ABSTRACT
This thesis report how firms should manage planning and control related activities in warehouse systems in today’s world of rapidly changing customer’s demand, small internet orders, tight delivery schedules and high service level requirements. This literature review first describes current, traditionally planning and control policies in warehouse systems, subsequently with new approaches to manage planning and control policies more efficient and to reduce response time in order to maintain warehouse performances in today’s world of rapidly changing customer’s demand. It can be concluded that the main savings can be derived in planning related activities and recommended to put more effort in the development of new models instead of optimizing existing ones.

Bachelor Thesis Organization & Strategy

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Chapter 1: Introduction

1.1 Problem indication

Nowadays, in supply chain management, modern companies attempt to achieve high-volume production and distribution, while keeping inventories low and delivering products with short response time (Zijm, 1999). Today's production companies are faced with a substantially more complex situation than ever before because of the increasing market demands and growing complexity of production (Zijm, 1999; Ito and Abadi, 2001).

The changing demand market requirements on firm's warehouses have affected warehouse operations tremendously (van den Berg, 1999; Selen, 2002; Chen and Wu, 2005). In these circumstances warehouse managers have to react constantly to market changes because customers have been gaining more power to influence the market structure (Chen and Wu, 2005). Characteristics of a demand-driven organization are high product variety, small order sizes, and reliable short response times throughout the supply chain (Chen and Wu, 2005). According to Selen (2002), Internet caused a reconfiguration of the demand chain concept with a shift away from supply chains towards demand chains. Other terms are shifting away from ‘push’ to ‘pull’ (Gonçalves et al. 2005) or from Material Requirements Planning (MRP) to Just-in-Time (JIT) (Benton and Shin, 1998).

Besides the consequences of changing demand market requirements on firm’s warehouses, it is worthwhile to examine what the consequences are for the firm’s planning and control activities in their warehouse systems (Zijm, 1999). Planning refers to management decisions that affect the intermediate term (one or multiple months), such as inventory management and storage location assignment. Control refers to the operational decisions that affect the short term (hours, day), such as routing, sequencing, scheduling and order-batching (van den Berg, 1999; Roodbergen and Vis, 2009).

Finally, Roodbergen and Vis (2009) mentioned in their article that it will be increasingly difficult to maintain a good performance when using existing static solution techniques in contrast with today’s world of rapidly changing customer’ demand, small internet orders, tight delivery schedules, high competition and high service level requirements. Hence, there is a great need for sophisticated techniques that provide a dependable basis for adequate planning and control of warehouses in such complex environments (van den Berg, 1999).
1.2 Problem statement and research questions
The observation of rapidly changing customer demands, subsequent with the consequences of a firm's process to plan and control the activities in warehouse systems leads to the following problem statement:

*What is the influence of demand-driven supply chains on planning & control activities in warehouse systems?*

In order to examine this problem statement, research questions are defined:

1. What types of warehouse systems are there?
2. What are the planning and control activities in warehouse systems?
3. What are the consequences of demand driven supply chains in order to plan and control a firm’s warehouse system?

1.3 Research design
The research will be a literature review that is especially descriptive and causal in nature. The process and objectives of a warehouse system and their planning and control activities will be described in the next chapters, subsequently by the influence of rapidly changing customer demands. The warehouse systems can be seen in as the independent variable, while planning and control activities are the dependent variable. This is because the author of this thesis believes that firms should revise their planning and control activities in warehouse system cause of changing market requirements. This is the main objective of the thesis to investigate and is illustrated in figure 1. ABI Inform, Proquest, Web of Science and Google Scholar are the mainly used sources to retrieve secondary literature. The short available time frame is the reason why this research is restricted to available literature. The keywords which are mainly used to find relevant data about this topic are: Warehouse systems, planning and control activities within warehouse systems, demand driven supply chains.

![Figure 1 - Conceptual model](image-url)
1.4 Academic and managerial relevance
Many authors indicated the same observation; new market forces have affected the operation of warehouses tremendously (Zijm, 1999, Van den Berg, 1999; Rouwenhorst, 2000; Gu et al, 2007; Roodbergen and Vis, 2009). A number of warehouse operation decision support models have been proposed in the literature, but there remains considerable difficulty in applying these models to guide warehouse operations (Rouwenhorst et al. 2000). Reading multiple articles about this topic indicates that there is much is known about this topic, but the findings are contradictory, incomplete, and / or dated. Especially in circumstances of rapidly changing market requirements.

Hence, there is a great need for sophisticated techniques that provide a dependable basis for adequate planning and control of warehouses in such complex environments (van den Berg, 1999). These observations are proving academic relevance of this thesis. In addition, the managerial relevance is that a firm can accomplice with a better insight in warehousing systems and in the key factors for improving both their planning and control. This may lead to significant further reductions of inventory levels and improvement of response times.

1.5 Structure of this thesis
In the following chapter the first variable, warehouse systems, will be discussed. It is important to make the reader aware what is meant with warehouse systems and how it is coordinated. Chapter three will discuss planning and control activities in warehouse systems. Activities that belong to planning and control in warehouse systems will be explained individually. The last research question will be discussed in chapter four. In this chapter the influence of the changing market corresponding to planning and control activities will be analyzed. Finally, this thesis ends with conclusions and suggestions for future research.
Chapter 2: Warehouse systems

This chapter discusses warehouse systems. However, before analyzing this variable the principles and functions of a warehouse in general will be described.

2.1 The warehouse in the supply chain and the functions

Warehouses are an essential component of any supply chain (Rouwenhorst, 2000; Gu et al. 2007). Both authors report that the major roles of a warehouse include: (1) buffering the material flow along the supply chain to accommodate variability caused by factors such as product seasonality and/or batching in production and transportation; (2) consolidation of products from various suppliers for combined delivery to customers; (3) and value-added-processing such as kitting, pricing, labeling, and product customization.

The adoption of new management philosophies such as Just-In-Time (JIT) or lean production creates new challenges for warehouse systems, including tighter inventory control, shorter response time, and a greater product variety (Gu et al, 2007). On the other hand Gu et al. (2007) says that the implementation of new information technologies (IT), such as bar coding, radio frequency communications (RF), and warehouse management systems (WMS), provides new opportunities to improve warehouse operations. These operations of a warehouse consist of four basic functions: receiving, storage, order picking and shipping (Rouwenhorst et al., 2002; Gu et al. 2007). Both authors describe these functions as follow:

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<td>Receiving</td>
<td>The receiving process is the first process encountered by an arriving product. Once products are arrived, they may be checked or transformed and wait for transportation to the next process.</td>
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| Storage             | Storage is concerned with the organization of goods held in the warehouse in order to achieve high space utilization and facilitate efficient material handling. Goods in storage can be organized into different departments. The drivers of department organization are classified into:  
  - Physical characteristics of the goods (e.g., pallet storage vs. case storage);  
  - Management considerations such as a dedicated storage area for a specific customer |
Material handling considerations such as a forward area for fast picking. Within a department/zone, goods are assigned to storage locations, and the storage location assignment has significant impact on storage capacity, inventory tracking, and order picking.

**Order picking**
Order picking is generally recognized as the most expensive warehouse operation, because it tends to be either very labor intensive or very capital intensive (Frazelle, 2002). Furthermore it refers to the retrieval of items from their storage locations and can be performed manually or (partly) automated.

**Shipping**
At the shipping area, orders are checked, packed and eventually loaded in trucks, trains or any other carrier.

### 2.2 Warehouse system
Among various business units in supply chain, *warehouse system* plays an important role (Yusaf et al., 1999). The objective of this section is to provide a definition and the process of a warehouse system associated with the capabilities of such system.

#### 2.2.1 Definitions of warehouse systems
Hsieh and Tsai (2005) define a good warehouse system once it ensures easy and efficient access of merchandise, properly use the storage location to find the shortest path, and finally to deliver the merchandise in a reasonable time. Ito and Abadi (2001) describes in their study the definition of a warehouse system; “A warehouse system takes care of fluctuation and uncertainty of demands from customers, and provides just-in-time delivery of materials”. In case the exchange of orders and materials smoothes effectively in a warehouse system it contributes to the success of supply chain systems. Finally, Zijm (1999) refers a warehouse system to the combination of equipment and operational policies used in an item picking or storage/retrieval (S/R) environment.

#### 2.2.2 Warehouse system functions
Ito and Abadi (2001) designed a warehouse system model which can be seen in figure 2. The model describes the functions of a warehouse system which is divided in three subsystems: (1) agent-based communication systems, (2) agent-based material handling system and (3) agent-based inventory planning and control system.
In the authors warehouse system model, inventory planning and control is responsible to manage the inventories and to minimize the total costs of inventory holding and stock-out. It manages the assignment of inventories to be sent to customers, and to make orders to suppliers to keep appropriate inventories. The material handling system is another subsystem of this model, which is responsible for management of automatic-guided vehicle (AGV) assignment to keep smooth flow of materials inside the warehouse. Finally the third subsystem (communication system) takes care of communication with geographically distributed customers and suppliers.

Van den Berg (1999) describes a warehouse system from different perspectives and classifies such system into three groups: (1) Picker-to-product systems. (2) Product-to-picker systems. (3) Picker-less systems.

As the name of a picker-to-product system already implies, manual order-pickers ride in vehicles along the products. There are numerous different vehicles available from manually vehicles to automated vehicles which also enable vertical movement for order-picking from elevated positions. Furthermore, van den Berg (1999) classifies a product-to-picker system. Such systems can be seen as an Automated Storage/Retrieval System (AS/RS). Such systems have been developed for use in factories and distribution centers because they improve inventory cost, labour cost, material tracking, space
utilization, average time in the system and system throughput (Meller and Mungwattana, 2005). Lastly, Picker-less system make use of robot-technology or automatic dispensers, whereby two product retrieval methods are distinguished: unit load retrieval systems and order-picking systems. In a unit load retrieval system complete unit-loads are retrieved. Accordingly, the vehicles either perform one stop (storage or retrieval) or two stops (storage followed by retrieval) in a single trip. In an order-picking system typically less-than-unit-load quantities are picked, so that there will be multiple stops per trip (multi-command cycle).

Summarized, the warehouse systems models of Ito & Abadi (2001) and Van den Berg (1999) some comparisons and differences are observed. Ito and Abadi (2001) describe their warehouse system model from a broader perspective. According to them a warehouse system is not only responsible in a physical way, (how to actually pick to products most efficient and move them to the following destination, e.g. expedition) but also includes informational duties, such as communication and administration (inventory management) responsibilities. This is why Ito and Abadi (2001) composed a warehouse model into three subsystems. Ito and Abadi (2001) warehouse system is more ICT based, while van den Berg (1999) refers to procedures corresponding to the level of automation. Van den Berg (1999) classification regarding warehouse systems has a more detailed approach. First of all van den Berg distinguishes types of warehouses with respect to the level of automation. Secondly, this classification is particularly from a physical point of view; so how to pick and move, regarding the level of automation, the products most efficient. Inventory planning and control related duties as well as communication policies are not included in their description and responsibilities of a warehouse system.

2.3 Conclusion
This chapter was concerned about warehouses and in specific a warehouse system. To avoid confusion the first section describes the importance and functions of a warehouse in general. In this thesis a warehouse system is seen as combination of equipment and operational policies used in an item picking or storage/retrieval environment (Zijm, 1999). Furthermore the function of a warehouse system corresponds to the level of automation, which was classified by van den Berg (1999). These observations will be further used in this thesis, in order to analyze planning and control activities in warehouse systems.
Chapter 3: Planning and Control activities in warehouse systems.
The central theme of this research is planning and control activities in warehousing systems. What these activities are and how they function is discussed in this chapter. Planning in warehousing systems refers to the policies which are developed at the tactical level concerning the assignment of goods to storage locations and inventory management (van den Berg, 1999). Control problems concern the actual sequencing, scheduling and routing of the movement of goods. First the relation between planning and control will be described, followed by a separate analysis of on the one hand planning and on the other hand control related policies regarding warehouse systems.

3.1 Planning and Control.
The division between planning and control is not clear, either in theory or in practice (Slack et a. 2007). The author reports some general features to distinguish them; Planning is a formalization of what is intended to happen at some time in the future. However, customers change their minds about what they want and when they want it or suppliers may not always deliver on time (e.g. machines may fail or staff may be absent through illness). That is where control is the process of coping with changes in these variables (Slack et all. 2007). According to the author, control makes the adjustments which allow the operation to achieve the objectives that the plan has set, even when the assumptions on which the plan was based do not hold true.

This implies that planning and control can be related with a time horizon, which is illustrated by Slack (2007) in figure 3. In this figure the division between the importance of planning or control is situated. According to this figure it can be concluded, from a general perspective, which in case of a long term time horizon the emphasis is on planning rather than control.

[Figure 3 - Relation between Planning and Control.]
3.2 Planning activities in warehouse systems
Planning activities in a warehouse system involves high level decisions, like assignment of goods to the storage locations (random, class-based, correlated product clustering policies) or the designing of the warehouse system itself. (Amato et al, 2005) In this section planning in warehouse operations will be described, whereby two terms are distinguished; Inventory management and storage location assignment. In related studies (van den Berg, 1999; Zijm, 1999; Rouwenhorst et al, 2000; Gu et al, 2007) these two activities within warehouse systems were mainly used.

3.2.1 Inventory management
Concerning inventory management, managers must decide which products, and how much of each product need to be stored in the warehouse (Strack and Pochet, 2010). Subsequently, the objective is to reduce total operating costs while satisfying customer service requirements (Ghiani et al, 2004). Achieving this objective, an optimal ordering policy has to be determined by answering to questions such as when to order and how much to order. Ghiani et al. (2004) mentioned that the operating costs consists of the procurement costs, the holding costs and the shortage costs which are incurred when the demand of a client cannot be satisfied (either lost sales costs or backorder costs). The author distinguishes two inventory policies: periodic review policy and the continuous review policy. A periodic implies that the stock level will be checked after a fixed period of time, subsequently an ordering decision will be made in order to complete the stock to an upper limit (order up to point), if necessary. Regarding a continuous policy, the stock level will be monitored continuously. In this case a fixed quantity will be ordered when the stock level reaches a reorder point. The order quantity will only be delivered after a fixed lead time and shortage can exist if the inventory is exhausted before the receipt of the order quantity. According to Zijm (1999) such inventory policies may reduce the inventory levels and thereby the operational costs for storage and order picking in warehouse systems.

3.2.2 Assignment of storage location
Storage location assignment decides where the products are to be stored. Here we may distinguish between a forward and a reserve area while also the basic storage policy in S/R systems is determined (e.g. dedicated, class-based or random storage). Characteristics of the assignment of storage locations are determining which products should be stored in which department, in what quantity, and what are the corresponding inter-departmental moves for that product (Petersen and Aase, 2003). According to Gu et al. (2007) different storage strategies can be used such that a careful decision could to be made in order to balance the trade-off between storage and material handling cost and capacities.
A popular approach to reduce the amount of work associated with order picking is to divide the warehouse into a forward area and a reserve area (Zijm, 1999). When a product in the forward area is out of stock, it will be replenished from the reserve area. Van den Berg (1999) names a well-known forward-reserve configuration where manual order picking is used in the lower levels forward area and the higher level contains the bulk storage (reserve area). Creating this separate “fast pick” area for picking high demand, fast-moving products reduce order picking costs. However the expense of requiring additional material handling to restock the forward area and additional space as storage is less efficient in the forward area than in the reserve area (Gu et al. 2007).

Five often used storage assignment policies for AS/RSs exist for assigning products to storage locations in the racks (Hausman et al, 1976; Graves et al. 1977; van den Berg, 1999; Rousenhorst et al, 2000; and Roodbergen & Vis, 2009). These policies are: Dedicated-, Random-, closest open location-, full-turnover-based-, and class-based storage assignment.

For dedicated storage method each product type is assigned to a fixed location, whereby replenishment of that product always occur at the same location (Roodbergen and Vis, 2009). According to the author the need of high space requirements and consequent low space utilization are main disadvantages about this policy. Advantages of this policy are related to non-automated order-picking areas and are not interesting for AS/RS, such as location heavy products at the bottom (Rouwenhorst, 2000). In case of random storage all empty locations have an equal probability of having an incoming load assigned to it, while for closest open location storage the first empty location that is encountered will be used to store the products (Roodbergen and Vis, 2009). A policy based on their demand frequency, whereby frequently requested products get the easiest accessible locations is named a full-turnover storage policy (Roodbergen and Vis, 2009). The author refers to a cube-per-order index (COI) rule, which is a form of this policy. This rule can be defined as a ratio of the load’s required storage space to the number of request for this product per period. The COI rule assigns loads with the lowest COI to the locations closest to the Input/Output-point (I/O-point) (Roodbergen and Vis, 2009). Finally, the class-based storage policy distributes the products, based on their demand rates, among a number of classes and reserves a region within the storage area for each class (van den Berg, 1999). Accordingly, an incoming load is stored at an arbitrary open location within its class. According to Roodbergen and Vis (2009) the main advantage of class-based storage is an increased efficiency due to storing the fast-moving items near the I/O-point, while at the same time the low storage space requirements and flexibility of a random storage method apply.
3.3 Control.
The planning policies define a framework under which the control of warehousing operations takes place (van den Berg, 1999). Activities regarding control in a warehouse system can mainly be distinguished to batching of orders, routing and sequencing, and dwell point positioning. (Van den Berg, 1999; Rouwenhorst et al, 2000; Gu et al, 2007)

3.3.1 Batching policies
According to van den Berg (1999) and Chen et al. (2005), batching is a popular strategy for reducing the mean travel time per order. A batch is a set of orders that is picked in a single tour and may not exceed the storage capacity of the order-picking vehicle. The system throughput may be maximized by gathering large batches with orders at nearby pick locations. However according to Chen et al. (2005) this will extend response times and it might delay orders at the far end of the warehouse. Van den Berg (1999) says that a tradeoff between efficiency and urgency must be achieved. According to the author this may be achieved by selecting a block with the most urgent orders and an order batching within the block that minimized travel time. Another approach may be to assign due dates to the orders and release each order immediately.

3.3.2 Routing policies
Petersen and Aase (2004) describe routing policies which determines the picking sequence of products on the pick list. Using simple heuristics or optimal procedures, the goal of routing policies is to minimize the distance traveled by the picker. The difference between optimal procedures and heuristics is that optimal procedures offers the best solution, but may result in confusing routes, while heuristics often yield near optimal solutions while being easy to use (Petersen and Aase, 2004). In practice, the problem of routing order pickers in a warehouse is mainly solved by using simple heuristics (de Koster, 2007). Those will briefly be described in this section. The S-shape heuristic is used when any aisle containing at least one pick is traversed entirely, while if an order picker enters and leaves each aisle from the same end a return method is used (De Koster, 2007). De Koster (2007) refers to a midpoint method when the warehouse is divided into two areas, whereby picks in the front half are accessed from the front cross aisle and vice versa. A strategy similar to the midpoint strategy except that an order picker enters an aisle as far as the largest gap within an aisle, instead of the midpoint, is named the largest gap strategy. According to Hall (1993) the largest gap method always outperforms the midpoint methods, however the implementation of the midpoint strategy is simpler. Lastly, the combined heuristic, aisles with picks are either entirely traversed or entered and left at the same end. However, for each visited aisle, the choice is made by using dynamic programming (de Koster, 2007).
3.3.3 Dwell-point policies

The dwell-point location problem for the S/R machine arises when the S/R machine becomes idle either after a storage or a retrieval request (van den Berg, 1999; Meller and Mungwattana, 2005). According to the authors the premise behind the dwell-point problem is that this idle time can be used to locate effectively the S/R machine in anticipation of its next request. Van den Berg (1999) says that an effective dwell-point strategy may reduce the response times of the AS/RS, since the S/R machine typically performs a sequence of operations following an idle period. Various dwell-point strategies which have been formulated in the literature will be discussed in this section.

Egbelu (1991) designed a framework for selecting the dwell-point location via linear programming models (LP). The author developed two strategies, which were based on the relative likelihood that the next request was a storage or a retrieval. The first strategy uses an objective of minimizing the expected response time, and the second uses an objective of minimizing the maximum response time for an AS/RS (Egbelu, 1991). Important drawbacks of this dynamic approach are the facts that LP solution techniques need to be implemented in the AS/RS control system and that computation times may be too high to be of practical value (Roodbergen and Vis, 2009). With analytical models, Peters et al. (1996), determined the optimal dwell-point location. In case of continuous racks, analytical models were provided and established into closed-form expressions for the dwell-point location in an AS/RS. In case of rectangular racks under random storage, the optimal dwell-point location can be determined in terms of the probability of occurrence of a certain type of request (Park, 2001). Van den Berg (2002) presents analytical expressions for determining dwell-points under randomized and class-based storage policies, which can be used for various AS/RS configurations with input/output locations.

It can be concluded that many approaches have been formulated, either single rules of thumb, closed-form analytical expressions and mathematical programming, in order to position idle AS/RS cranes at a dwell-point in various AS/RS configurations.

3.4 Conclusion

In this chapter a literature review was done in order to describe how firms manage planning and control activities in warehouse systems. For planning, inventory management and storage assignment, are activities which consist of different policies. For control, batching, routing and dwell-point selection were taken into perspective. The objective of the following chapter is to describe innovative policies or new techniques for these activities such that firms can maintain their warehouse performances in rapidly growing customers demands'.

13
Chapter 4: The influence of market driven supply chains.
As mentioned in chapter one, there is a great need for sophisticated techniques that provide a dependable basis for adequate planning and control of warehouses in such complex situations (van den Berg, 1999). In this chapter the influence and consequences of market driven supply chains on planning and control activities in warehouse systems are analyzed. In the previous chapter, traditionally often used planning and control policies were described. The objective of this chapter is to guide firms with solutions how to manage these planning and control policies in environments with rapidly growing customers demands.

4.1 Inventory models
Nowadays, managers are faced with the need to deliver a high service level with minimal warehouse and inventory cost (Strack and Pochet, 2010). As mentioned in the previous chapter warehouse managers have to decide where to assign the products inside the warehouse (warehouse management issues) and manager must decide which products, and how much of each product need to be stored in the warehouse (inventory management).

Those decisions are interrelated but are treated separately (Rouwenhorst, 2000). According to Strack and Pochet (2010) warehouse and inventory issues are handled in a pyramidal top-down approach where the flexibility of decisions decreases from top to bottom. Consequently, strategic decisions are taken first into account which creates limits to decisions at the tactical and operational levels. As an example the authors refer to a warehouse whereby the size and design are fixed. These decisions will have to be respected when replenishment policies have to be designed as well as when the size of the different warehouse areas has to be optimized. Van den Berg (1999) mentions that on top of this, decisions taken at each level also handled independently and sequentially.

Strack and Pochet (2010) change this traditionally decision process for the planning of inventory models to evaluate the value of integrating tactical warehouse and inventory decisions. The authors reported a mathematical model, whereby two solutions methodologies were developed which offer different level of integration of warehouse and inventory decisions. As a result, the authors concluded that the total cost of the inventory and warehouse systems can be reduced drastically by taking into account the warehouse capacity restrictions in the inventory planning decisions, in an aggregate way. Moreover additional inventory and warehouse savings can be achieved by using more sophisticated integration methods for inventory and warehouse decisions.
4.2 Assignment of goods to storage locations

As mentioned in chapter three planning of warehouse systems refers to the policies which are developed at the tactical level concerning the assignment of goods to storage locations (Van den Berg, 1999). The storage location planning procedure serves as a framework for the actual location selection of incoming goods. According to van den Berg (1999) the behavior on the intermediate terms is estimated by historical demand patterns and this procedure consists of three steps.

1. Distribution of products among warehouse systems.

Class based storage and/or forward-reserve storage are different procedures to classify and divide products among warehouse systems. In this section authors provided solutions to process this with more efficiency in complex warehouse situations. Traditionally, many warehouses use separate systems or areas for order picking (forward area) and for bulk storage (reserve area) (van den Berg, 1999). However, it is Hackman and Rosenblatt (1994) who presented a model where order-picking from the reserve area is possible. The authors presented a knapsack-based heuristic\(^1\) what assigned which products in which quantities should be replenished to the forward area. The optimal product quantities are derived analytical as a function of the available storage space, where the objective is to reduce the total costs for order-picking and replenishing. Frazelle et al. (1998) incorporate the heuristic into a framework for determining the optimal size of the forward area. Furthermore they mentioned another advantage of this model in means of reducing the congestion within a warehouse by minimizing the activity in the forward area. Frazelle et al. (1998) proves that the procedure in Hackman and Rosenblatt (1994) gives an optimal solution to the continuous reduction of the problem. As a practical example, Frazelle et al. (1998) proved in a case study a 20% saving on labor cost by re-sizing the forward area down to 32% of its original size and by reallocation the products among the forward and reserve area. Sharp et al. (1998) continues this approach by considering a warehouse with busy and idle periods where reserve-picking is possible. Via advance replenishments their model reduced the replenishment activity during subsequent busy periods. The author report that this not only increases the throughput during the busy periods, it also reduces congestion and accidents.

In addition, Sharp et al (1998) present a knapsack-based heuristic with a tight performance guarantee that attempts to find an allocation of products to the forward area that minimizes the total expected

\(^{1}\) The knapsack heuristic is one of the most studied heuristics problems in combinatorial optimization (Dobson and Nambimadom, 2001).
amount of work related to order-picking and replenishing during a busy period. The authors show results of experiments up to 30% savings in comparison with procedures used in practice.

2. Clustering of correlated products.

A common happening in warehouses is that products are often ordered together. Van den Berg (1999) refers in such situation as correlated products. He states that warehouses may reduce travel times for order-picking by storing correlated products close to each other in the warehouse. A procedure which first set up clusters of correlated products and then provides a sequence of the clusters and the products in the clusters according to increasing Cube-per-Order Index (COI)\(^2\) is developed by Lee (1997). According to Lee (1997) this procedure assigns the products one by one to storage locations following a space filling curve. Van den Berg (1999) notes that Lee (1997) model looks promising, although the procedure for clustering the correlated products seems randomly and lengthy. To create a less randomly procedure, Rosenwein (1998) formulated the problem of clustering correlated products as a p-median problem. The cluster median is the product that has the highest correlation with the other products in its cluster, which can be calculated with a branch-and-bound algorithm\(^3\). However, the authors mentioned that the algorithm can solve a typical problem in 1 minute, which includes the calculation of the correlation coefficients, the model formulation is still lengthy (van den Berg, 1999; Ashayeri et al., 2005). Finally, van Oudheusden et al (1994) proved in a case study based on real data a 46% reduction in travel time when assigning correlated products to opposite storage locations. Van Oudheusden et al. (1994) created clusters of two correlated products which were assigned to opposite storage locations in the aisles so that these can be accessed by the order-picker in a single stop.

This clustering heuristic seems preferable if the overlap among orders increase. In case that there is little overlap among the orders, a dynamic programming heuristic presented by van Oudheusen et al. (1994) seems preferable which assigns the products in to storage locations based on the recurrent orders.

3. Assignment of products to storage locations.

As described in chapter three many warehouses traditionally use warehouse storage policies such as dedicated storage, random storage and class based storage policies (Hausman, 1976). In addition, Graves et al. (1977) added two more storage policies: Closest open location storage and full-turnover storage policies. Both authors address these planning problems in static environments and were

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\(^2\) The COI is defined as the storage volume divided by the turnover rate of a product (Lee, 1997)

\(^3\) Branch and bound is a technique to reach the exact solution (Ashayeri et al, 2005)
designed decades ago. However, in today’s world of rapidly changing customer’ demand, small internet orders, tight delivery schedules, high competition and high service level requirements, it will be increasingly difficult to maintain a good performance when using existing static solution techniques (Roodbergen and Vis, 2009). To keep up to these high performances with changing market circumstances different authors came up with more dynamic and stochastic aspects. Kulturel et al. (1999) and Van den Berg & Gademann (2000) proved with simulation more extensive experiments under stochastic conditions can be performed. In addition, Malmborg and Altassan (1998) developed a storage policy trade-off for respectively unit-load and small systems to roughly compare different policies in a short time prior to a simulation study. Both studies showed that full-turnover-based and class-based storage outperforms random storage (Roodbergen and Vis, 2009).

In static environments with independent demand of products, the COI policy is usually well applicable (Roodbergen, 2009). However, Moon and Kim (2001) mentioned that re-location of items is inevitable when production quantity of each item changes over time. Such policy was developed by Sadiq et al (1996); a dynamic storage assignment policy to reassign items to storage locations in systems with a rapidly changing product mix and short product life cycles. This can be established by using predicted future product mix, correlated demand of products and demand forecasts, which will minimize total order processing times. It is shown that this dynamic policy outperforms the static COI rule (Roodbergen, 2009).

4.3 Batching policies.
Traditionally, warehouses may maximize the system throughput by establishing large batches with orders at nearby locations (van den Berg, 1999). However, the author notes that large batches will lead to long response times and selecting orders at nearby pick locations might delay orders at the far end of the warehouse. In contrast with the current market circumstances a trade-off between efficiency and urgency must be observed (van den Berg, 1999). In addition, Gu et al. (2007) agrees with van den Berg (1999) who noticed that the majority of literature has been focused on the objective to minimizing the total order pricking time, while there might be other important criteria such as lead time and tardiness. As a practical example the firm Bol.com offers their costumers services like order today, get delivered tomorrow. In such situation urgency has priority and might be in contrast with traditional batching policies.

The achieve this trade off, van den Berg (1999) mentions two approaches. By selecting a block with the most urgent orders (static approach) and find an order batching within the block that minimizes travel
time. All orders in the block are executed before the next block is released. Assigning due dates to the orders and release each order immediately (dynamic approach) is another approach by van den Berg (1999), whereby a schedule is established that satisfies these due dates. The performance of both approaches differs per situation according to Roodbergen en Vis (2009). For example, Eben-Chaime (1992) concludes that in a specified non-deterministic environment, the static approach might be inappropriate. However, a static approach is more transparent and simpler with respect to implementation according to the author.

Gademann et al. (2001) approached this batching problem by minimizing the maximum lead time of the batches and solve the formulation optimally using a branch-and-bound algorithm. Won and Olafsson (2005) developed a mathematical model and heuristic that solved this joint problem of order batching and picking by considering both efficiency and order lead time.

4.4 Routing and sequencing
The objective of routing policies is to sequence the items on the pick list to ensure a good route through the warehouse (de Koster et al, 2007). In chapter three, five routing heuristics were mentioned to solve the problem of routing. According to de Koster et al. (2007) routing problems in warehouse are mostly solved by using these heuristics, which is due to disadvantages of optimal routing in practice. The author names that an optimal algorithm is not available for every layout and cannot take aisle congestion into account, while with heuristic methods it may be possible to avoid or reduce the aisle congestion. Finally, optimal routes may seem illogical to the order pickers who then, as a result, deviate from specific routes (Gademann and Van de Velde, 2005).

Petersen (1997) carried out multiple experiments to compare the five routing methods and concluded that that a best heuristic solution is on average 5% over the optimal solution. This solution is best appropriate for single-block warehouses (de Koster, 2007). For multiple-block warehouses, Roodbergen and de Koster (2001) reported that the combined+ heuristic gives the best results in 74 of the 80 instances they analyzed. A combined+ heuristic uses dynamic programming to determine order picking routes (de Koster and Roodbergen, 2001). According to the authors, in such case routes having a clear pattern to reduce the time spent by order pickers on searching for locations and reduce the risk of pick errors. The combined routing method generates such routes, whereas every sub aisle that contains items is visited exactly once.
In situation with high uncertainty and little information approaches such as neural networks, expert systems, artificial intelligence and genetic algorithms can be applied to find solutions to the sequencing problem (Roodbergen and Vis, 2009). The authors mention that these methods are capable of learning and adapting to changes in the environment, such as fluctuations in demand.

Various methods are described in the literature to schedule storage and retrieve requests such that the total (empty) distance travelled is minimized. Optimal sequencing methods do exists, but are not regularly used due to some disadvantages mentioned earlier in this section. Roodbergen and Vis (2009) concludes that general dynamic sequencing problem is hard to solve and, therefore, heuristics have been developed to find feasible schedules.

### 4.5 Dwell Point

Simple rules of thumbs, closed-form analytical expressions and mathematical programming approaches have been formulated to position idle AS/RS cranes at a dwell-point in various AS/RS configurations (Roodbergen en Vis, 2009). The most important strategies were mentioned in the previous chapter. However, both authors conclude that no extensive and statically simulation studies have been performed on dwell-point strategies, which makes it according to them difficult to provide designers with an advice when to use which policy. Meller and Mungwattana (2005) confirm that there has been a high level of research activity on how to determine the optimal AS/RS dwell point strategy. However, non appears to be a computational study that illustrates the benefits of using the optimal dwell-point over the more simple rules used in practice.

According to the authors it is believed that the dwell-point location of the SR machine greatly affects the system response time. However, in their study both authors tested via several dwell-points strategies the difference between the performance of optimal versus simple dwell-point strategies for systems were the response times need to be minimized. For example in complex warehouse environments which struggle with rapidly changing customer’ demand.

The simulation study of both authors showed that the benefit of the dwell-point locations was marginal when the system is highly utilized. Therefore, the simulation results have confirmed the hypothesis and it is noted that the dwell-point strategies used in practice, perform very well as compared with the optimal dwell-point location strategy when utilizations are high (Meller and Mungwattana, 2005).
Chapter 5: Conclusion and discussion

In the thesis, a review of warehouse systems is presented and subsequently discussed planning and control related activities in contrast with rapidly changing customers demand’s.

The adaption of new management philosophies such as Just-in-Time (JIT) or lean production as well as changing customers demands brings new challenges for warehouse systems, including tighter inventory control, shorter response time, and a greater product variety (Gu et al. 2007). The objective of this thesis was to provide firms with solutions how to achieve more efficiency and policies to reduce response time within warehouse systems. Hereby, a distinguish was made between planning and control policies.

From this literature survey, it can be concluded that most of the literature addresses planning and control problems in static environments. However, as referred in the problem statement, firms should maintain a good warehousing performance in today’s world of rapidly changing customer’s demand, small internet orders, tight delivery schedules and high service level requirements which will be difficult when using static solution techniques. Literature showed that most solutions provided algorithms were mainly focused for the planning related activities, while control related activities still use simple heuristics. Besides the optimal performance, algorithms provide insight into the problems and may be used as benchmarks for heuristics procedures (van den Berg, 1999).

It can be concluded and at the same time recommended to put more effort in the development of new models. As an example, in section 4.2 the forward/reserve problem showed that significant time savings are possible by allowing order-picking from the reserve area. These savings considerable exceeded the savings between different allocation rules. It can be concluded that designing new models will establish larger savings than optimizing the existing ones. As van den Berg (1999) mentions; introducing new working procedures will achieve larger savings than optimizing the existing working procedures.

Roodbergen and Vis (2009) observe the same change: “The research should now move towards developing models, algorithms and heuristics that include the dynamic and stochastic aspect of current business. They report aspects like: self-adoptive storage assignment methods, on-line-batching policies and dynamic dwell-point rules. According to them algorithm for physical design may need to focus more on robustness of the design than on perfect optimality to ensure that the system will be capable of remaining efficient in yet unknown future situations.

Lastly, most literature addresses one or two decision problems simultaneously, instead of jointly optimizing a combination of planning and/or control problems. So far, one article changed traditionally
decision process for the planning of inventory models to evaluate the value of integrating tactical warehouse and inventory decisions. With the design of a mathematical model, two solution methodologies were developed which offer different level of integration of warehouse and inventory decisions. As a result, the total cost of the inventory and warehouse systems can be reduced drastically by taking into account the warehouse capacity restrictions in the inventory planning decisions, in an aggregate way. The development of such model, which are obviously not a simple exercise, are recommended which compare numerous designs while taking combinations of design aspects and control policies into account.

As a final conclusion the main savings can be derived in planning related activities. In particular, the integrated inventory model of Strack and Pochet (2010) and order picking from the reserve area. Such new models, instead of optimizing existing ones, provide firms to maintain their performance with today's rapidly change customers demands'. On the control side, often optimizing solutions of existing heuristics are observed. It is not that algorithms are not designed for control related activities, but rather that the simple heuristics are easier to implement and that benefits of optimal sequencing and dwell-point strategies were marginal compared to simple heuristics strategies. It is preferable, in today's rapid changing customers demands, to focus on planning related activities rather than control.

**Suggestions for future research**

In the previous section, the development and introducing of new procedures instead of optimizing existing ones is an aspect for future research. It is seen that for most common used control procedures optimal solutions exist. So if firms want to be more competitive focus should rely on innovative models instead of optimizing the existing policies.

Of course this is easier said than done, so from another perspective it is suggested to focus on flexibilization of labour for future research. This implies that throughout the day personnel are shifted between activities whenever extra capacity is needed. In this thesis it is concluded that new planning policies may reduce response time in warehouse systems, which can lead to reduced labour costs. Effective capacity planning procedures determines the number of personnel and resources that are required at any warehouse activity. New procedures should be developed for planning such difficult warehousing operations under tight time constraints.
References


