$$

$i, j = 1..m \quad = Number\ of\ SKUs$

$D_i = Demand\ volume\ of\ SKU_i$

$Q_{\max} = Maximum\ volume$

$T = Throughput\ time$

$m = Number\ of\ SKUs\ combined\ on\ single\ location$

Equation 4: Maximum storage volume

The formula calculates the lowest possible maximum storage space that is needed for a number of products that share a storage location (in this case m = 2). It is important to mention the underlying assumptions of the model that has been presented.

- It is obvious that the storage space that is needed depends to a large extent on the deliveries of the products that are stored together. In the model it is assumed that the deliveries occur at the ideal moment.
- The model does not take into account safety storage. The inventory is assumed to be equal to zero when a delivery of a certain product takes place.
- Products are assumed to have exactly the same throughput time (T). The time between two deliveries is equal for all products that are stored together.

It is necessary to take the underlying assumptions of the model into account when making calculations. Ignoring them would result in unrealistic benefits, which cannot be realized in real life. Information with regard to which SKUs are applicable for being stored together, how the assumptions of the model are incorporated into the calculations and what effect shared storage has on the capacity requirements can be found in section 9.3. In this thesis, I have decided to refer to storing multiple SKUs on a single location as shared storage.

8.3) Storing and picking equipment

In order to determine which equipment is most suitable for storing and picking activities the following classification was used.

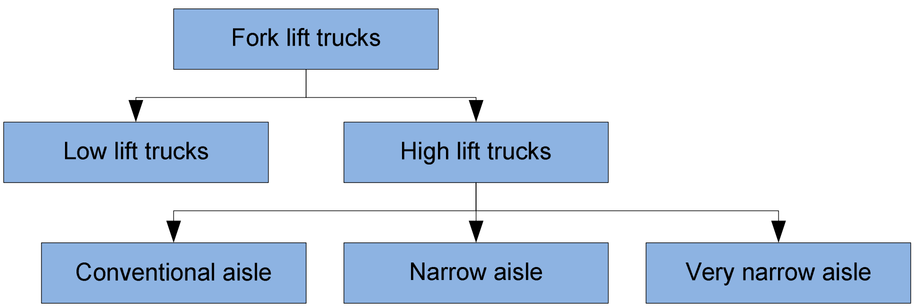


Figure 25: Categorization of fork lift trucks (Kulwiec 1985)

The trucks that Straatsma will use for order picking will require a lift capability, because of the large number of SKUs and the relatively limited warehouse floor. This combined with the decision to use back-to-back selective pallet racks results in the fact that both the trucks for unit load movements and order picking will have to come from the same category. After analyzing the advantages and disadvantages of both conventional aisles and very narrow aisle, it became clear that narrow aisles are the most appropriate for the new warehouse of Straatsma.

Within the category of narrow aisles there are multiple trucks that can be used for order picking and unit load movements. A list of key performance indicators (KPI) was drafted based on the articles of Brown et al (1996), Mulcahy (1994) and Piasecki (2003). I rated the different trucks on the basis of : cost/productivity, space utilization, flexibility and effective working conditions. How different trucks score on the KPIs is visible in the tables below.

Key performance indicators	Reach truck	Straddle truck
Cost / productivity	-	+
Space utilization	-	+
Flexibility	+	-
Effective working conditions	+	+

Table 8: Selection truck unit load movements

Key performance indicators	Reach truck	Straddle truck	High level order picker
Cost / productivity	-	-	+
Space utilization	-	+	+
Flexibility	+	+	+
Effective working conditions	-	+	-

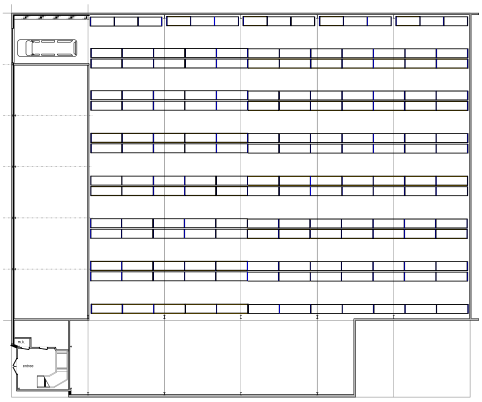
Table 9: Selection truck order picking

Based on the high emphasis on cost/ productivity and space utilization, it was decided to use straddle trucks for unit load movements and high level order pickers for order picking activities. A more detailed discussion about the selection of storing and picking equipment can be found in appendix 11.

8.4) Location of storage systems

Before being able to decide on where to locate certain storage systems, it was necessary first to make a number of preliminary decisions. Matters that required attention are: the direction of pallet placement, the aisle width, the exact type of racks, and the cross aisle.

Once the preliminary decisions were made, it was time to look at the layout of the main warehousing area. Not everything was incorporated at once. Based on the article of Frazier (1991) all obstacles except the main warehousing columns were initially ignored. A number of simplified layouts were created in order to determine which basic disposition is most promising. The basic disposition indicates in which direction to place pallet racks, and how to deal with the main warehousing columns. Two simplified rack layouts are visible in the figures 26 and 27.



Rows	Racks (2.70m)	Racks (3.60m)	Locations (pallets)
13	-	12	624
1	15	-	45
		Sum:	**669**

Figure 26: Simplified rack layout basic disposition 1

Rows	Racks (2.7m)	Racks (3.6m)	Locations (pallets)
18	-	9	648
		Sum:	**648**

Figure 27: Simplified rack layout basic disposition 2

The aisles are a bit shorter in the second layout, which normally has a positive effect on material handling. This does not compensate for the difference in storage capacity however. The higher space utilization in layout one is a convincing reason why this basic disposition is the most promising when bearing in mind the shortage of storage space.

The fact that placing pallet racks along the long side of the building results in a potentially higher capacity did not automatically mean that this disposition was selected. It was first necessary to analyze the effect of staircases, fire extinguishers, fire escapes, the expedition area, the cross aisle and the corridor to the second warehousing area. Although these matters do of course affect the storage capacity, it appeared that there was no reason to alter the basic disposition.

Once the rack layout of the main warehousing area was created, it was necessary to design a layout for the secondary warehousing. Relevant to mention is that the direction in which to place racks was determined based on the location of the windows. Of course various obstacles like a security laser and a door influenced the exact layout.

With regard to storage capacity, the main warehousing area offers space for 522 pallet locations on the ground. The number of locations in the secondary warehousing area, when assuming three locations (0.50m x 1.00m x 1.00m) located on top of each other is 675. In figure 28 the total rack layout has been depicted. A more detailed discussion about the location of the storage systems can be found in appendix 12.

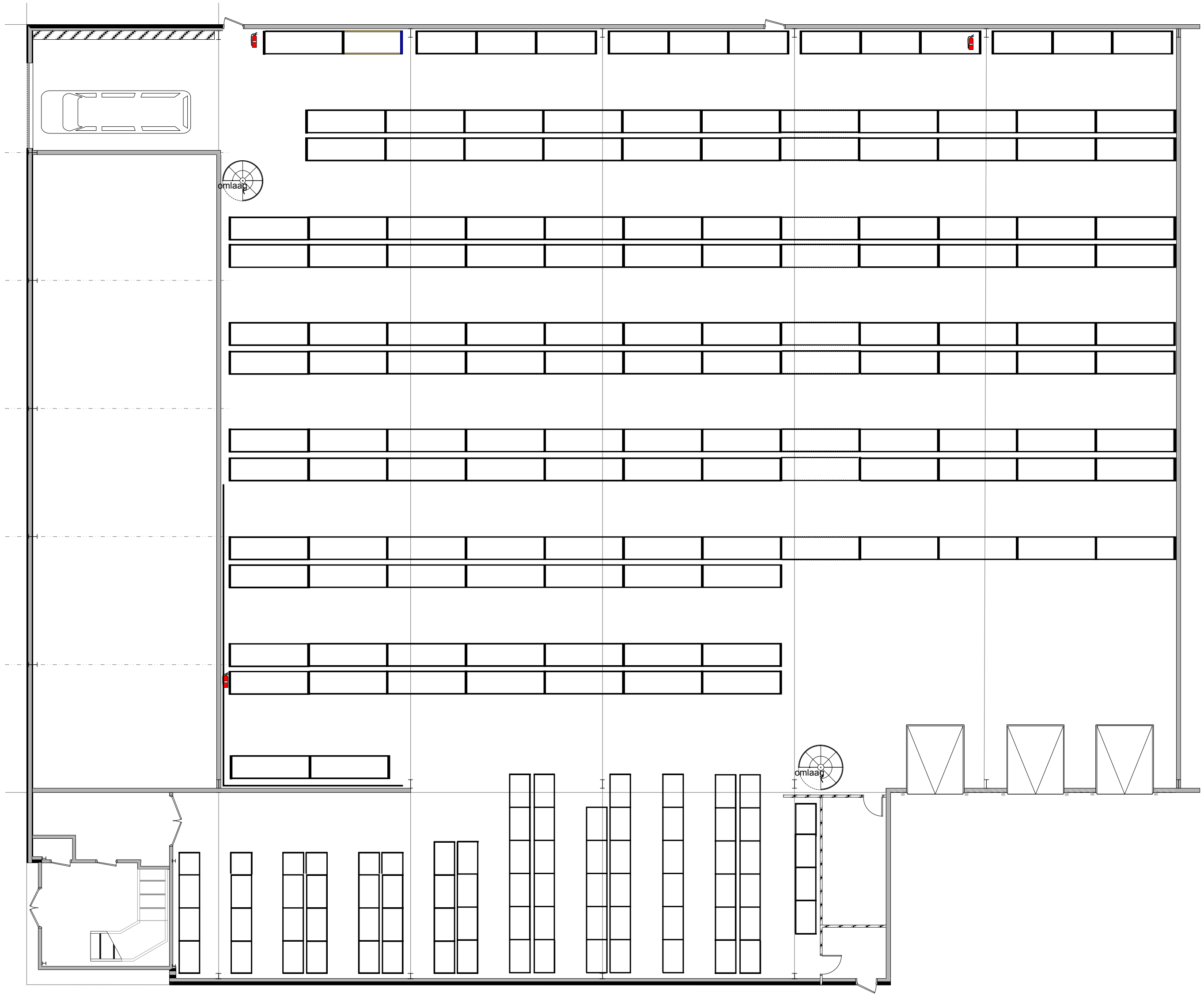


Figure 28: Final rack layout

8.5) Conclusions tactical decision making

In this chapter decisions have been made about the storage policy, the type of trucks that Straatsma needs and the layout of the racks. It appeared that Straatsma requires different storage policies in order to attain the right balance between space utilization and material handling. It is sensible to store products always on the same location since this facilitates an efficient order picking process. Random storage is the most appropriate policy for bulk pallets. As a consequence of the large amount of pick locations, compared to bulk, it is not possible to achieve high space utilization solely by storing bulk pallets in a random fashion however. It will be necessary to store multiple SKUs on a single location in order to compensate for the fact that pick locations generally have a space utilization that is only slightly higher than 50%. Since no theory was available in literature, a new method was developed to incorporate the fact that multiple SKUs can be stored on a single location. SKUs are first assigned a separate location in order to subtract the number of instances in which two SKUs can share a certain storage location.

After making a classification with regard to the different types of trucks that exist, it appeared that the trucks that Straatsma will use for order picking and unit load movements will have to come from the same category. After analyzing the advantages and disadvantages of different aisle widths, it became clear that high lift trucks that can operate in narrow aisles are the most suitable for Straatsma. Within this category multiple trucks can be distinguished. With regard to both order picking and unit load movements, different trucks have been compared on the basis of cost/ productivity, space utilization, flexibility and effective working conditions. Using a combination of the straddle truck and the high level order picker proved to be the best option for Straatsma.

Several topics needed to be discussed before it was possible to design a layout. Once these topics had been discussed, a number of simplified rack layouts were created for the main warehousing area in order to determine the most promising basic disposition. The effects of objects within the warehouse, the cross aisle, the corridor to the secondary warehousing area and the expedition area on the storage capacity were analyzed in order to determine whether the most promising basic disposition was in fact the best choice. Since there was no need to deviate from the basic disposition that was initially selected, the next step was to design the rack layout for the secondary warehousing area. After completing the total rack layout, it became clear that the storage capacity of the new warehouse entails 522 pallet locations on the ground in the main warehousing area, and 675 shelf locations in the secondary warehousing area.

9) Operational decisions warehouse Straatsma

Section 9.1 will be an introduction about the decisions of an operational nature that need to be made. In the next few sections, each of the operational decisions that need to be made will receive individual attention. In section 9.5 the main findings of this chapter will be summarized.

9.1) Introduction

This introduction will differ from the introductions that were given at the beginning of the last two chapters. As was mentioned in section 6.3, most operational decisions are outside the scope of this thesis. Displaying an overview to compare the differences between the operational decisions that were mentioned by Rouwenhorst to the decisions that will receive attention in this chapter is therefore useless. A confrontation matrix is not displayed either because the nature of the decisions in this chapter do not really require a tradeoff between the various design objectives. A flow diagram is presented in order to illustrate which operational decisions will be discussed in this chapter and to explain why the decisions are made in a certain order.

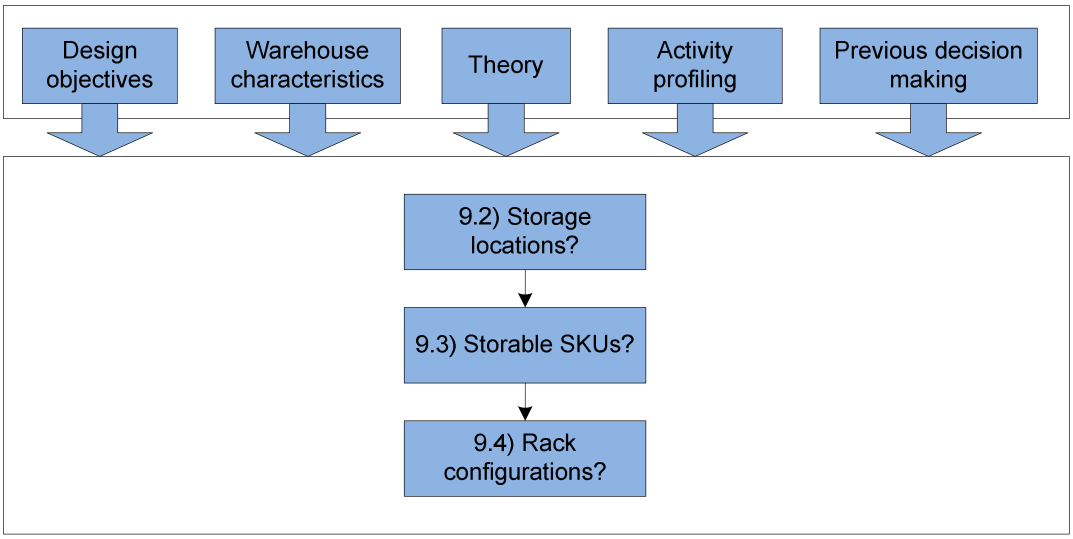


Figure 29: Flow diagram operational decisions

Before discussing which SKUs can be stored in the new warehouse and where to place which pallet rack configuration, it is necessary to determine the dimensions of the storage locations that will be used to assign SKUs to. Once the sizes of the storage locations have been determined, it can be analyzed which SKUs can be stored in the new warehouse in which quantity. Where to position which pallet rack configuration is the last decision, since it obviously requires the input from the previous two decisions.

9.2) Sizes of storage locations

It was important to carefully consider the number of different locations that are used to assign SKUs to. This number cannot be too small, since this would result in a loss of storage space. Choosing this number too high is not wise either. Having a large number of different storage height results in an inflexible warehouse, in which cannot easily be operated. The fact that certain products can best be placed on block pallets is also something that needs to be taken into account.

The dimensions of the storage systems were chosen in such a way that locations are suitable for the storage of certain large product groups. It was made sure that block and euro pallet locations have similar heights, in order to facilitate an easier rack design. SKUs are assigned to the following locations.

Location	Width (m)	Depth (m)	Location height (m)	Stackable height (m)
Shelf	0.40	0.80	0.60	0.60
Euro 0.60m	0.80	1.20	0.95	0.60
Block 0.60m	1.00	1.20	0.95	0.60
Euro 1.00m	0.80	1.20	1.35	1.00
Euro 1.55m	0.80	1.20	1.90	1.55
Block 1.55m	1.00	1.20	1.90	1.55
Euro 2.05m	0.80	1.20	2.40	2.05

Table 10: Sizes of storage locations

An explanation of each size of location can be found in appendix 13 .Although it is labeled an operational decision, sizes of storage locations were already analyzed at an early stage. In fact it was not clear that multiple products would be assigned to a single storage location. Although SKUs are assigned to these locations, three of the locations mentioned above will not be visible in the new warehouse:

- When analyzing the sizes of the locations, it was not clear that existing racks would be used in the shelving area. As a consequence, the dimensions of the smallest locations in the warehouse will deviate from the dimensions that are mentioned above.
- Both locations Block pallet 0.60m and Euro pallet 0.60m will not be found in the new warehouse. As a result of storing multiple SKUs on a single location, the locations with a stackable height of 0.60m will disappear.

How these matters are incorporated in the capacity problem will be dealt with in the next section.

9.3) Storable SKUs new warehouse

In order to be able to state where to position which type of pallet rack configuration, both the type and quantity of the SKUs that will be stored in the new warehouse must be known. To obtain this information, it was first necessary to assign SKUs to storage locations. It might be clear that both the purchase size and the size of the boxes were taken into account when assigning SKUs to storage locations. When not dealing with a bulk item, an estimation of the safety stock was also incorporated in order to achieve space utilization. There is one important remark that needs to be made.

The number of bulk pallets that Straatsma has in storage will be reduced in the future because Straatsma is going to use the storage capacity of its major suppliers. In order to evaluate the effect that this has, the purchase sizes from all SKUs that arrive in batches of 50 items or more have been reconsidered. After deliberating with the purchase manager, the purchase sizes of 292 SKUs were altered. It appeared that this policy reduces the storage requirements by at least 200 pallet locations. Which SKUs have received an alternate purchase size, and how SKUs are assigned to storage locations can be seen in the SKUs-Straatsma.xls[1].

After assigning the SKUs to storage locations, it was necessary to analyze the effect of shared storage. It is not possible to apply shared storage when dealing with large storage locations. SKUs that are stored on these locations often enter the warehouse on full pallets. Adopting

[1] The file SKUs-Straatsma.xls can be found on the disc containing this report.

shared storage would result in an excessive amount of material handling. SKUs that are assigned to shelves, Euro 0.60m-, Block 0.60m- and Euro 1.00m locations can sometimes benefit from shared storage.

The proportion of the actual stacking height compared to the overall size of a location was one of the reasons why shared storage was investigated. While the total location height of the Euro 0.60m and the Block 0.60m is 0.95m, the actual stacking height is only 0.60m as a result of the joist, the pallet and the room that is needed to place the pallets. This means a loss of storage space of 37%, which could not be tolerated. When applying shared storage, the SKUs that were initially assigned a Euro 0.60m were relocated to a Euro 1.00m. SKUs that were assigned a Block 0.60m were placed on a Block 1.00m, a new type of location. The big question was of course how many locations of Euro 1.00m and Block 1.00m are needed in order to store not only the SKUs that were originally assigned to the Euro 1.00m, but also all SKUs that were in first instance assigned to a location with a stacking height of only 0.60m. To analyze this, it was first assumed that all SKUs are assigned an individual location, in order to subtract the number of instances in which two SKUs can share a single location.

In appendix 14, the benefits of shared storage have been calculated. It is also elaborated on how the assumptions of equation 4 were incorporated into the calculation. It must be noted that the essence of the calculations is not to see which combinations of SKUs can be stored on a single location. The model is used to give an estimation about the number of storage locations that is not needed in the warehouse as a result of allowing multiple SKUs to be stored together.

It appeared that lowering purchase levels and applying shared storage alone does not lead to a reduction in the storage requirements that is large enough for all remaining packaging materials to be stored in the warehouse. Since Straatsma decided that moving certain customer groups to an external location was not an option, alternative measures needed to be taken. After consulting the management of Straatsma, I decided to complete the warehouse design on the basis of as much fast moving SKUs as possible.

After an extensive analysis, it appeared that the storage capacity of the new warehouse was reached when including all the SKUs with a sojourn time of 1.3 years or less. Although this seems perfectly acceptable it does entail that the warehouse does not facilitate the storage of 406 SKUs that were stored at July 2008. The warehouse design process will continue on the basis of the 2333 most fast moving products. A justification why it is not possible to store more SKUs in the new warehouse can be found in appendix 15.

9.4) Pallet rack configuration

To determine which type of pallet rack is most appropriate in a certain section of the warehouse, it must be clear which types of products are stored in that section. It is therefore necessary to assign groups of SKUs to specific sections of the warehouse. As mentioned in chapter two, assigning individual SKUs to specific storage locations is outside the scope of this investigation.

Based on the correlation between SKUs, the COI of a specific group of SKUs and the means of transportation of a group of SKUs, it is possible to distinguish six groups of SKUs. In normal situations when assigning groups of SKUs with varying COIs to sections of a warehouse, an important question is whether to adopt within aisle storage, or across aisle storage. In this case this decision was rather easy because of the correlation between SKUs. A major starting point in assigning the groups was to locate the groups in which the SKUs have a high correlation in as little aisles as possible. This is wise since this minimizes the number of aisles that an order picker has to traverse. What groups can be distinguished, and how the groups are assigned to sections of the warehouse based on the COIs, the storage requirements, the means of transportation and the within aisle storage principle can be seen in the figure below. Which SKUs belong to which group can be seen in the file SKUs-Straatsma.xls[1].

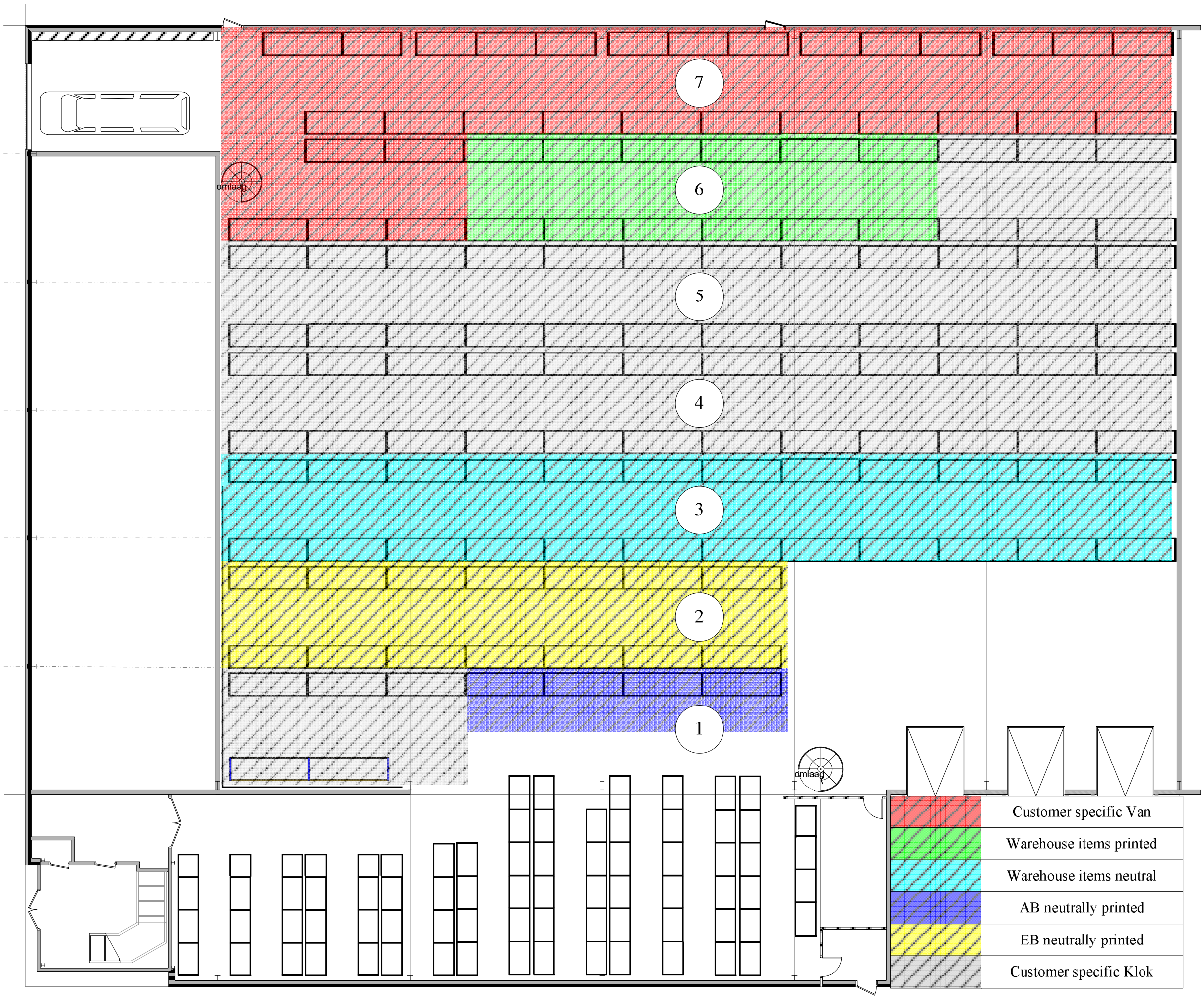


Figure 30: Location of groups of SKUs

Figure 30 might give the impression that SKUs from different groups have to stored in strictly separated sections. This is however not the case. It will most definitely be necessary to store SKUs from different groups within the same rack. In some situations, a rack that is suitable for a certain group is placed outside the specific section to which it is assigned. When there are compelling reasons to do so, there is no problem. Groups of SKUs have been assigned to sections of the warehouse as a guideline to know which type of pallet rack racks can best be placed in that section of the warehouse.

When taking into account the stacking height of 5m, and the heights of the locations, there are three possible ways (C1 to C3) in which locations can be combined. This does not mean however that there are only three different types of racks. Besides the fact that there are racks

[1] The file SKUs-Straatsma.xls can be found on the disc containing this report.

of both 2.7m and 3.6m, there are two other reasons why the number of different pallet racks is higher:

- Two pallet racks that consist of the same type of locations may differ from one another with regard to the positions of the locations within the rack.
- When discussing the straddle truck it was already mentioned that certain locations will have a joist located right above the ground in order to cope with the outriggers of the truck, while dealing with block pallets.

In order to position the racks within the warehouse, there had to be insight into both which types of racks are suitable for storing SKUs of a certain group, and in which proportion the racks are needed. Besides the number of each type of location that a certain group needs, three factors played an important role: storing fast movers at favorable locations, storing heavy items on the ground, and facilitating block pallet storage. It appeared that seven different type of pallet racks are needed in order to store all SKUs in a proper manner.

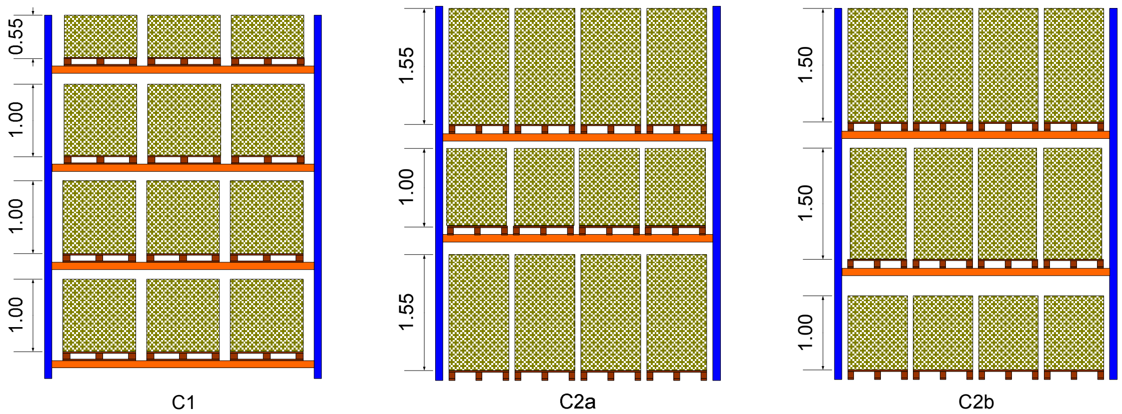


Figure 31: Pallet racks and dimensions(m) (1) :C1, C2a & C2b

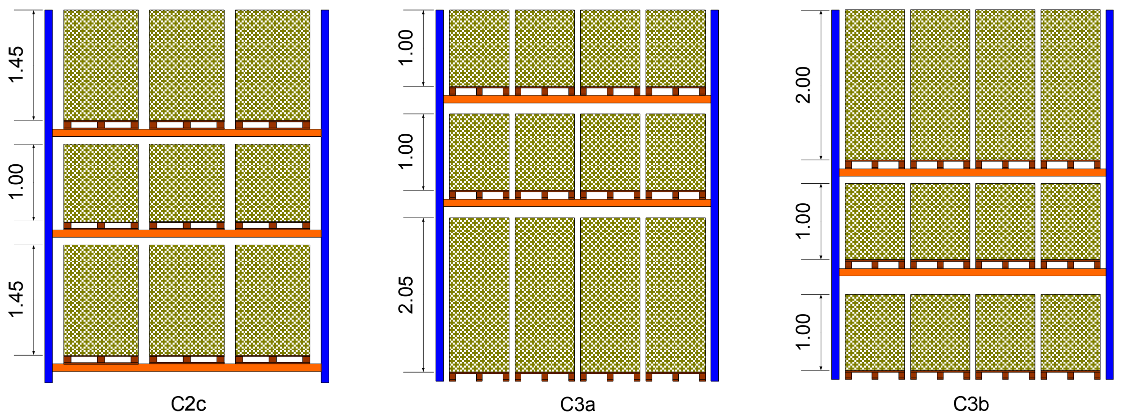


Figure 32: Pallet racks and dimensions (m) (2): C2c, C3a & C3b

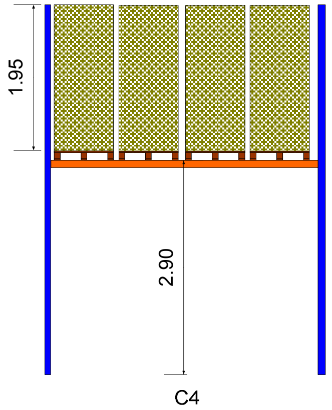


Figure 33: Pallet racks and dimensions (m) (3): C4

Once there was insight into the preferred location of the different groups of SKUs and knowledge about the different types of pallet racks that are most suitable for storage purposes, the different rack types had to be assigned certain locations. While this might seem a rather straightforward next step based on previous analysis, this was most definitely not the case. There exists a major trade off between assigning pallet racks based on gathered data and creating a rather uniform warehouse. Besides uniformity, flexibility also influenced the decisions with regard to the positions of pallet racks. In the figure below it is indicated how the different type of pallet racks have been positioned in the new warehouse.

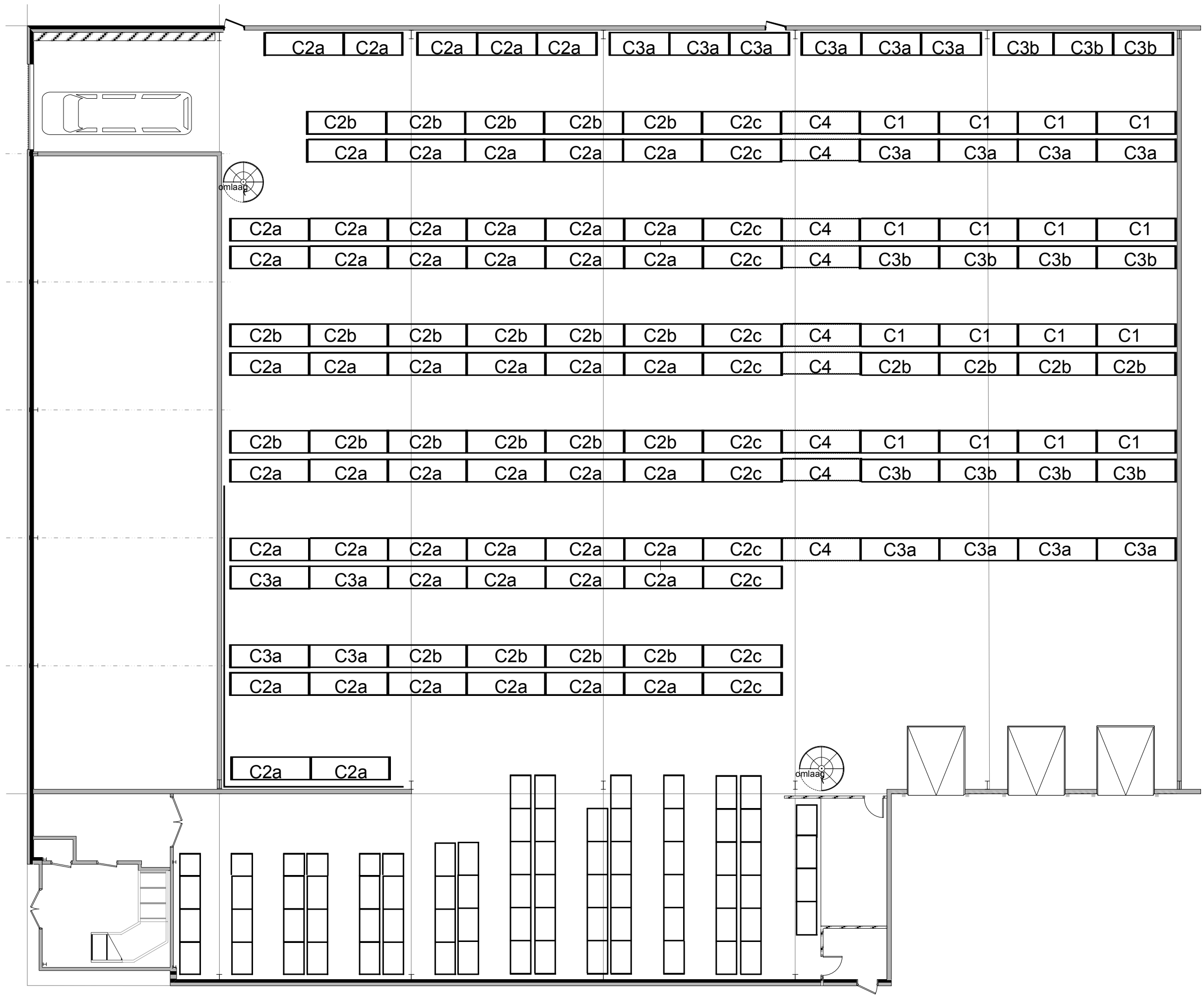


Figure 34: Pallet rack configuration in main warehousing area

A more detailed discussion about the pallet rack configuration can be found in appendix 16.

9.5) Conclusions operational decision making

In this chapter a number of decisions of an operational nature have been made. Main topics were the dimensions of storage locations, determining which products to store in the new warehouse, and developing a pallet rack configuration. In the first section, the dimensions of the storage systems to which SKUs have been assigned were introduced.

Designing a warehouse is only possible when it is clear which products will be stored in the new warehouse. It appeared that even after reducing the inventory level and applying shared storage, 406 SKUs needed to be excluded from further analysis, because the new warehouse does not offer enough storage capacity.

Once it was clear which SKUs to store in the warehouse, a pallet rack configuration was created. In order to do so the list of SKUs was first divided into six groups. Each of the groups were then assigned to a certain section of the warehouse to have an indication about where to store certain SKUs. The final step was to determine the exact location of the different types of pallet racks. During this process both uniformity and flexibility played an important role.

10) Conclusions and recommendations

This chapter will consist of three sections. In section 10.1, the major conclusions of this research will be summarized. Once the conclusions have received attention, a reflection on the warehouse design model will take place in section 10.2. A number of recommendations for successfully exploiting the new warehouse in section 10.3 will conclude this research.

10.1) Conclusions research

The goal of this research was to design the warehouse in such a way that it corresponds to the design objectives that are relevant to Straatsma. In order to achieve this, the three research questions had to be answered:

- What design objectives are relevant to Straatsma?
- In what way can a warehouse design process be structured?
- What is the best way to design the new warehouse of Straatsma?

In the beginning of this research, both the current practices and the new warehouse of Straatsma have been analyzed in order to find out what matters to Straatsma. Based on the slow moving nature of the SKUs that Straatsma wholesales, the insufficient storage capacity of the new warehouse and the fact that the usage period of the new building is only three to five years, it became evident that cost and space utilization are the two main design objectives.

Once there was clarity with regard to the design objectives it was necessary to find a model that could help in designing the warehouse in a structural manner. After discussing a number of different models, it became clear that the model of Rouwenhorst et al (2000) was the most suitable for the design of the warehouse of Straatsma. A reflection on this warehouse design model will take place in the section 10.2.

The last step was of course to actually design the warehouse. It must be noted that almost the entire warehouse design process was executed. Topics ranging from the required level of automation to a detailed interior layout of the new warehouse have all received attention. The fact that the decision to move into the new warehouse was made without extensive calculations with regard to the storage capacity, severely complicated the design process. Although space utilization played an important role throughout the warehouse design process, there are two initiatives that were executed in order to cope with the insufficient storage capacity that need to be mentioned specifically:

- In regular warehouse designs, it is customary to place one single SKU on a location. This was however not an option for Straatsma. A new method was developed to incorporate the fact that two SKUs can be stored on a single location into the warehouse design process.
- It was analyzed when Straatsma can make use of the storage capacity of its main suppliers in order to reduce the inventory levels of certain SKUs.

By incorporating these initiatives into the warehouse design process, it was possible to minimize the number of SKUs that cannot be stored in the new warehouse.

As a result of using the model of Rouwenhorst et al (2000) the design phase consisted of three stages. To provide a good overview of the design process, the major conclusions of each of the stages will be mentioned briefly.

Strategic decisions

- Because of the emphasis on cost, it is not sensible for Straatsma to have a high level of automation.
- Forward areas are not suitable for Straatsma. They either negatively affect space utilization, or they require substantial investments.
- Based on the order profile of Straatsma, it became clear that discrete order picking is the most suitable for Straatsma.
- After considering various storage systems, it appeared that the single selective pallet rack and shelving are the most appropriate storage systems for Straatsma.

Tactical decisions

- No single storage policy will be used. Bulk pallets will be stored in a random fashion, while pick locations will remain fixed. It will be necessary to store multiple items on a single location.
- Based on cost /productivity, space utilization, flexibility and effective working conditions it appeared that using a combination of the straddle truck and the high level order picker is the most sensible for Straatsma.
- Space utilization played the most important role in deciding on the location of the storage systems.

Operational decisions

The goal of the last stage was to create the complete pallet rack configuration. This could only be done after assigning SKUs to storage locations, and analyzing which SKUs can be stored in the new warehouse. It must be noted that despite the emphasis on space utilization, the warehouse will not be able to provide storage space for all the SKUs that Straatsma had in storage during July 2008. The warehouse was designed on the basis of SKUs with a relatively short sojourn time. The remaining SKUs were excluded from the research.

10.2) Reflection on warehouse design model

In this research the model of Rouwenhorst et al (2000) was used to structure the warehouse design process. During the selection of this model, it was already indicated that the model would be used in an altered fashion. Still it is useful to give a number of comments on the basic assumptions of the model.

The division in strategic, tactical and operational decisions worked well. In this research there was only one instance in which it was necessary to adjust decisions on a higher design level based on findings on a lower level. After it became clear how significant the shortage in storage capacity was (operational), it was necessary to adjust the storage policy (tactical). Instead of storing all SKUs on a single location, the final storage policy allows multiple SKUs to be stored on a single location.

When designing much larger warehouses, the division in design levels may be more problematic. I can imagine that in these situations it is more often needed to adjust decisions on a higher design level based on the outcomes of certain operational decisions. As was already emphasized by various authors, a certain degree of iteration seems inevitable. It is rather difficult to pass judgment on whether the division in multiple design levels is an appropriate way of reducing the number of iterations that are necessary based on one warehouse design project.

A second assumption of the model is that decisions on a similar design level need to be made simultaneously in order to reach a global optimum. I think that finding the optimal solutions is hardly ever possible. The number of different possibilities is simply too big. Besides the global optimum, I also disagree that decisions on a similar design level need to be made simultaneously. It is clear that the decisions on a single design level are interrelated. But instead of stating that matters need to solved simultaneously, I think a more appropriate option is to create a stepwise approach in order to deal with the complexity. It must be noted that this may involve a certain degree of iteration again. In this research flow diagrams have been presented to indicate the order in which to make decisions. Two situations which show that matters do not need to be solved simultaneously are the following:

- In my opinion the decision with regard to the level of automation is something that needs to be decided upon before making various other decisions.
- With regard to the tactical level, it is possible to decide on the storage policy before making a decision with regard to the layout and material handling equipment. I think activity profiling serves as the most important input for the decision with regard to the storage policy, not the location of certain racks.

I think the warehouse design model could be improved by giving one or multiple schedules indicating logical relations between decisions. Simply stating that all decisions on a similar design level should be made simultaneously is not adequate in my opinion.

Most warehouse design models, including the model of Rouwenhorst, are (somewhat) prescriptive in the sense that it is clear in which order to make certain decisions. They do not indicate however, how these decisions should be made. I think the next step of warehouse design models should incorporate this aspect of warehouse design to a greater extent. It must be noted that in the article of Baker et al (2007), this already received some attention. It is outside the scope of this investigation to make recommendations with regard to the exact way how this should be incorporated into warehouse design models.

10.3) Recommendations

In the sections below, a number of recommendations will be made in order for Straatsma to successfully exploit the new warehouse.

Rejecting slow movers

During the investigation, it was noted that Straatsma officially has the policy to send off packaging materials to customers when items are in storage for more than one year. After analyzing the sojourn time of the various SKUs, it became clear that this policy was completely neglected in the past. Adopting this policy would result in an enormous decrease of the total storage requirements that Straatsma has.

Instead of the reactive action to send off packaging materials to customers when the items are in storage for more than one year, adopting a proactive approach can be even more beneficial. Straatsma should not offer to keep a SKU on stock, when it can be predicted in advance that a complete batch of this SKU will not be sold within one year. This way, the storage capacity of the new warehouse would only be used for products that are actually sold to customers on a frequent basis.

It might be clear that it is not possible to send off every item that has been in storage for more than one year instantly without any warning. This would result in a large number of dissatisfied customers. The measure should be incorporated into day to day operations in the short run however. It can have a major impact on the capacity shortage that Straatsma will be faced with at the end of 2009, when it can no longer use the storage capacity of both the new warehouse and the warehouse situated at the Cargadoorweg. It would be beneficial if Exact could be used in order to signal when certain SKUs are in storage for more than one year.

Scheduling suppliers
As previously mentioned, space utilization played an important role in the design of the warehouse. It has also been a factor in determining the size of the expedition area. The expedition area does not offer the space to unload multiple trailers. In order to prevent that the size of the expedition area becomes a problem, it is essential to make arrangements with suppliers as soon as possible. Before moving into the new warehouse, large suppliers should have agreed to deliver their products at certain pre specified moments in time. This way it is possible to prevent multiple large suppliers from arriving simultaneously.

Using storage capacity of suppliers
The purchase sizes of SKUs that arrive in large quantities have been reconsidered, since it is possible for Straatsma to make use of the storage capacity of its major suppliers. In order for the total storage requirements to be reduced at the end of 2009, it is important to start utilizing these opportunities as soon as possible. Since the sojourn time of certain SKUs are rather long, it will take some time before these measures will make a significant difference.

Transferring products into new warehouse
In order to design the pallet rack configuration, groups of SKUs were assigned to sections of the warehouse. Furthermore it was investigated that it is efficient to store customer specific SKUs from a customer in close proximity to each other. It must be noted that this information is not sufficient however when moving SKUs into the new warehouse. When transferring products to the new building, there must be detailed information about the specific location in which to store a certain SKU. In order to create an efficient order picking process, fast moving SKUs or customers must be assigned to favorable locations within the section to which they have initially been assigned. A sound preparation will be key.

Structuring processes and data gathering
The last recommendation is not so much related to the new warehouse, but involves the day to day operations. During this investigation it became clear that many things happen without being documented properly. A number of examples can be given:

- There are no procedures that indicate how a customer receives their packaging materials.
- There are no formal policies that state when to hold packaging materials in stock.
- Straatsma does not have guidelines with regard to a maximum inventory value for a customer.

Besides the absence of formalized policies, it also came to my attention that certain important pieces of information are not registered:

- The sizes of the boxes is not entered into Exact.
- The number of pallets that arrive at the warehouse of Straatsma is not registered.
- There is no information with regard to the height of a pallet on which a product arrives.
- Exact does not indicate whether there is a difference between the purchase entity and the sales entity.
- The number of orders that are delivered by the Straatsma van on a daily basis is not easily accessible.

- No performance indicators are used to measure the performance of for instance suppliers or De Klok.

While the absence of formalized procedures is largely compensated by having knowledgeable personnel, it does induce errors. The fact that certain pieces of information are not registered is relevant because it hinders sound decision making. These are definitely areas where Straatsma can improve in the future.

Bibliography

Apple, J. (1977). *Plant layout and material handling*. New York: Wiley

Baarda, D.B., Goede, M.P.M. de (2001). *Basisboek: handleiding voor het opzetten en uitvoeren van kwantitatief onderzoek*. Houten: Stenfert Kroese.

Baker, P., Canessa, M. (2007). Warehouse design: A structured approach. *European journal of operational research*.

Bartholi, J., Hackman, S. (2007). Warehouse and distribution science. *Georgia Institute of technology*.

Beek, H.J.G. (2007). Jip en Janneke en de paarse krokodil: Een onderzoek naar de processen en procedures binnen een klantgerichte organisatie. *Straatsma Verpakkingen*.

Beek, H.J.G. (2008). SWOT analyse. *Straatsma Verpakkingen*.

Berg, J.P. van den, Zijm, W.H.M. (1999). Models for warehouse management: classification and examples. *International journal of production economics*.

Bodner, D.A., Govindaraj, T., Karathur, K.N., Zerangue, N.F., McGinnis, L.F. (2002). A process model and support tools for warehouse design. *Proceedings of the 2002 NSF design service and manufacturing grantees and research conference*.

Brown, T.W., Firth, R.V.D., Misenheimer, L.P., Adams, N.D. (1996). *Warehouse and Distribution Automation Handbook*. New York: McGraw-Hill.

Choe, K.I., Sharp, G. (1991). Order picking. *Georgia institute of technology.*

Coyle, J.J., Bardi, E.J. (2003). *The management of business logistics*. St. Paul: West.

Duc, T. Le (2005). Design and control of efficient order picking processes. *Erasmus university Rotterdam.*

Egberts, T. (1999). Ruimtewinners. *Transport + Opslag.*

Firth, D., Apple, J., Denham, R., Hall, J., Inglis, P., Saipe, A. (1988). Profitable logistics management. Toronto: McGraw-Hill Ryerson.

Frazier, D. (1981). How to plan an efficient rack layout. *Material handling classics.*

Goetschalckx, M., Ashayeri, J. (1989). Classification and design of order picking systems. *Logistics world*

Govindaraj, T., Blanco, E.E., Bodner, D.A., Goetschalckx, M., McGinnis, L.F., Sharp, G.P. (2000). Design of warehousing and distribution systems: an object model of facilities, functions and information. *Georgia institute of technology.*

Gu, J. (2005). The forward reserve warehouse sizing and dimensioning problem. *Georgia institute of technology*.

Gue, K.R., Meller, R.D., Skufca, J.D. (2006). The effects of pick density on order picking areas with narrow aisles. *Auburn University*.

Hall, R. (1987). A multi item EOQ model with inventory cycle balancing. *Naval research logistics*.

Hatton, G. (1990). *Designing a warehouse or distribution centre*. Aldershot: Gower Publishing.

Heskett, J.L. (1963). Cube-per-order-index – a key to warehouse stock location. *Transport and Distribution Management*.

Heskett, J.L., Glaskowsky, N. , Ivie, R. (1973). *Business logistics, Physical distribution and materials handling*. New York: Ronald press.

Koster, R. de, Duc, T. Le, Roodbergen, K.J. (2006). Design and control of warehouse order picking: A literature review. *Erasmus Research Institute of Management.*

Kulwiec, R.A. (1985). *Materials handling handbook*. New York: Wiley and sons.

Lambert, D.M., Stock, J.R., Elram L.M. (1998). *Fundamentals of logistics management.* Boston: McGraw-Hill.

Mulcahy, D.E. (1994). *Warehouse distribution and operations handbook*. New York: McGraw-Hill.

NPR 5054 (2003). Palletstellingen - bediening door magazijntrucks - verklaring van toegestaan verbruik. *Nederlands normalisatie instituut*.

Oxley, J. (1994). Avoiding inferior design. *Storage handling and distribution*

Parrot, R.C. (1981). The storage rack as part of your integrated handling system. *Material handling classics*.

Piasecki, D. (2001). Order picking: Methods and equipment for piece pick, case pick and pallet pick operations. *Inventory Operations Consulting L.L.C.*

Piasecki, D. (2003). The aisle width decision. *Inventory Operations Consulting L.L.C.*

Petersen, C.G. (1997). An evaluation of order picking routing policies. *International journal of operations & production management*.

Pluygers, M.P. (2006). Strategisch plan. *Straatsma Verpakkingen.*

Rapportage F23819-rap01a (2008). Berekening Rook- en Warmteafvoerinstallatie conform NEN 6093. *Colt*.

Rouwenhorst, B., Reuter, B., Stockrahm, V., Houtum, G.J. van, Mantel, R.J. Zijm, W.H.M. (2000). Warehouse design and control: Framework and literature review. *European journal of operational research*.

Saenz, N. (2005). *The seven keys to effective order picking system design*. Consulted on 16th of July 2008, http://www.scdigest.com/assests/newsviews/05-09-01-3.cfm?cid=2208&ctype=content

Saenz, N. (nd). *Developing your large load storage area*. Consulted on 12th of June 2008, http://www.mhia.org/signing?ReturnUrl=%2flearning%2fresources2%fdownloadfile.aspx%3fid%3d4670&id=4670

Schuur, P.C. (2007) Lectures warehousing 2007. *University of Twente.*

Tompkins, J.A. (2003). *Facilities Planning*. Hoboken: Wiley.

Zwaan, A.H. van der (2003). *Organisatie-onderzoek, leerboek voor de praktijk: het ontwerp van onderzoek in organisaties*. Assen: Van Gorcum.