Aalto University
School of Economics

A warehouse design framework for order processing and materials handling improvement - Case Etra Oy

Logistics

Master's thesis

Tommy Blomqvist

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Department of Business Technology
Aalto University
School of Economics

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Abstract
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A WAREHOUSE DESIGN FRAMEWORK FOR ORDER PROCESSING AND MATERIALS HANDLING IMPROVEMENT – CASE ETRA OY

PURPOSE OF THE STUDY

Warehouses function as node points in the supply chain linking the material flows between the supplier and the customer As a result of the highly competitive market environment companies are continuously forced to improve their warehousing operations. Many companies have also customized their value proposition to better meet customer demands, which has led to changes in the role of warehouses. In such conditions improvement of order processing and materials handling can bring significant cost savings and at the same time increase customer value. The purpose of this study is to develop a warehouse design framework that supports systematic decision making, and show that this framework can be used to reduce order processing cycle times and improve the overall performance of a warehouse.

DATA AND METHODOLOGY

The empirical part of this thesis was conducted as a case study in a Finnish technical wholesales company. Data for the study was collected from two primary sources. The first source was a review of the company's order history. The material was profiled to determine ordering patterns of products and to understand order processing needs. The second source of research material came from a participant-observation of warehouse employees. This allowed assessing the overall distribution of time between different warehousing activities and identifying most critical bottlenecks in the warehousing process.

RESULTS

The results of this study show that even simple planning methodologies can provide general guidelines for designing warehouse processes. The results also imply that companies with poor information infrastructure are unable to efficiently track operations that are performed within the warehouse. This emphasizes the fact that management of information flows is becoming an increasingly important criterion to successfully plan and allocate resources within the warehouse.

KEYWORDS

Warehousing, order processing, materials handling, value added services, product customization

Aalto-yliopiston Kauppakorkeakoulu
Pro Gradu -tutkielma
Tommy Blomqvist

Tiivistelmä
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VARASTONSUUNNITTELU OSANA TILAUSTEN KÄSITTELYN JA MATERIAALINHALLINNAN KEHITTÄMISTÄ – CASE ETRA OY

TUTKIMUKSEN TAVOITTEET

Varastot toimivat toimitusketjun solmukohtina, jotka ohjaavat yrityksen tavarantoimittajilta tulevan materiaalivirran asiakkaille. Kilpailun kiristyessä yrityksen toimintaympäristössä on sen jatkuvasti pyrittävä kehittämään varastotoimintojaan. Monet yritykset ovat myös alkaneet räätälöimään palvelukonseptejaan pyrkimyksenä vastata paremmin asiakkaiden kysyntään, mikä on merkittävästi muuttanut varastotoiminnan roolia. Tällaisissa tilanteissa tilaustenkäsittelyn ja materiaalin hallinnan tehostamisella on mahdollista saavuttaa merkittäviä kustannussäästöjä ja samalla luoda lisäarvoa asiakkaalle. Tämän tutkimuksen tavoitteena on kehittää järjestelmällistä päätöksentekoa tukeva varastonsuunnittelumenetelmä ja osoittaa, että sen avulla voidaan lyhentää tilaustenkäsittelyn läpimenoaikoja sekä parantaa varaston yleistä suoriutumiskykyä.

TUTKIMUSAINEISTO

Tutkimuksen empiirinen osio toteutettiin case-tutkimuksena suomalaisessa teknisen alan tukkuliikkeessä. Tutkimusaineisto kerättiin käyttäen kahta pääasiallista lähdettä. Ensimmäisenä lähteenä toimivat yrityksen tilaushistoriasta poimitut tiedot, joita hyväksikäyttäen luotiin varaston profilointi. Toisena tutkimusaineiston lähteenä käytettiin varastotiloissa suoritettua keräilijöiden havainnointia. Tätä kautta pyrittiin päättelemään työajan keskimääräinen jakauma eri varastotoimintojen välillä ja tunnistamaan ongelmakohdat, joita tilaustenkäsittelyprosessissa esiintyi.

TULOKSET

Tutkimuksessa näytetään, että yksinkertaisiakin menetelmiä hyödyntäen on mahdollista tunnistaa varastonsuunnittelun keskeisimmät tarpeet. Tutkimustulokset myös osoittavat, että mikäli yrityksessä on heikko tietojärjestelmäinfrastruktuuri, varastotoimintojen yleinen seuranta vaikeutuu. Tämä korostaa informaatiovirtojen merkitystä nykypäivän varastotoiminnassa, koska ne mahdollistavat varastoresurssien suunnitelmallisen ja tehokkaan käytön.

AVAINSANAT

Varastointi, tilaustenkäsittely, materiaalin hallinta, lisäarvopalvelut, tuotteiden kustomointi

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1. Introduction

1.1 Thesis background

Large product varieties and shortening customer response times have placed a tremendous emphasis on the ability to establish smooth and efficient logistics operations. Warehouses play a vital role in determining the effectiveness and efficiency of these operations because they function as nodes that direct the flow of materials within a distribution network. The effects of organizing warehousing activities can directly be seen in customer service levels, lead times, and the cost structure of a company. In other words, warehousing influences the performance of an entire supply chain. Warehousing has also been recognized throughout the scientific literature as one of the main operations where companies can provide tailored services for their customers and gain competitive advantage.

The logistics costs caused by a warehouse are often determined already during its design phase. As such warehouse design is a complex task where managers often need to cope with multiple conflicting objectives. Managing warehouses involves making decisions on the policies that are used to govern the tangible material flows and the intangible information flows. These flows are unique for each warehouse and may change over time. This means that there is a continuous need to systematically analyze and rearrange warehouse processes according to latest trends in the business.

This thesis has been conducted as an initial study of warehouse processes in Etra Oy. The company is playing the vital role of a wholesaler, controlling the flow of goods from the producers to the end customer. As a result, there is a constant need to improve the cycle time of internal logistics processes. From the company perspective, the interest towards this study came from the fact that it is about to set up a new distribution warehouse in Hämeenlinna. The warehouse will be taking a significant role in the fulfillment of customer orders and materials processing. Hence, it is important that the current state of processes and future needs of warehousing are properly mapped out before operations in this facility go live.

1.2 Topic area

This thesis concentrates on the study of materials flow management in industrial distribution and warehousing. In this context, warehouse operations can be classified into four core activities: receiving, putaway, order picking, and shipping. Each of these functions represents an extensive subset of managerial decisions. The challenge is to identify efficient ways to organize the overall flow structure and optimize working policies within each warehouse process.

The empirical part of this study will concentrate on order processing which represents the outbound part of warehouse operations. Order processing and internal material movements are typically the most cost intensive areas of warehousing. Hence, the evaluation of picking and storage policies is commonly an important part in warehouse design related studies. Issues such as inventory planning, sourcing policies and transportation allocation will be left on minor discussion as they are not considered core responsibilities of the warehousing function.

The role of warehousing is also constantly changing as companies aim to perform value added activities within the warehousing environment. These activities often extend warehousing beyond its traditional roles. One goal of this study is to find out how these activities influence the cycle time and overall flow of processes within a warehousing facility.

1.3 Objectives

The primary objective of this study is to construct a warehouse design framework for cycle time improvement. A number of supporting models exist in the literature but there remains considerable difficulty in applying these models to practical situations. Also the amount of information companies must cope with is often enormous. How systematic decision making can backup the warehouse design process is an interesting question. An important goal of this study is also to identify which part of the warehousing related information is relevant for organizing processes.

Cycle time reduction is one of the most important elements of successful warehousing. More and more customers are demanding that their suppliers quickly respond to their needs and deliver perfect quality products on time. This trend has led companies to focus more attention on their order processing capabilities. On the practical level, cycle time improvement requires finding a good set of policies to organize warehouse processes for functionality and effectiveness. Reducing order processing cycle times can improve customer satisfaction and internal operations of a company but in order to do so there is a need to understand the relationship between warehouse complexity and control structure.

1.4 Research problem

The number of alternative ways to organize warehouse flows is enormous. The chosen approach often represents a mixture of decisions based on organizational needs and intuition of the decision maker. The general problem of this study is to identify whether there is common agreement in the literature on warehouse design approaches and thus whether some basic steps could be used as an overall framework in the warehouse design process. After this, the objective is to validate the framework by applying it to the practical planning of order processing operations.

The main issue regarding the case company of this study is to find ways to improve warehouse cycle times through reorganization of order processing and materials handling activities. The aim is to take advantage of existing product information in the company and apply it to the design of warehouse processes. In order to accomplish these objectives, there is a need to answer a set of question such as: what is the average distribution of work effort between different warehousing activities; what influence will value added activities have on order processing times; and how can warehouse resources and space be allocated between different product categories in order to optimize material handling efficiency?

1.5 Research methodology

The basic way to divide business research methods is to look at qualitative and quantitative research streams. Quantitative studies focus on statistics and numbers. They can provide accurate information on a specific research area but lack the ability to explain phenomena and cannot be used when the phenomenon is unclear itself (Koskinen et. al 2005). Qualitative research, on the other hand, is hard to define as it has no theory, paradigm or methods, which would be completely its own. A qualitative study focuses on increasing the understanding of a certain area and is helpful when the research phenomenon is unclear or completely new.

The research methodology used in this thesis closest resembles to the definition of a case study. The major advantage of a case study methodology is that it is capable of combining the quantitative and qualitative research streams to conduct a holistic and in-depth investigation (Tellis, 1997). Case study is an especially useful methodology for organizing a wide range of information. It also allows using multiple sources of data which increases the reliability and brings out the smallest details of the case problem.

The primary sources of information in this study were the review of internal databases and a participant-observation of warehouse personnel's daily working routines. The major advantage in participant-observation is that it offers access to information that is not available to scientific investigation and an ability to perceive reality from the viewpoint of someone inside the case study (Yin, 2003, 93). On the other hand, problems with this methodology include that the participant-observer easily becomes a supporter of the group being studied. Another problem is that the way people behave in an observation situation may not resemble their normal behaviour.

1.6 Thesis structure

This thesis has four main chapters. Chapter 2 begins the theoretical part by presenting central concepts of warehousing and discussing the different roles warehouses play in a supply chain. This chapter also categorizes most essential warehousing activities, identifies resources needed to accomplish these activities, and presents the role of technology in modern warehousing. Chapter 3, on the other hand, discusses the increasing importance of service orientation in industrial distribution. The chapter presents the concept of customized warehousing and its implications on performing logistics operations.

Chapter 4 concludes the theoretical part by presenting some of the common practices used to organize warehousing activities. The chapter begins by discussing the physical layout of a warehouse which is a relevant factor influencing the flow of materials. The chapter also describes some of the tools that can be helpful when organizing and measuring the performance of warehouse processes and presents the warehouse profiling methodology that is used in the empirical part to plot the nature of warehouse operations.

Chapter 5 concentrates on the empirical part of the study. It starts by describing how the warehouse design framework was built. The case study on warehouse operations is then conducted according to this framework. Finally, chapter 6 summarizes the theoretical results and managerial implications of this thesis.

2. Managing Warehouses

Warehousing comprises a set of activities or processes that are performed to ensure the seamless flow of materials and information. Assessing and improving the performance of these activities requires careful study of the way warehouse flows relate to each other. Important factors influencing process efficiency in the warehousing environment are e.g. layout choices and the policies by which work routines are controlled (Aminoff et al., 2002). It has also been claimed that the flow of information between different parts of a process can be significantly improved by taking advantage of information technology and increasing the level of automation (van den Berg & Zijm, 1999). This chapter introduces the role of warehousing in today's business environments. The aim is to discuss general concepts of warehousing and identify the different problems that may arise in the context of warehouse management.

2.1 The purpose of warehousing

A warehouse or a distribution center is a commercial building used for the storage of goods. The principal element of warehousing is order processing which generally refers to the work flow associated with delivering products ordered by a customer to a shipping carrier. The primary aim for warehouses and distribution centers is to facilitate the movement of goods from suppliers to customers while meeting the customers' demand in a timely and cost-effective manner.

In the old days of warehousing, inventory was seen to represent the wealth of a company. However, these days this is not the case anymore. Instead, many companies have noticed the high cost associated with holding inventory. In their purest form warehouses should be transshipment areas for dispatching and receiving where products remain in the warehouse for a short period of time only (Faber et al, 2002). In practice, however, there are overriding factors such as meeting customer demand and expectations that make it hard to operate without inventory. Valid reasons for holding inventory include, for example, buffering cycles between two production processes, covering demand during supplier's lead-time, enabling savings by using volume discounts, coping with seasonal fluctuations, providing a variety of products in a centralized location, or holding anticipation and investment stocks (Krajewski & Ritzman, 2005). As a result, the basic aim of most warehouses is simply to minimize the total cost of operations while providing a desired level of service.

Warehousing also plays an important role from the supply chain perspective. Despite all of the integration initiatives, supply chains will never be so well coordinated that warehousing can be completely eliminated. Frazelle (2002) states that warehouses are important for a supply chain because they provide storage for raw materials, components, work-in-process, and finished goods; operate as distribution and order fulfillment centers; and perform localized and value added warehousing. Figure 2-1 illustrates warehouses performing these functions in a logistics network.

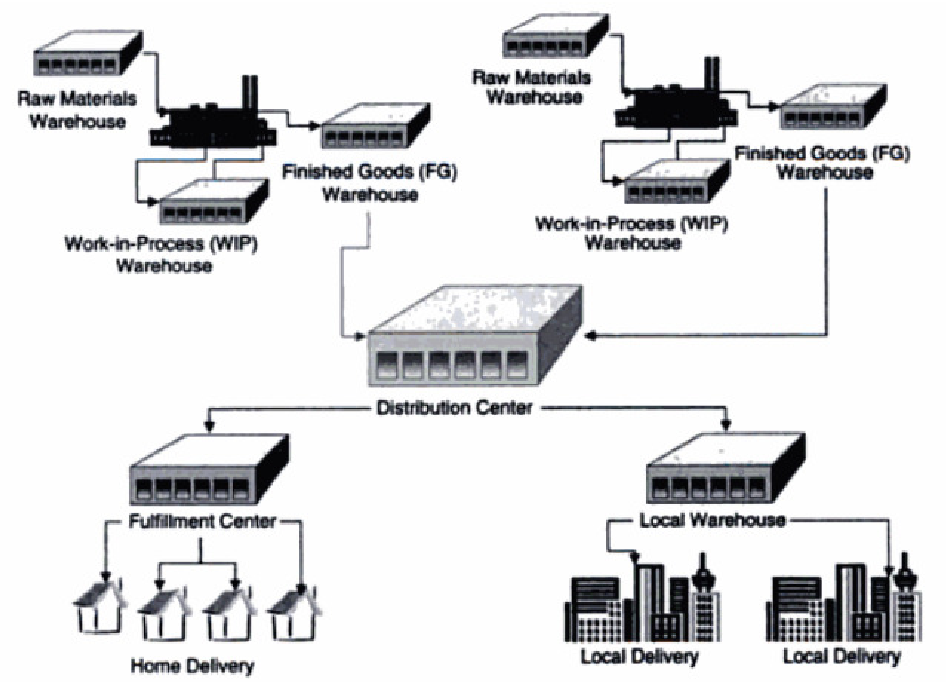

Figure 2-1 Roles of warehouses in a supply chain (Frazelle, 2002, 2)

Although the traditional role of warehousing has been associated with holding products in stock, some new trends are emerging. For example, Higginson & Bookbinder (2005, 71-80) list the roles of distribution centers as following:

- **Make-bulk / break-bulk consolidation centers** in order to consolidate customer orders together into one delivery and gain transport economies.
- **Cross-dock centers**, whereby customer orders are satisfied from another source (e.g. a manufacturing plant) and just pass through the facility.
- **Transshipment facilities**, which are used to change transport mode (e.g. from large line-haul vehicles to smaller delivery vehicles).

- **Assembly facilities**, where the final configuration of the product to individual customer requirements can take place.
- **Product-fulfillment centers**, responding directly to product orders from the final consumer (e.g. internet fulfillment operations).
- **Returned goods depots**, handling unwanted and damaged goods, as well as goods returning under environmental legislation such as product recovery and packaging waste.
- **Miscellaneous roles**, such as customer support, installation and repair services.

A number of these roles may be associated with the concept of value added warehousing. However, these activities are still relatively minor in nature and normally occur as a part of other warehouse functions. This implies that many firms have noticed the possibilities lying in value added activities but have been unable to deploy warehousing strategies that would support them. For example, Baker (2004) noticed that although up to 70 percent of warehouses perform various value added activities, they only account for about 5 percent of the floor space. Similarly, Jones et al. (1997) noticed that it is common to find that in a service facility less that 5 percent of activities actually add value, 35 percent are necessary non-value-adding activities and 60 percent add no value at all. Thus, a good way to start eliminating warehousing costs is to identify the non-value adding activities and remove them.

2.2 Warehouse design in the scientific context

Designing warehouses is challenging because it involves so many trade-off decisions. Each warehousing function needs to be carefully implemented in order to achieve operational targets. These targets are often expressed in terms of capacity, throughput, and customer service levels. The literature also, acknowledges that the warehouse design process is highly complex (Baker & Canessa, 2009). The authors often seem to tackle this complexity by describing sequenced procedures for creating an appropriate warehousing solution. However, because there are a high number of decision variables, it may not be possible to identify an “optimal” solution. As a result, steps in the design process are typically interrelated and reiterative decision making methods are needed during the process.

2.2.1. The warehouse design problem

The overall warehouse design problem is to specify the relations between systems and processes by which material and information flows are governed. Warehouses must be designed to accommodate the loads of materials to be stored, the associated trucking in receiving and shipping operations, and the needs of the operating personnel. The design of the warehouse space should be planned to best accommodate business service requirements and the products to be stored and handled. The economics of modern commercial warehouses also dictate that goods are processed in minimal turnaround time.

It is possible to approach the warehouse design problem in a number of ways. A common approach has been to view the process of designing warehouses from a top-down perspective. Results from such studies have provided frameworks to conceptualize different design problems and create step-by-step guidelines on how the design process should be sequenced. For example, Baker & Canessa (2009) tried to formulate a structured approach to warehouse design based on a review of warehouse design specialized consulting companies.

Another common approach in the warehouse related literature has been to concentrate on specific warehousing sub-problems. Models employed in such studies typically concentrate on optimizing operations in certain areas of warehousing such as layout design, picking policies or equipment choice. However, there is little information about the synthesis of these methods and how they can be incorporated to the overall warehouse design process. Instead, they can be seen as a rather deterministic effort to optimize performance within a limited range of warehouse functionalities.

The most common warehouse design and operation planning problems are shown in Table 2-1. According to Gu et al. (2007) issues related to warehouse design are divided into five interrelated categories. Design related issues comprise decisions about the overall warehouse structure, department layout, operational strategy, equipment selection, and sizing and dimensioning of departments. Operational planning problems, on the other hand, concentrate on organizing activities in the different warehousing functions. Past research has focused strongly on storage and order picking operations. This is not surprising since these are typically the two operations with highest influence on warehouse performance measures such as storage capacity, space utilization, and picking efficiency.

Table 2-1: Warehouse design and operating problems (Gu et al., 2007)

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 strategy selection (e.g., random vs. dedicated)
			▪ Order picking method selection
Warehouse operation	Receiving and shipping		▪ Truck-dock assignment
			▪ Order-truck assignment
			▪ Truck dispatch schedule
	Storage	SKU assignment	▪ Assignment of items to different warehouse departments
			▪ Space allocation
		Zoning	▪ Assignment of SKUs to zones
			▪ Assignment of pickers to zones
		Storage location	▪ Storage location assignment
			▪ Specification of storage classes (for class-based storage)
	Order picking	Batching	▪ Batch size
			▪ Order-batch assignment
		Routing	▪ Routing and sequencing of order picking tours
			▪ Dwell point selection (for AS/RS)
		Sorting	▪ Order-lane assignment

To be able to operate efficiently a warehouse needs to have a set of pre-described management policies. However, the warehouse planning process is complicated because setting these policies includes facing a large number of interrelated trade-off decisions (Rouwenhorst et al., 2000). While significant research has been done in the area of warehouse design, it has also been found that the research results are rarely used in actual business contexts by industry practitioners (Bodner et al., 2002).

2.2.2. Scope of warehouse design

Rouwenhorst et al. (2000) suggest that the warehouse design related issues may be situated on three different levels: strategic, tactical and operational. This hierarchical framework reflects the horizon of warehouse decisions on long-term, mid-term and short-term time frames. The approach is practical especially when information on current operations is not available or doesn't exist (e.g. starting a new warehouse facility). Because warehouse design is often started with limited information, outlining higher level issues first provides constraints for lower level problems and the outcome should be a more coherent design plan.

Strategic level represents long-term and high investment decisions which can be divided into two groups. The first group of decisions is concerned with the overall design of warehouse flows. A basic flow consists of the stages receiving, storage, order picking, and shipment. Additional processes may be included which has a straight influence on the selection of work tasks and technical equipment. For example, a sorting process will require means to batch and sort processed orders. The second group of decisions is concerned with selecting the type of warehousing systems to be used with the specified processes. The two groups of decisions are connected in the sense that selected processes dictate the need for assisting systems but a process may only be implemented if such systems are available. For example, a sorting process may be selected only if a sorter system exists that is suitable for handling products in the warehouse.

Tactical level decisions are mid-term decisions that are based on the outcomes from the strategic level. These are decisions that have less impact but still represent moderate investments. Therefore it is not worth reconsidering them too often. Tactical decisions are typically related to issues such as allocating resources, organizing warehouse layout, or determining storage rules.

Operational level includes daily working decisions that support decisions made on the previous levels. They are often made with less thought and their impact on operations is restricted. Operational decisions can be pre-programmed, pre-made, or set out clearly in policy manuals. Decisions concerning warehousing processes on the operational level include for example allocation of free storage locations, order sequencing and assignment to pickers, and picking route decisions.

2.3 Basic concepts

The objectives and priorities of a warehouse and its role in the supply chain define to a large extent the type of activities and resources that are needed (Hassan 2002). The various activities performed in a warehouse and their sequence should be identified to help develop a functional layout structure. Since warehousing is a necessary cost activity, it is important to maximize the effective use of warehouse resources such as space, equipment and labor. The integration of warehouse activities into a rational process flow plays a critical role in accomplishing this goal.

2.3.1. Categorization of warehouse activities

The basic function of a warehouse is to receive customer orders, retrieve required items, and finally prepare and ship those items. There are many ways to organize these operations but the overall process in most warehouses shares the following common phases (Frazelle, 2002; Rouwenhorst et al., 2000):

- **Receiving** – the process of unloading, checking quality and quantity, and dissembling or repacking items for storage
- **Putaway** – defining the appropriate location for items and transferring them to the specified storage location to wait for demand
- **Order picking** – retrieving items from their storage locations and transporting them either to a sorting process or straight to the shipping area
- **Shipping** – inspecting, packing, palletizing and loading items into a carrier for further delivery

Out of these activities, receiving and putaway belong to the inbound logistics process which means that they are concerned with the flow of materials coming into the warehouse. Order picking and shipping, on the other hand, belong to outbound logistics and are concerned with moving materials out of the warehouse. Figure 2-2 represents the typical distribution of costs between various warehousing activities as a percentage of total warehousing costs.

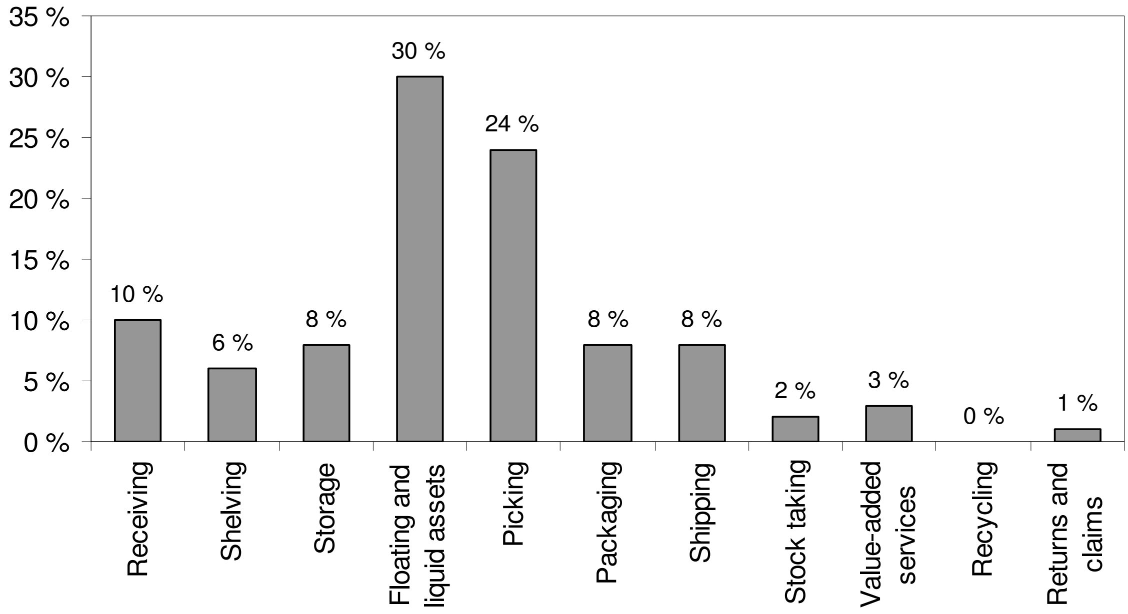

Figure 2-2: Average costs of warehousing operations (Aminoff et al., 2002)

The way, in which various warehousing functions are arranged, depends on many issues. Firstly, the physical quality of the warehouse facility may set certain restrictions. For example, receiving and shipping functions should normally be located near the facility input and output points. On the other hand the facility may have some fixed obstacles that hinder entering and performing work tasks in certain areas. Second, management typically wants to balance the flow patterns between various activities and minimize the travel distances for stock movement. This can be achieved through systematic identification of stock locations and adjacency requirements between different warehouse activities. Finally, product attributes may require certain kind of handling procedures. Some items, for example, may be temperature sensitive which requires processing them in a climate controlled location.

2.3.2. Warehouse resources

Typical issues involved in designing and performing warehouse processes include allocating resources in terms of costs and capacity. When looking at the value of a product or service, the goal is to have the value of the end-product exceed the cost of producing it. Identifying the value added activities inside the warehousing process is an essential but demanding task. Basically, the value assessment is made by examining each activity within the process and defining its criticality to operations. The cost of the product or service includes all resources used to produce it (e.g. raw materials, labor, storage space, transportation, equipment). According to a classification by Rouwenhorst et al. (2000), it is possible to identify the following list of distinguishable warehouse resources:

- **Storage units** – Used for the storage of products e.g. pallets, trays, boxes
- **Storage systems** – May range from simple shelves up to automated cranes and conveyors
- **Pick equipment** – Used for the retrieval of items from the storage system e.g. standard forklifts, reach trucks, pallet trucks
- **Auxiliaries** – Equipment, such as barcode scanners, that support warehouse activities
- **Computer systems** – Enable computer control of processes
- **Material handling equipment** – Equipment for preparing retrieved items e.g. sorter systems, palletizers, truck loaders
- **Personnel** – Human resources that operate and control all of the pre-described resources

Warehouse resources normally represent a sizeable capital investment. Approximately 50 percent of the costs in a typical warehouse are labor-related while facilities, machinery and storage equipment represent smaller portions of the investment (Aminoff et al., 2002). Reducing the amount of labor or pursuing higher labor productivity can be seen as a means to lowering warehouse operating costs. This is typically done by investing in expensive warehouse technologies. However, to obtain an acceptable rate of return on equipment investments, they must be selected and used properly.

2.4 Warehouse technologies

Many developments in the warehouse efficiency have been made possible due to the advances in warehouse technologies. It is useful to think of warehouse technologies consisting of two elements. The first element involves the use of computers for planning and directing activities. The second is the degree of mechanization or automation. Naturally, the goal of automating warehousing operations is to enhance efficiency of material handling through reduction of labor costs and increased throughput. The evolution of systems created for warehousing is not very different from many other technology solutions in the sense that most of them are based on few core functionalities on top of which developers have started to add small features that they have seen as valuable for accomplishing specific tasks.

2.4.1. Automating and mechanizing processes

A warehousing system refers to the combination of equipment and operating policies that are used in a storage/retrieval environment. The simplest storage method is block stacking which is a typical method for stocking bulk items. Although block stacking is very cheap it results in low accessibility to items due to the honey combing effect. To enhance accessibility, most warehouses consist of parallel aisles with products stored along sides. Small items can usually be placed in bin shelves or modular storage drawers fairly efficiently while larger items are typically placed on pallet racks.

Warehouse technologies are used for three main reasons: save storage space, improve productivity, and reduce errors (Aminoff et al., 2002). Selecting the appropriate level of warehouse automation is a difficult task. Capital investments can be considerable but the rewards often include significant savings in terms of labor costs and productivity, inventory accuracy, or order processing times. With respect to the level of automation it is possible to distinguish three types of warehousing systems (van den Berg & Zijm, 1999):

- **Manual warehousing systems** (picker-to-product) – The order picker collects the product in the warehouse by travelling to the storage location.
- **Automated warehousing systems** (product-to-picker) – The picking operation is performed by an automated device, delivering items to a stationary order picker.
- **Automatic warehousing systems** – This system is similar to the automated warehousing system except that the picker is replaced by a robot.

One key to effective design of warehouse processes is the relative dominance between picking and storage activities because these two warehousing functions typically have opposing requirements. Techniques that maximize space utilization tend to complicate picking and render it inefficient while large storage areas increase travel distances which reduces picking efficiency. Ideal picking requires small stocks in dedicated, close locations.

Automation of picking, storage, handling and information can compensate for these opposing requirements to a degree. However, automation is expensive to install and operate. Table 2-2 shows how different transaction volumes, storage requirements and technologies lead to different warehousing concepts.

Table 2-2: Different warehouse concepts (Phillips, 2010)

Picking activity requirements \ Storage requirements	High	Low
High	▪ High density storage ▪ Automated handling	▪ Dedicated locations ▪ Low density storage ▪ Automated handling
Low	▪ Random location ▪ Dense storage ▪ Manual handling	▪ Dedicated pick locations ▪ Dual storage ▪ Low density storage ▪ Manual handling

High picking and storage requirements indicate a large and active warehouse. In these situations mechanized handling of orders and high density of storage often justifies itself. On the contrary, a simple small warehouse seldom needs such sophisticated systems and can be operated completely manually. A picking dominated warehouse should be compact and dense with simple storage. While on the other hand, a storage dominated warehouse should enable high density multi-level storage with simple manual picking operations.

2.4.2. The role of information systems

Warehouse execution systems can be classified into two categories - the warehouse management systems (WMS) and warehouse control systems (WCS). The primary purpose of a warehouse management system is to control the movement and storage of materials within a warehouse and process the associated transactions. Typical roles of a warehouse management system include directing and sharing transaction data for the picking, replenishment, and putaway operations. The system may be standalone applications although most modern Enterprise Resource Planning (ERP) systems have modules with corresponding functionalities. Faber et al. (2002) distinguished three types of warehouse management systems:

- **Basic WMS** – Support stock and location control only. The system is mainly used to register information. Storing and picking instructions may be generated by the system and possibly displayed on RF-terminals. The warehouse management information is simple and focuses on throughput mainly.
- **Advanced WMS** – In addition to the functionality offered by a basic WMS, an advanced WMS is able to plan resources and activities to synchronize the flow of goods in the warehouse. The WMS focuses on throughput, stock and capacity analysis.
- **Complex WMS** – With a complex WMS the warehouse or group of warehouses can be optimized. Information is available about where each product is (tracking and tracing), where it is going to and why (planning, execution and control). Furthermore, a complex system offers additional functionality like transportation, dock door, and value added logistics planning which help to optimize the warehouse operations as a whole.

The primary function of a warehouse control system is to receive information from the upper level host system, most often being the warehouse management system, and translate it for the daily operations. A common goal is to ensure a situation where warehouse employees never have to retype information because it already lies in one system or is collected automatically (Yao & Carlson, 1999). Warehouse control system is usually the interface that is used to manage processes, people and equipment on the operational level. The roles of warehouse control systems commonly include:

- Transmit information and manage automated equipment
- Direct and schedule work processes (e.g. job sequencing, job verification)
- Monitor and report performance (e.g. picking rates, error rates)
- Simplify or provide a graphical user interface
- Interface with other management information systems

WMS systems are complex and data intensive applications, which require a highly risky implementation project. In addition, many information systems require changes in the existing organizational structures and creation of new working policies. A major question, for example, has been the ability to link a new warehouse management system with other pre-existing logistics execution systems. The increasing sales of standardized software packages show that the trend on many markets has become to purchase a standardized software package and hope that it can be easily linked to the existing application infrastructure. Warehouse management systems must also interface with various information controlling systems like data collection devices and material handling equipment which imposes certain challenges. In fact, this equipment is typically so expensive that the choice of the management system is overruled by the equipment controlling system.

Most warehouses could certainly benefit from the functionality provided by a warehouse management system. Investments in warehouse systems are often reasoned by their ability to reduce operational costs and increase performance accuracy through real-time control of operations, easier communication throughout the supply chain, and higher levels of automation (Gu et al., 2007). However in the end, the determining factor in deciding whether to implement these systems tends to be associated with the improvement of customer service.

3. Industrial Distribution and the Service Approach

Industrial markets involve the sale of goods between consumer groups that are composed of companies and organizations. These markets include selling finished goods, raw materials, components, and services. Whereas consumer marketing is aimed at the mass market, industrial marketing tends to be focused to a smaller number of customers.

Many industrial companies are facing an increasingly challenging market situation. Because of globalization and increased competition, many firms are confronted with price pressures and time-based competition. In these circumstances, providing product related services is becoming an increasingly tempting option as it represents a key source of potential growth. The previous research in this area has been relatively vague and requires taking a different view to the way logistical activities in the organization are arranged. There is a need to study the effects of value added activities on the warehouse cycle times and costs as well as to identify how these additional activities will influence the overall flow of processes.

3.1 Characteristics of industrial distributors

In this thesis, the terms industrial distribution and industrial wholesaling are used interchangeably to refer to the sale and supply of goods to professional business users. Sometimes industrial distribution can be perceived as the straight resale of goods without transformation. These days however, distributors are increasingly trying to integrate logistical value-addition processes to be a part of their service.

Although distributors may perform some manufacturing related activities, they differ from industrial manufacturers in several important ways. Firstly, distribution is a capital intensive industry where facilities, inventory, and other capital investments constitute a large portion of assets. Second, distribution is market driven, which means that a distributor’s inventory is likely to include several thousands of unique products. There are also significant differences in the logistics costs structure between different industrial branches. These differences are demonstrated in Figure 3-1 which shows the ratio between turnover and logistics costs for various industries in Finland.

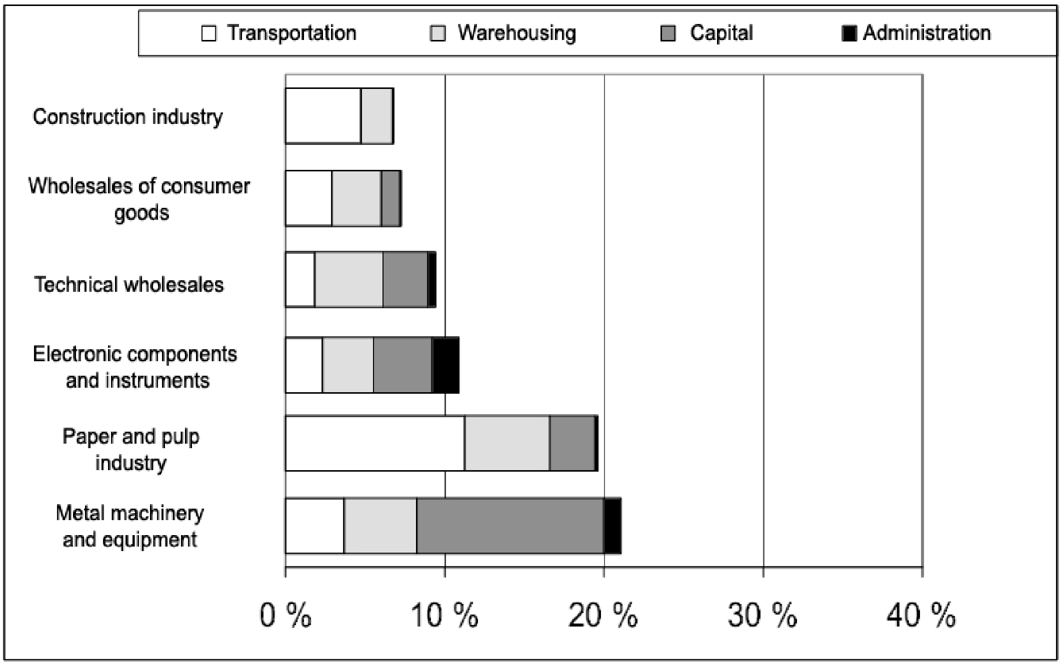

Figure 3-1: Logistics costs for various industries (Salanne et al., 2005)

Over 25 years ago Narus et al. (1984) defined industrial distributor as the full-service middleman who takes title to the product sold, maintains inventories, provides credit delivery, wide product assortment, technical assistance, and may even do some assembly and manufacturing. For most parts, this definition still holds true. Using economics of scale, distributors are able to reduce unit costs for inventory, transportation, warehousing, and ordering. On the other hand, many customers desire rapid delivery, which has resulted in more extensive and technical warehouse and distribution facilities developed and maintained by distributors.

Because of limited resources distributor's investments must reflect the needs of its customers. In addition, distributor's sales are closely tied to the economic vitality of the local marketplace. Traditionally, the primary responsibility of distributors has been the storage and physical movement of goods but both manufacturers and retailers are expecting more and more from their distributors. In particular, retailers expect their suppliers to provide technical sales training, electronic order processing, on-time delivery, and customized services. In addition to being a distributor of goods, wholesalers are to a larger degree also expected to exhibit a particular image and assume the role of a marketing intermediary (Burkink, 2002).

3.2 Trends in supply chain management

From the logistics point of view, the changing product and service offerings present a completely new challenge. The importance of supply chain design has increased when more and more companies have realized the possibilities of gaining additional value for the customers by restructuring their service approach (Korpela et al., 2001). Since warehousing is one of the essential parts of most supply chain operations, it has also been forced under the pressure of change. In general, the need to improve efficiency and develop new service offerings in the industrial warehousing environment seems to be driven by two major trends. The first one is the intensifying competition inside the industrial market. The second trend is related to the entrance of external logistics service providers with increasingly customizable value propositions.

The majority of manufacturing and wholesales oriented companies not only deliver a tangible product but also promote a set of value added market offerings (Jiao et al., 2001). Especially among manufacturing-based industrial companies, the shift towards service orientation has been acknowledged throughout the literature (Oliva & Kallenberg, 2003). Eventually this means that there is a need to ensure that the operations strategy of a firm also conforms to the service supply side (Johansson & Olhager, 2004). This transition constitutes a major managerial challenge. Shifting towards services requires organizational principles, structures and processes that are new and unfamiliar. The situation is especially challenging because most customers in the business-to-business world expect that services are automatically accommodated to their needs. If their supplier doesn't manage to do this, the customer company is likely to go and look after the same service from a competitor.

A mere observation reveals that a large variety exists in the way firms approach their product-service strategy. Many industrial firms provide services to sell and support their product. In a way, they already are in the market of product-related services. Those services, however, have traditionally grown in different parts of the organization, are fragmented and considered an unprofitable necessity to sell the product (Oliva & Kallenberg, 2003). This is why identifying the value added activities inside an organization is highly important. Another important question relates to the way organizational structures and processes should change or be managed to facilitate services in a cost-efficient manner.

In the logistics field, the range of value propositions offered by third party logistics providers has changed dramatically in recent years. By definition, third party logistics companies can be identified as firms that provide certain supply chain functions as a service to its customer. The third party logistics business has developed as a result of the emerging demand of advanced logistics services. Third party logistics providers typically specialize in integrated operations that can be scaled and customized to customer's needs based on market conditions. The most commonly outsourced services by industrial firms are transport, warehousing, and inventory management (Hertz & Alfredsson, 2003). From a service point of view, there are multiple reasons for an industrial company to outsource its logistical activities. The organization may, for example, lack the capability to perform a service in required quality, does not have the scale and ability to perform service efficiently, or it may simply run out of capacity.

From the perspective of this thesis, interest towards these logistics services derives from the argument that this industry is actually out of its formative stages and a reasonably clear segmentation in terms of value offerings has already emerged (Berglund et al., 1999). Thus, studies concentrated on the operations of third party logistics companies can provide valuable insight to the management of warehousing activities. Another important argument is that even privately owned warehouses compete with third-party warehouses. If these warehouses are not competitive with potential third-party providers, then the justification for being in the warehousing business should be reconsidered (Frazelle, 2002).

3.3 Deriving value from warehouse related services

In economics, the difference between the sales price of a product and the cost of resources used to produce it is called the value added. The effort to gain additional value is typically a customer-driven process aimed at retaining a higher monetary value for each unit being sold. This can be achieved by enhancing the product and its associated service offering. In other words, the success of a company is defined by its capability to respond to the demand of tailored products and services. The company has to realize the value that is created when customer specific needs are met. On the other hand, the company must also be aware of the costs that are associated with this effort.

Although the role of warehouses has changed tremendously over time, it has traditionally been an essential part of industrial distributors' operations. Industrial companies rely heavily on raw materials, work-in-process, and finished goods inventories which are almost unexceptionally placed in warehouses or production facilities with departments that resemble warehouses. The simplistic approach to warehousing assumes that it is only concerned with the storage, repacking, and shipment of products. However, the modern competitive environment has shown that redesigning the functionality of a warehouse can play a significant role in the value offerings a firm is capable of delivering. Most of the customer specific service offerings are physically performed in the warehousing environment. Therefore, paying attention to the customer needs should be an essential part of the warehouse planning and order fulfillment strategy.

3.3.1. Customized warehousing

The focus of logistics is increasingly turning towards providing better services for customers instead of minimizing the total transportation or logistics costs, or maximizing total profits (Korpela et al, 2001). As a result, warehouses are becoming to larger extent flow-through facilities that perform certain value adding functions or customer specific activities before products continue their movement through the supply chain. This, however, sets completely new challenges to warehousing operations. Rather than just picking items and sending them on to packaging prior to final shipment, something additional has to be done to the picked items.

As a result, many companies have realized the practicality of customized warehousing. Customized warehousing refers to the postponement of manufacturing activities down the supply chain. The approach is especially viable for distributors that are located near the end users because it allows them to avoid obsolete inventories and low demand responsiveness while at the same providing a valuable service to the customer. The essence of customized warehousing lies in the storage of a generic product in the warehouse until receipt of a customer order. Once the order has been received the warehouse performs required customization activities and delivers a floor-ready merchandize to the customer.

This kind of warehousing strategy, however, comes with a new set of challenges. According to Tompkins (1997), customized warehousing blurs the line of responsibility between manufacturing and warehousing. Tasks that were formerly performed by a factory will be moved to the warehouse, resulting in significant changes at least in four areas:

1. **Facilities:** Customization warehouses will naturally need more space to perform the increased number of activities. The activities performed may also have adjacency requirement which can result in certain restrictions on the facility layout.
2. **Equipment:** New and different equipment will be required for customized warehousing as a result of changing storage requirements and the addition of some manufacturing functions to the warehouse. Depending on the customization to be provided by the warehouse, the appropriate equipment with considerable flexibility will be necessary.
3. **Technology:** To handle the demands of customization, the warehouse must have a real time based warehouse management system. The system must provide functionality to kit materials, schedule production, and track work-in-progress.
4. **Labor:** Depending upon the specific warehousing design, more labor may be needed to perform the customization processes. It is also likely that an enhanced set of skills and level of flexibility is required.

In many cases, adding postponed manufacturing activities to warehouse and transportation operations can be a logical extension to the existing customer relationship. However, a fundamental distinction between various industries has been that while third party logistics companies have marketed themselves as industrial value added providers, wholesalers and manufacturers traditionally perform the same activities on their own account and integrate the cost of performing these activities to the sales price of the products (van Hoek, 2000).

3.3.2. Common customization activities

Customized warehousing can be as simple as transferring finished goods to a unique pallet configuration, or as complex as a significant portion of what has traditionally been considered a part of the manufacturing process (Tompkins, 1997). The basic idea behind customization activities is that the material handling requirements from the customer's point of view are minimized. This means that the customer receives the ordered items in a condition that is readily usable for the purpose they are purchased for. Table 3-1 summarizes and describes some of the most typical customization activities performed in warehousing facilities.

Table 3-1: Common customization activities in warehousing (van Hoek, 2000)

Activity	Description
Assembly/Kitting	Packaging and configuring individual items into one unit
Adding manuals	Including instruction or technical specifications for the use of the customer
Labeling/Tagging	Applying labels for identification, pricing and other communication means
Packaging/Palletizing	Protecting and unitizing products for distribution, storage or sale
Sizing	Cutting or downsizing the product according to customer specifications

From a value creating perspective, it is important to focus on the degree of service customization required by the customer. The usual approach of value-adding strategies is that the supplier adds technical product features or supporting services to the core solution so that the total value of the offering is increased (Hertz & Alfredsson, 2003). At the same time the service offering becomes more advanced. According to Andersson & Norrman (2002), the complexity of procuring logistics services is related to issues such as the number of services included (single or multiple bundled services); the tangibility of the service definition; whether focus is on handling or value adding; whether focus is on execution or management of activities; and whether the service is pre-defined and stable or if development and re-engineering is part of the service (see Figure 3-2).

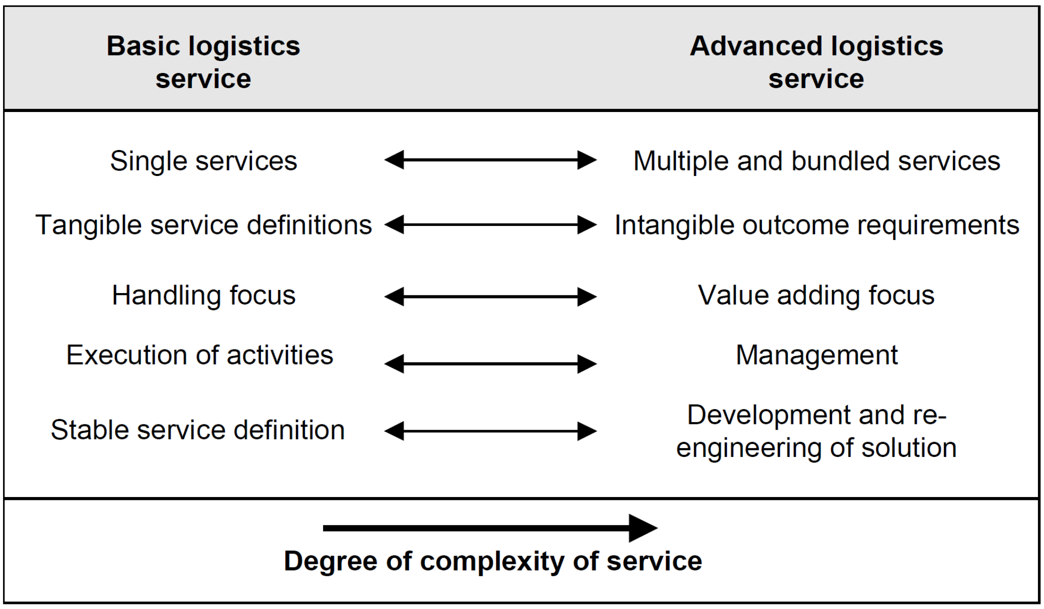

Figure 3-2: Advanced versus basic logistics services (Andersson & Norrman, 2002)

Apart from the question whether or not customized warehousing is a viable area of supplementary services for industrial distributors, it is also relevant to assess the size of employment created by the pre-described activities. Value from the customer's point of view is independent of the cost to produce it but to the company that is providing the service there can be a great difference based on which activities are performed during the order fulfillment process and how the activities are arranged. The inclusion of value added activities in the overall warehouse process flow can be compared to adding new process steps to a manufacturing process because they will have a straight influence on process cycle times and the use of warehouse capacity. For these reasons it is important to clarify the approach a company wants to take in its order fulfillment strategy.

3.4 The order fulfillment process

The order fulfillment process involves generating, filling, delivering, and servicing customer orders. A large part of these activities are considered responsibility of the logistics and warehousing function. At the operational level, the order fulfillment process focuses on physical transactions, while on the strategic level the focus is usually on making critical improvements to the processes that influences financial performance of the firm, its customer, and its suppliers (Croxton, 2003). The order fulfillment process is complex because it is composed of several activities executed by different functional entities. The order fulfillment strategy has strong implications on how firms customize their products and deal with product variety. Industrial service orders typically have quite variable demand patterns, which makes planning and forecasting difficult (Johansson & Olhager, 2004). In times of high demand, capacity utilization will increase which leads to higher work-in-process and longer queuing. This will result in variable lead times, with potential implications on delivery reliability and service levels to the customers.

Physical handling of customer orders is a key element in the order fulfillment process. Order processing is the term generally used to describe the process or the work flow associated with the picking, packing and delivery of the packed items to a shipping carrier. The specific process and operational procedures are determined by many factors. Because each warehouse typically has its own unique requirements and priorities, a common notion has been that there is no single process that universally provides an optimized solution. Instead, the specific process flow of a warehouse is determined by factors such as the nature of the products and the number of differing items requested in each order.

3.4.1. Cycle time improvement

While time is a basic business performance variable, management seldom monitors its consumption with the same precision accorded to throughput and cost of processes. The order fulfillment cycle time is defined as the period from order receipt to product delivery. Time-based competition has increased the importance of accomplishing service processes efficiently. A common challenge in logistics these days is to find methodologies that improve the ratio between value added time and cost-added time (Cristopher, 2005, 159). Cycle time reduction is often a good place to start the overall effort to improve warehousing efficiency because it can be done without heavy capital investments. Using company specific data to create a cycle time improvement plan optimizes physical processes and ensures high traceability of information flows. This, in turn, results in better operational efficiency.

Value added time refers to the sum of processing times of the value added warehousing steps. Strictly speaking a process step is value-adding only if the product undergoes a transformation that is valuable to the customer or when the product is brought closer to the customer. This draws attention to concepts like Lean and Just-in-Time (JIT) and their applicability to order handling as a means to reduce the overall processing time. These production practices consider the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful. The basic idea is to have the right material, at the right time, at the right place, and in the exactly right amount. The mentioned management philosophies have been frequently discussed as a means to achieve efficiency improvements in industrial warehousing and manufacturing processes. Mentzer et al. (2001) proposed that the value of a product realizes only after it has been delivered to the customer. This implies that a part of the value of a product is created by the logistics service which occurs inside a warehouse. Warehouses are linked to the service aspect of a firm by their customer service capability. This is typically a representation of their ability to perform internal logistics functions and fulfill customer orders according to given time constraints.

There are several efforts suitable for reducing warehouse cycle times. Streamlining multiple efforts, however, can yield a much more efficient process resulting in cost and time savings and customer satisfaction. For example, Mason-Jones & Towill (1999) proposed that reducing cycle times can be done by considering the following ideas:

- **Performing activities in parallel.** Most of the steps in a business process are often performed in sequence. A serial approach results in the cycle time for the entire process being the sum of the individual steps, not to mention transport and waiting time between steps. When using a parallel approach different process task become overlapping which can reduce the cycle time dramatically.
- **Changing the sequence of activities.** Documents and products are often transported back and forth between machines, departments, buildings, and so forth. For instance in a warehouse, a document might be transferred between two departments a number of times for inspection and signing. If the sequence of these activities can be altered, it may be possible to perform much of the document's processing when it comes to the building the first time.
- **Reducing interruptions.** Any issue that causes long delays and increases the cycle time for a critical business process is an interruption. The production of an important order can, for example, be stopped by an order from a far less valuable customer request which must be rushed because it has been delayed. Similarly, anyone working amidst a critical business process can be interrupted by a phone call that could have been handled by someone else. The main principle is that everything should be done to allow uninterrupted operation of the critical processes and let others handle interruptions.
- **Improving timing.** Many processes are performed with relatively large time intervals between each activity. For example, some orders may only be issued at certain time intervals. Individuals processing such orders should be aware of deadlines to avoid missing them, as improved timing in these processes can save many days of cycle time.

Redesigning warehouse processes also requires profiling existing operations and estimating new time standards for company specific use. Operational standards are important if one expects to have control of any given process. Benchmarks obtained by measuring warehouse operations can help determine whether processes are performed at an acceptable pace and whether progress is being made. The ability to know when and where resources are needed is also necessary to achieve proper control (Tompkins et al., 2010, 450). As a result, the frequently performed warehouse activities should have a standard value assigned that reveals the amount of work involved in the activity. This measure is typically expressed as the processing time per unit or cycle, or a number of units processed per hour.

3.4.2. Interruptions and process accuracy

There is a crucial link between order processing accuracy and the order cycle time because the faster an order can be processed, the sooner it is available for shipping to the customer. Customer expectations have put greater emphasis on the warehouse service level. The service level is composed of a variety of factors such as the average and variation of order delivery time, order integrity, and accuracy. If an order misses its shipping due date, it may have to wait until the next shipping period. Reduction in order processing times also increases flexibility in handling late changes in orders.

The warehouse process quality can be seen as a constrained logistics service quality problem which consists of seven quality parameters (Seven R's): right product, right quantity, right condition, right place, right time, right customer, and right cost (Rutner & Langley, 2000). Research on logistics service quality has predominantly concentrated on measuring and quantifying the value created for customers as this is typically seen to determine the level of customer satisfaction (Mentzer et al., 2001). However, effects of poor process quality on the overall warehouse costs have been less frequently studied. There are numerous aspects that can be used to represent the quality of a warehouse process. Some examples are provided in a process quality model by Beamon & Ware (1998):

- **Reliability** - concerns the time between failed delivery of products
- **Order accuracy** - concerns the probability the correct order is taken, arrives or departs from the warehouse on time
- **Customer satisfaction** - concerns whether the internal or external customer is satisfied with the service
- **Worker quality** - concerns safety issues, damaged goods, etc
- **Cost** - the resulting cost incurred in a supply chain system by stages or throughout the entire system

It is essential to identify most important customer needs and ensure that errors in these areas are avoided. After the appropriate quality measures are identified, procedures must be developed to capture these measurements. Naturally, as process quality errors decrease, labor productivity, on-time delivery, and unit cost performance improve significantly. Further, process errors made early in the process tend to drive overall process performance measures such as unit cost. For example, Schneiderman (1996) assigned causes for warehouse errors into four categories: equipment down, absenteeism, excessive workload (volume over capacity), and human error. Most common order processing errors include wrong items, wrong quantities, or items completely missing from the order. Ackerman (1997) states that error free order processing has four principal requirements. Firstly, the locating code system must be clear enough so that employees can easily navigate through the sections within the warehouse. Second, items must be clearly labeled and distinguishable from each other. Third, the quantities to be processed must be clearly indicated. Finally, the order processing documentary should be specifically designed for the use of the warehouse.

4. Organizing and Measuring Warehouse Activities

The warehouse planning process is a commonly discussed topic in warehouse management literature. Hassan (2002) suggests that before any further steps in the warehouse planning process are taken, it is relevant to specify the purpose and mission of the warehouse. This helps to conceptualize warehousing priorities and formulate the expected level of operations. Basically it is possible to distinguish three main types of warehouses (van den Berg & Zijm, 1999):

- production warehouses
- distribution warehouses
- contract warehouses

Production warehouses are used to hold raw materials used in a manufacturing process, as well as storing finished and semi-finished items in the production facility. In *distribution warehouses* product storage is considered a very temporary activity. These warehouses most often serve as points in the supply chain at which products are received from many suppliers and quickly shipped out to customers. *Contract warehousing*, by definition, involves warehousing and logistics services that are provided to one or more customers.

4.1 Materials flow and physical layout

Materials handling deals with the techniques that are used to move, handle and store materials with or without machinery. In materials management, effective planning and control of processes is crucial. There are a number of key elements in good materials management such as space utilization, load unitization, safety, total movement minimization, and environmental concerns. In warehousing, therefore, it is necessary to use suitable equipment for easy and safe handling of unit loads, and fast movement of packages along the supply chain.

As mentioned earlier, functioning of a warehouse can be divided into several activities. These activities constitute the material flow inside a warehouse, which then is largely influenced by the chosen layout structure. The overall flow structure should facilitate accomplishment of general warehousing objectives. In effect, this means that warehouse layout should be based on the space requirements and the interrelationships between individual processes (Frazelle, 2002). Tompkins et al. (2010) suggest that the work simplification method can be used to minimize the total process flow. This approach includes:

1. Delivering materials, information and people to the point where actual processes happen and eliminating any intermediate steps
2. Planning for the flow between two consecutive points to take place in as few movements as possible
3. Combining flows and operations whenever possible by planning the movement of materials, information, and people to be combined with the processing steps

Warehouse layout design can be defined as the art of planning the relative location of functions, departments, and equipment within a warehouse facility. The common goal has been to find a warehouse layout that minimizes the throughput costs of processing items within a warehouse. In practice this means that warehouse layout should facilitate the overall throughput time needed to process an order or a batch of orders (de Koster et al., 2007). The most important criterion affecting these costs is commonly identified as the total traveling distance required to process an average order (Le-Duc, 2005).

The most commonly adopted method in materials flow planning is called the U-shape layout. In the U-shape flow warehouse activities are organized literally to form a letter U. This flow type represents the general layout standard in many industries as it facilitates flow-through distribution that requires cross-docking operations. It also helps responding to changes in delivery schedules and facilitates usage of class based inventory as closest storage locations are natural positions for fast moving items. Figure 4-1 shows an example of the typical functional areas and flows between them in U-shape warehouse layout arrangement.

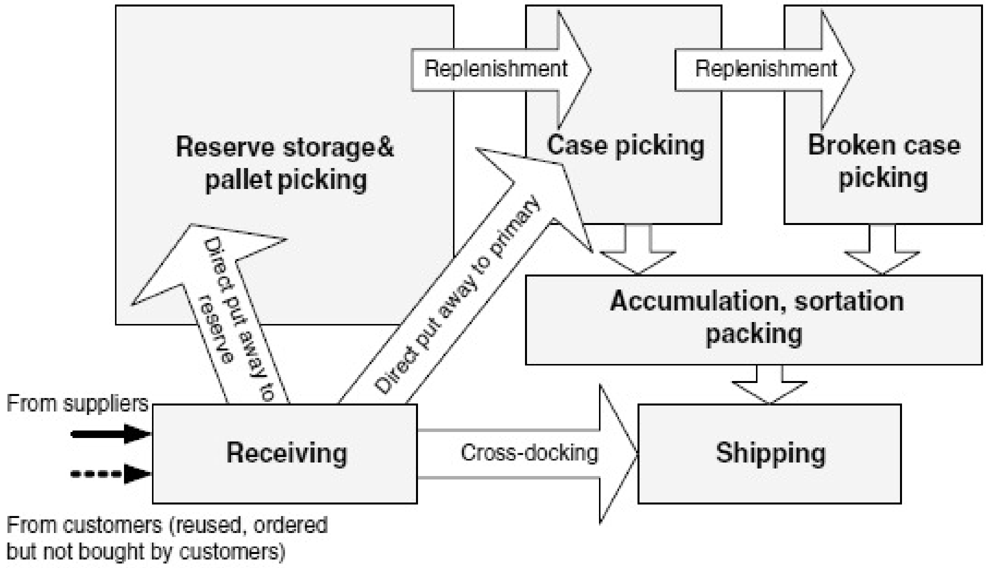

Figure 4-1: Typical warehouse functions and flows (de Koster et al., 2007)

The different configurations available in layout design affect not only temporary working efficiency but also set restrictions for the ability to expand warehouse operations in the future and absorb variances in expected storage volumes. Layout design is frequently seen as a means to accomplish following warehousing objectives (Smith, 2007, 1530):

- maximize the use of space
- maximize the use of equipment
- maximize the use of labor
- maximize the accessibility to all items
- maximize protection of all items

Although these objectives are easy to recognize, warehouse layout problems are often complicated by large varieties of products, varying storage space requirements, and irregular demand patterns causing fluctuation in inventory levels. Also because integration between different business functions has increased in modern firms, warehouses have to meet new challenges. For example, many warehouses are used as a means for marketing which requires that the warehouse not only functions efficiently but also is visually appealing.

4.2 Picking and storage procedures

Existing research has addressed many warehouse design and operations related issues with the goal to reduce order fulfillment costs and improve system performance. According to Petersen & Aase (2004) the three questions considered most often are; how to store items; how to pick the items; and how to route pickers to the items.

4.2.1. Storage assignment policies

Storage assignment or product slotting is defined as the placement of products to intelligent locations in a warehouse or distribution center. Some warehouses with few stock keeping units and simple order lists may not need slotting at all. The larger and more complex a warehouse becomes, the more slotting will have an impact. The purpose of product slotting is to optimize material handling efficiency. In addition to size and weight of the stock keeping units, the time to retrieve an item from a storage location is dependent on the height of the storage location. Storage areas are often divided into different zones such as golden, silver, and bronze. Golden zones refer to the optimal storage area between a picker's waist and shoulders (Petersen et al., 2005). Storage locations other than these require a bigger effort to be reached which reduces picking efficiency.

Achieving slotting successfully brings efficiency to picking and replenishment of items, balances activity across multiple picking zones by reducing congestion, and improves worker ergonomics. Each slotting instance is unique and depends on a variety of factors. Thus, efficient product slotting requires planning the storage assignment methodology, which is a set of rules that can be used to quickly determine a positioning for any given item. For example, Frazelle (2002, 174) suggests performing slotting by progressively sifting items. The decision tree framework for this methodology is described in Figure 4-2.

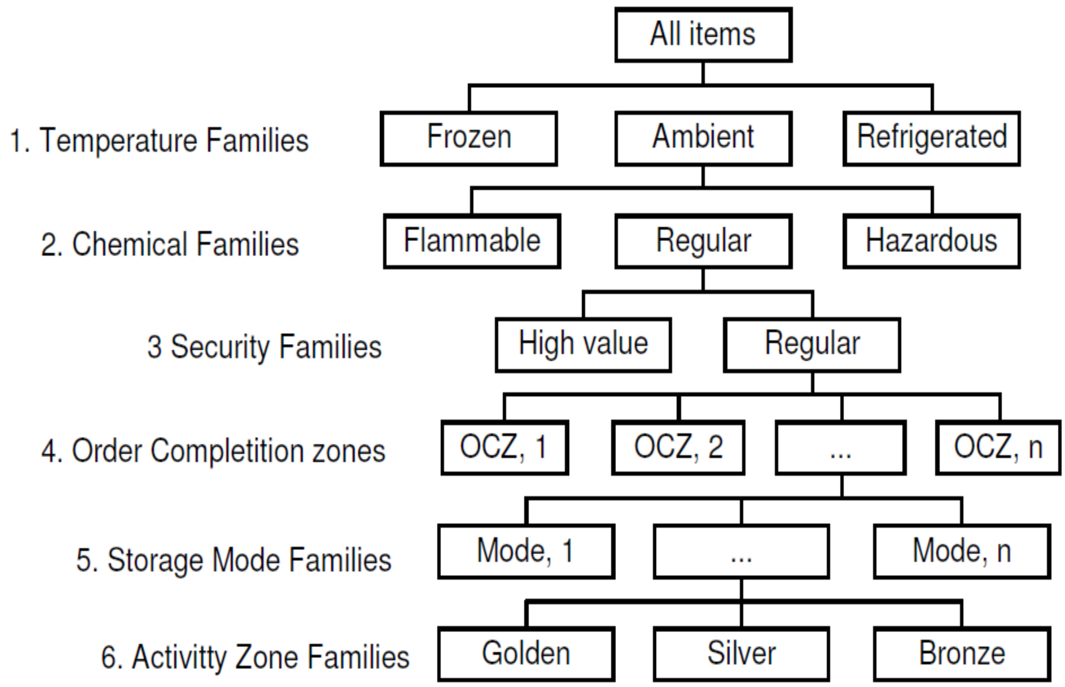

Figure 4-2: Slotting decision tree (Frazelle, 2002, 174)

Storage location assignment policies refer to the selection of a storage mode. Five frequently used types of storage assignment include random storage, closest open location, dedicated storage, family grouping, and class-based storage (De Koster et al., 2007). In random storage, on the other hand, each incoming pallet is assigned to a random location in the warehouse. The closest open location method is similar but assembles items to the first available position that is encountered. These methods results in high space utilization but may cause long traveling distances (Petersen & Aase, 2004). They also require effective use of information systems to maintain a track on item locations. The dedicated storage method prescribes a particular location for each item where no other items can be stored. Family grouping refers to a storage method where correlated items are located close to each other. The idea is to locate products that are often required simultaneously into positions that are nearby each other.

Class-based storage is basically a compromise between random and dedicated storage. By using class-based storage, it is possible to increase floor space utilization, decrease material handling costs, and increase storage flexibility (Petersen et al., 2005). In this method items are assigned to classes based on a chosen criterion such as product demand, type, or size. Each class is then given a block of storage locations where materials can be stored randomly. Figure 4-3 illustrates different ways in which warehouse space can be allocated between the classes.

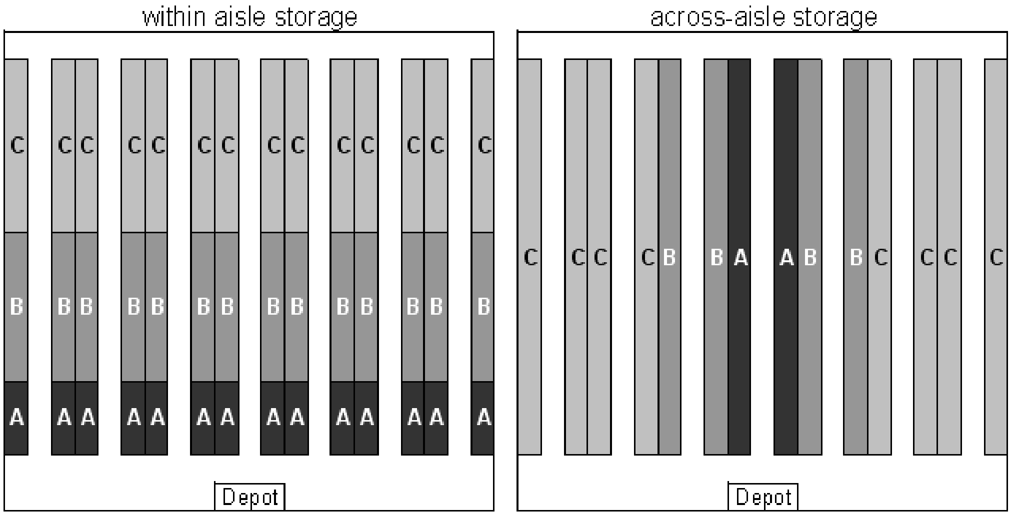

Figure 4-3: Common ways of organizing class-based storage

The performance of some warehousing functions can be improved by dividing storage into distinct forward and reserve areas. Typically this involves separating the bulk stock from the operating stock so that activities can be performed in a restricted area with reduced travel distances (de Koster et al., 2007). However, dividing inventory over multiple areas implies regular internal replenishments. As a result, the problem is to decide which products should be stored in the forward area and in what quantities. According to van den Berg & Zijm (1999) the goal is to find an allocation of product quantities which minimizes the expected labor time during the picking period. In practice, however, allocation policies need to be easily administrable. Because of this, visual methods such as two bin replenishment are widely adopted.

4.2.2. Picking policies

Picking policies determine which SKUs are placed on a pick list for a single picking tour. The two common ways of assigning orders to pickers are strict order picking and batch picking. In single order picking each picker completes one order at a time. The major advantage of single order picking is that it is easy to implement and order integrity is always maintained (Frazelle, 2002). In strict order picking the decision about which order to process next can be made with the help of priority sequencing rules (Krajewski & Ritzman, 2005, 780-781). The following rules are used commonly in practice:

- **First Come, First Serve** – The order arriving first has the highest priority
- **Earliest Due Date** – The order with the Earliest Due Date is first
- **Shortest Processing Time** – The order requiring the shortest processing time is processed first.
- **Critical Ratio** – The critical ratio is calculated by dividing the time remaining until a job's due date by the total order processing time remaining. The order with lowest critical ratio is processed first

In many warehouses items are processed in smaller numbers than their original storage unit. In such cases combining several orders into batches can be used to reduce the mean order processing time efficiently (Petersen & Aase, 2004). This is possible mainly because the travel time per line is reduced dramatically. The major disadvantage of batch picking is that time is required to sort line items into each specific customer order after a batch has been completed.

Literature has suggested different ways for arranging orders into batches. Ruben & Jacobs (1999) refer to the simplest heuristics as naive heuristics because they take no advantage of item location information. Such are, for example First Come, First Serve and First-Fit-Decreasing heuristics. The first one groups orders together until a maximum batch size has been reached. In the latter the problem is to determine the minimum number of batches necessary to accommodate all customer orders. More complex criteria include location proximity and time window batching (Gademan et al, 2001). Proximity batching heuristics aim at minimizing the travel time. These heuristics typically assign each order to a batch based on proximity of its storage location. Time window batching, on the other hand, tries to optimize due date performance by grouping orders that arrive during the same time interval. However, the disadvantage with these more complex batching techniques is that they may be difficult to convey to a normal warehouse employee (Petersen & Aase, 2004).

4.2.3. Routing methods

The objective of routing policies is to guide order pickers through the warehouse on their picking tour. In general, warehouse routing is a modified situation of the travelling salesman problem, in which the goal is to find the shortest possible way to visit a set of given locations. In practice, the problem of routing order pickers is mainly solved either by allowing the pickers to freely choose their route or by using heuristic approaches. The benefit of heuristics is that they provide solutions that are easily understandable by warehouse employees and often yield close to optimal results (Petersen & Aase, 2004). Some heuristic methods may also help avoid congestion which is a general problem in many warehouses with narrow aisle width or high picking density (de Koster et al., 2007). Figure 4-4 presents various routing methods in a single block warehouse layout.

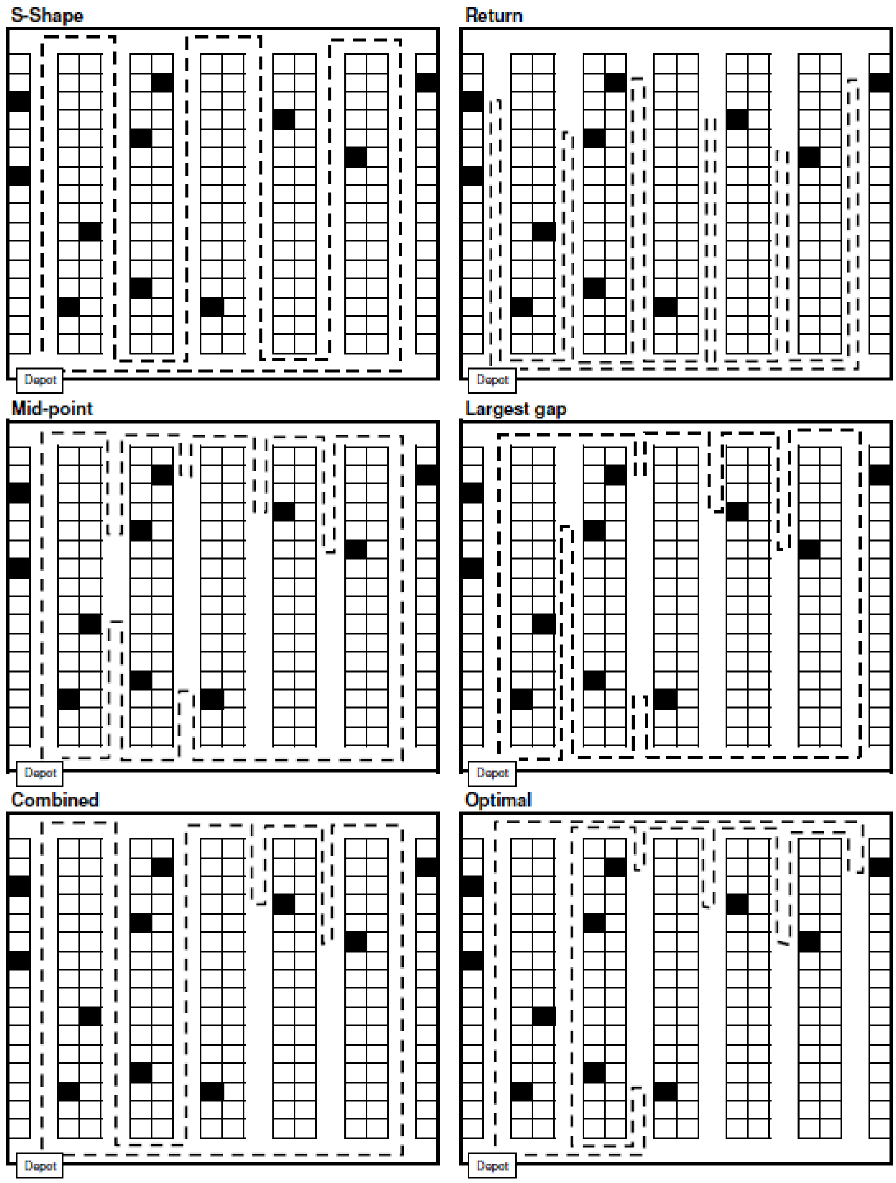

Figure 4-4: Various routing methods for single block warehouse

The simplest routing method is the S-shape heuristic in which each aisle with at least one pick location is entered and traversed entirely. The result is an S-shape route and after the last visited aisle the order picker returns to the depot. Another simple heuristic is the return method where the order picker enters and leaves the aisle from the same end.

The midpoint method divides the storage area into two partitions. The picker performs picks in an aisle until the mid-point is reached after which he returns back. The last aisle is traversed completely and the same picking pattern takes place on the other half of the storage block. The largest gap represents the separation between two adjacent picks, between the first pick and the front aisle, or between the last pick and the back aisle. The largest gap is the part of the aisle that is not visited by the order picker. The mid point and largest gap heuristics are especially useful when the number of picks per aisle is low. In the combined heuristic every time all items of one aisle are picked, the question is posed whether to go to the rear end of an aisle or to return to the front end. These two alternatives have to be compared with each other after which the one, resulting in the shortest route, is chosen. Finally, in the optimal routing strategy the shortest route is calculated by a computer, regardless of layout or location of the items.

Routing calculations become quickly more complex in warehouses that have multiple cross aisles. Roodbergen & de Koster (2001) focused on heuristic routing for warehouses with more than two cross aisles. They noticed that the gap between heuristic and optimal solutions may vary substantially but at the same time the implementation of optimized picking procedures may be impractical due to long computation times.

4.3 Warehouse activity profiling

Profiling warehouse activities can be a great help in understanding its operations. A comprehensive profile based on historical and current data may reveal characteristics that allow making decisions on storage and handling alternatives. Activity profiling can be especially beneficial when analyzing activities for the purposes of determining storage mode, product slotting, process work flow, and facility layout options. A comprehensive analysis of activity profiles can be used to assess the current situation of a warehouse. It also gives an idea of how to prepare for future needs and establish benchmarks on warehouse operations. There are two basic categories of warehouse profiles: customer order profiles and item activity profiles (Cooper & Mulaik, 2010).

4.3.1. Customer order profiles

Customer order profiles represent the outbound activity, i.e., how the customers are ordering the products. The general idea in this type of profiling is to zone warehouse operations into self-contained cells that enable processing orders more efficiently (Frazelle, 2002, 21). The main areas of analysis in the customer order profile are the order mix distribution, order increment distribution, and lines per order distribution.

The order mix distributions are helpful for plotting warehouse operating strategies because they provide information about the interdependencies of items in customer orders. For example, a family mix distribution shows whether orders are pure or require items from multiple product families. It can be used as an early indicator for locating items into family zones. Order mix profiles can also be created to analyze the percentage of order lines for full versus broken handling units. Orders that contain only full cartons or full pallets can be handled in a dedicated area.

The order increment distribution is used to determine the portion of a unit load most typically requested on a customer order. This distribution is beneficial when evaluating whether the current packaging is in logical increments for the customer. For example, if most customers are ordering carton quantities options could involve suggesting the supplier to change their carton size, breaking down cartons at receiving in order to save time during picking, or encouraging sales customers to place orders in full carton quantities.

The order lines distribution lists the number of lines per order. This profile is useful for evaluating different operating strategies. For example, single line orders are very common in cases where individual customers or technicians place orders (Frazelle, 2002, 28). Typical examples of such include e-commerce industries and service parts logistics. Another common case occurs often in the retail and wholesales industries. This is the reverse situation where most orders include a high number of item positions that often represent an efficient workset as such. Thus, one of the greatest opportunities to improve warehouse efficiency is choosing a different mechanism for picking single unit orders from multi-unit orders.

4.3.2. Item activity profiles

The question of where to store each item is answered by determining two things: how to rank the SKUs and how to assign ranked SKUs to storage locations (Petersen et al., 2005). Slotting measures are used to determine the ranking of the SKUs while storage assignment strategies help to assign each SKU to a storage location. Item activity profiles are used to map the internal dynamics of a warehouse. They can provide especially valuable insight into viable storing and slotting options for each item within the warehouse. There are several ways to form item distributions that can then be used as a basis for slotting measures.

Item popularity distribution shows the frequency at which items are ordered. The most commonly used attributes for measuring popularity include SKU hits, turnover, and volume (cube movement). Practice has shown that the minority of items in a warehouse generate a majority of the work effort required. As a result rankings done using these attributes typically result in what is called an ABC curve or a Pareto distribution. Dramatic break points are typically used to classify items into different families (Frazelle, 2002, 31). These families may suggest different storage modes. For example, it may be justified to use automated processing for Family A items. Family grouping can also be used as a basis for locating items within the storage mode (de Koster et al., 2007). For example, A items may be assigned to the golden zones, B items to the silver zones, and C items to the remaining warehouse space.

Cube-movement or volume distribution reveals how storage mode and space allocation decisions should be made. It indicates the portion of items that fall into specific cube-movement ranges. For example, items with low volumes can be placed in storage drawers or bin shelves while items with higher volumes need to be handled in pallet quantities.

The popularity-volume distribution takes into account both the item popularity as well as its volume (e.g. cube movement, weight). Items with high volumes need to be restocked frequently and need a larger storage location as opposed to items with low volumes (Frazelle, 2002, 33). Figure 4-5 represents a classification scheme for mapping items into various storage modes and slotting them within the storage mode. Those items in the bottom right portion generate the most picking activity per unit of space. Thus, they should be assigned to positions in the golden zone. Items in the upper right corner and lower left corners generate a moderate number of picks per unit of space they occupy. Thus they should be allocated in the silver zone. Finally, items in the upper left portion generate the lowest ratio between picks and cube-movement, and should be assigned to least important locations.

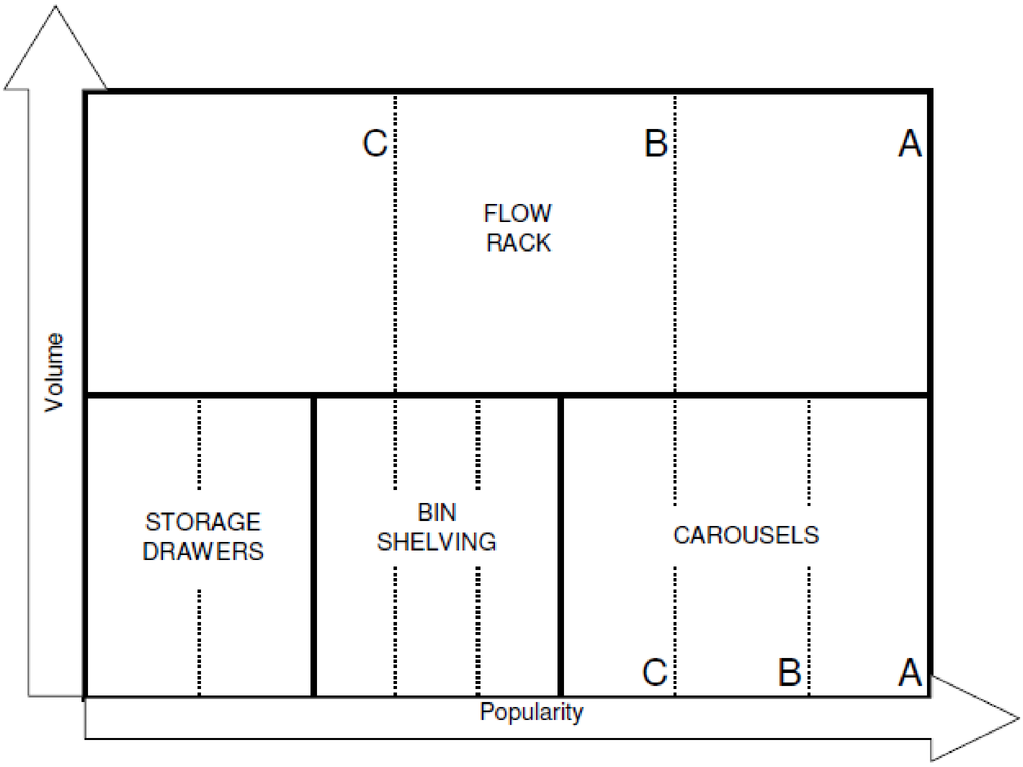

Figure 4-5: Slotting items by popularity-volume distribution (Frazelle, 2002, 177)

The item order completion profile reveals the percentage of the orders that can be completed by specific a subset of items. This way a small group of items that is capable of filling the majority of orders can be identified. These items can be positioned into order completition zones within the warehouse which enhances order processing rates and quality. The distribution is constructed by ranking items according to their popularity. Starting with the most popular, two most popular, etc. the items are compared to a set of orders to determine what portion of these orders they are able to complete.

The demand correlation distribution indicates the interdependence between two items or item families. This distribution can be used as a basis for family-grouping where similar products are located in the same region of the storage area (de Koster et al., 2007). The demand correlation distribution is created by ranking items based on their frequency of appearing together on orders.

Demand variability distribution indicates the standard deviation of a given period for each item. Demand variability can be used as a measure to ensure that the size of a storage location is sufficient. Another motivation for analyzing item demand variance is to avoid the need to restock a picking area during a picking shift (Frazelle, 2002, 37).

4.4 Process activity mapping

Process activity mapping is a traditional process design tool most often used in industrial engineering. Its purpose is to drill down to the job level of an individual person, a team, or a focused process and document all of the activities performed by a person, machine, at a workstation, with a customer, or on materials. The general approach consists of five stages (Jones et al., 1997):

1. the study of the flow of processes;
2. the identification of waste;
3. consideration of whether the process can be rearranged into a more efficient sequence;
4. a consideration of a better flow pattern involving different flow layout or transportation routing;
5. a consideration of whether everything that is being done is really necessary

To accomplish these steps, activities are divided into various categories depending on their nature. Choosing the right category for each activity requires taking the perspective of the subject being charted (Krajewski & Ritzman, 2005, 141-142). For example, a delay for an item could be inspection or transportation for the operator. In the warehousing environment activities can be grouped into following categories:

- Operation – Changing, creating, or adding something
- Transportation – Moving the subject from one place to another
- Inspection – Checking or verifying something without changing the subject in itself
- Delay – Occurs when the subject is held up waiting for further action
- Storage – Occurs when something is put away until later time

Once all activities have been identified, a simple flow chart can be drafted at any time. It is also possible to record and calculate the total distance moved, time taken and people involved. Exhibit 1 shows an activity mapping example using the order handling process in the case company of this study. The idea behind the activity mapping approach is to eliminate activities that are unnecessary, simplify or combine activities, and seek sequence changes that will reduce total processing cost (Jones et al. 1997).

4.5 Warehouse performance measures

One of the primary goals of logistics management is to establish appropriate indicators that measure and ensure that logistical activities are fulfilled as they were initially planned. Agreeing on variables that are the key to improving performance, systematically collecting data on these variables, and then displaying the set of data in statistical terms is a major goal of many process improvement projects. Despite their considerable success in some companies, process improvement programs can be difficult to implement because it appears that a key condition for their effectiveness is that employees through all levels of the organization develop a good understanding of the work process in which they are involved (Hoyles et al., 2007).

Key objectives in designing warehouse operations include increasing productivity, reducing cycle time, and increasing accuracy (Gunasekaran et al., 2004). Often times these objectives may conflict with one another because a method that focuses on productivity may not provide a short enough cycle time or a method that focuses on accuracy may sacrifice productivity. Researchers and managers typically attempt to find a set of measures which collectively capture most, if not all, of the performance dimensions thought to be important, over both short- and long-term horizons. It is also advisable to review the warehouse performance measures periodically because this way it is possible to estimate the development of warehousing operations by comparing results between different time periods with each other.

Because logistics performance is multi-dimensional, the selection of logistics measures is dependent on the nature the business. Typical business measures are based on financial, productivity, quality, and cycle time performance. Warehouses can be held accountable for same measures (Frazelle, 2002, 52). These so called hard performance measures are typically impersonal, accurate, easy and inexpensive to collect. Table 4-1 represents a summary of these measures with respect to each of the various warehousing functions. It is possible to use hard measures to track internal quality measures such as the timeliness of an order or shipping accuracy, but capturing customer satisfaction is typically the underlying reason for supplementing hard measures with soft, perceptual ones (Mentzer et al., 2001).

Table 4-1: Warehouse key performance indicators (Frazelle, 2002, 56)

	Financial	Productivity	Utilization	Quality	Cycle Time
Receiving	Receiving cost per line	Receipts per man-hour	% Dock door utilization	%Receipts processed accurately	Receipt processing time per receipts
Putaway	Putaway cost per line	Putaways per man-hour	% Utilization of putaway labor and equipment	% Perfect putaways	Putaways cycle time (per putaway)
Storage	Storage space cost per item	Inventory per square foot	% Locations and cube occupied	% Locations without inventory discrepancies	Inventory days on hand
Order picking	Picking cost per order line	Order lines picked per man-hour	% Utilization of picking labor and equipment	% Perfect picking lines	Order picking cycle time (per order)
Shipping	Shipping cost per customer order	Orders prepared for shipment per man-hour	% Utilization of shipping docks	% Perfect shipments	Warehouse order cycle time
TOTAL	Total cost per order, line, and item	Total lines shipped per total man-hour	% Utilization of total throughput and storage capacity	% Perfect warehouse orders	Total warehouse cycle time = DTS + WOCT

Because it may be hard to justify the profitability of warehousing, financial perspective of performance measurement is often concentrated on cost-accounting. This typically involves creating an activity-based costing program for the warehouse. Even private warehouses are constantly facing a competitive situation because of third-party logistics providers. These measures can be used as a basis for comparing third party proposals. A company whose warehousing costs are higher than those of a third party provider should reconsider the possibility of outsourcing its warehousing operations.

Productivity is measured by comparing the output from a process to each unit of input. In warehousing this typically means measuring the processing rate. The handling units represent a few possible variations. Small item operations usually measure the processing rate in line items processed per hour or cases processed per hour while pallet oriented operations can be measured in actual pallets. In some cases productivity can be a misleading indicator. It is, for example, possible to achieve exceptionally high productivity measures with overly high investments in warehousing technology.

Cycle time can be used as an indication of the warehouse’s service capability because reduction in the order cycle time leads to a reduction in the supply chain response time (Gunasekaran et al., 2004). The warehouse cycle time can be tracked in two areas. The Dock-to-Stock Time (DTS) measures the time from when a receipt arrives to the warehouse premises until it is ready for picking or shipping. The Warehouse Order Cycle Time (WOCT), on the other hand, measures the elapsed time from when an order is released to the warehouse floor until it is picked, packed, and ready for shipping.

Finally, different performance measures may be needed for the effective operation and monitoring of supplementary warehousing services. In, general these kinds of performance indicators depend on the type of activities that are included in the warehousing process. Relevant measures should be specifically related to customization and production activities because customization is the critical driver of supplementary services. For example, van Hoek (2000) suggested that customization activities can be measured by looking at the overall degree to which products are produced and delivered customer specific. Another possibility is to look at the efficiency-quality aspect and measure, for example, the percentage of scrap resulting from the customization activities.

5. Empirical Study of Warehouse Processes

The following chapter concentrates on the empirical part of this thesis. It starts with a general explanation of the way in which the research framework was constructed. It then describes the case company and the way in which the case study was organized and conducted. Finally, the obtained research material is analyzed in order to make conclusions and operational recommendations.

5.1 The warehouse design framework

The warehouse design process typically runs through a number of consecutive phases. By combining the basic warehouse design elements with specific tools and techniques, an overall warehouse design procedure can be developed. This procedure is described in Figure 5-1. The six main steps of this framework were chosen because they encompass the key features of various approaches found in the literature.

Table 5-1: Warehouse design framework

Step	Design tools, techniques and key references
1. Define basic requirements and identify role of the warehouse	Warehouse objective assessment (Higginson & Bookbinder, 2005) Distribution network assessment (Baker, 2004; Cristopher, 2005)
2. Define supplementary services and ancillary operations	Operational requirements assessment Additional equipment specifications
3. Define and obtain data	Database review (Frazelle, 2002) Process activity mapping (Jones et al., 1997)
4. Analyze and characterize data	Spreadsheet models Activity profiling and benchmarking (Frazelle, 2002) Statistical process control (Hoyles et al., 2007)
5. Consider possible operating strategies	Storage vs. picking requirements (Phillips, 2010) Picking method evaluation (Petersen et al., 2005) Item allocation policies (Frazelle, 2002) Layout planning (Hassan, 2002)
6. Identify preferred design alternative	SWOT analysis System functionality Standards assessment Financial estimation

In spite of the importance of warehouse design, a number of reviews in the literature have concluded that relatively little has been written on the systematic approach that should be taken by warehouse designers. These reviews have demonstrated that there is a wealth of material written on analysing particular aspects of warehouse design. It is the synthesis of these techniques that appears to be lacking (Rouwenhorst et. al., 2005). In scope of the framework described here are the design phases from the time when a specific warehousing need is identified through to an operational specification being produced which details for example possible operating methods, equipment, and layout. The subsequent steps, such as equipment tendering, installation, and project management are not covered. A more detailed description of each step in the framework is given below.

Define basic requirements and identify role of the warehouse. Issues related to the role of warehousing in a company were covered in chapter 2 of this thesis. Identifying the overall business strategy requirements and the system within which the warehouse operates is important because this defines the improvement goals and relevant constraints. Approaches described in business and supply chain strategy literature, such as competitive advantage and consumer value are relevant (Cristopher, 2005). For example, Baker (2004) provided a framework to identify the role of warehousing within supply chains and there are checklists on warehouse roles and functions in literature similar to the one created by Higginson & Bookbinder (2005).

Define supplementary services and ancillary operations. The role of warehouses as service facilities was discussed in chapter 3 in the context of customized warehousing. Whether the warehouse performs supplementary services should be specified because this impacts subsequent steps of the design process. There are, however, not many methodologies described in the literature to arrange services and ancillary warehousing operations. This may be because services provided to a customer often vary between each warehouse. Experienced warehouse designers may use some checklists to assess operational requirements and additional equipment specifications but in general it is hard to apply any standardized procedures or planning methodologies to this design step.

Define and obtain data / Analyze and characterize data. Designing warehouses typically involves obtaining a specific list of data (Bodner, 2002). Small adjustments may be added to this list depending on the precise nature of the project. The data may include product details, order profiles, processing times, cost data and building site information. Database and spreadsheet models can then be used to analyze the data. This often involves computing a number of routine statistics and using experience or benchmarks to interpret these statistics.

Consider possible operating strategies. This step involves determining high-level procedures and methods for each function of the warehouse. This requires evaluating picking methods and assessing the level of automation in the warehouse. In order to accomplish this step, it is important to group similar activities in the warehouse to activity zones. These zones can be based on different product groups, temperature regimes, or Pareto classifications. For example, Gu et al. (2007) identified papers that cover the operational design elements of a warehouse. These papers refer to techniques that may be useful in determining operating methods for specific warehouse activities. Some of the possible approaches that can be used to evaluate operating strategies were also summarized in chapter 4.

Identify preferred design alternative. The final step of the design framework is mainly concerned with drawing together all the above elements into a coherent design plan which identifies for example operations and flows, the information systems, equipment types, and internal layouts. Validating the operational and technical feasibility of the proposed solutions can be made by checking that the chosen design plan meets the requirements set in step one or by performing capital and operational cost evaluations. In general, there is no specific process described in the literature for this step.

5.2 Identifying basic requirements and the role of warehousing

The following parts in this thesis show how the framework described above can be applied in to a practical design situation. A central objective in the case company is to find ways to improve order processing cycle times. This is important because shortening the cycle time of a warehousing process at the same time means reducing the customer’s lead time. Shortening cycle times also makes warehousing more flexible because there is more time to handle unexpected situations such as fixing order handling errors. A central issue in reducing overall cycle times is to determine handling policies for small order sizes which are typically more complicated to process in terms of efficiency. It is also important to allocate items appropriately within the storage area to minimize traveling distances.

The analysis concentrates on the case company's hoses item group. This group had loads of room for improvement and provided a possibility to observe a customized warehousing process during order picking due to the sizing of hoses (Hokkanen 6.9.2010, interview). The choice to concentrate on a single product group was also made to simplify and maintain a specific level of focus in the analysis.

5.2.1. Presentation of the case company

Etra Oy is a technical wholesaler concentrated on the sales of products and services to manufacturing, maintenance, and construction industries. As an importer and distributor of numerous technical items warehousing plays an essential role in company operations. Because the company's distribution channel consists of multiple sales locations with localized warehouses, internal product movements represent a major part of logistical transactions. These transactions and their possible direction of movement are represented by the arrows in Figure 5-1.

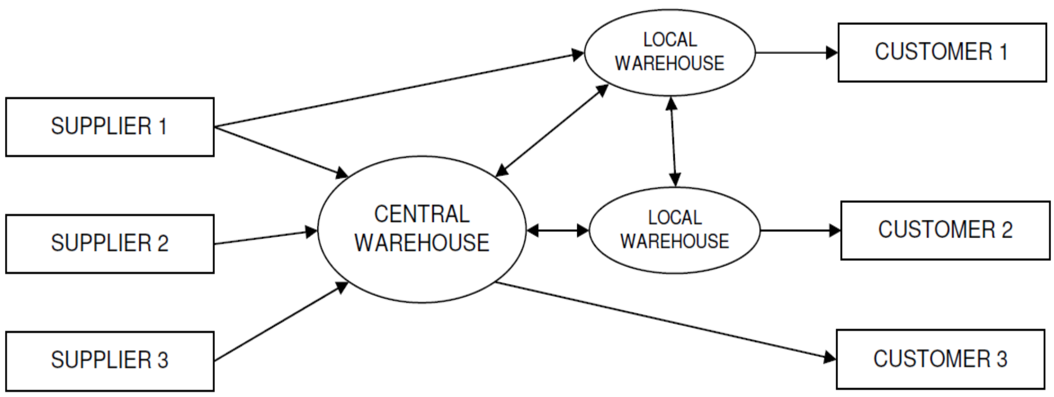

Figure 5-1: Description of Etra's distribution network

It has been estimated that a major part of items flow through the local warehouses. Reducing internal movement of products and enabling straight deliveries to customers would mean significant cost savings. In other words, the future goal in the company is to organize its supply chain so that the central warehouse functions as a node point attaching suppliers and customers directly to the internal distribution network. This strategy implies that most incoming customer orders will be handled by the central warehouse. The resulting workload is challenging especially in terms of storage and order processing capacity.

Table 5-2 shows the monthly distribution of delivery lines for various item groups. This distribution demonstrates the magnitude of work effort created by the different product groups. The items within each product group vary in their size and form but the number of order lines shows the average monthly work effort that will be needed to handle items in the central warehouse. An interesting notion is that nearly 60 percent of delivered item lines are created by the three largest product groups.

Table 5-2: Monthly number of delivery lines for different item groups

Item Group	Mar	Apr	May	June	July	Aug	Average	%
Work safety products	5002	4393	5090	4723	3138	4089	4406	29,4 %
Hoses and fittings	2345	2204	2403	2111	1971	2024	2176	14,5 %
Power transmission	1759	2041	2233	2302	2006	1981	2054	13,7 %
Packaging materials	1416	1309	1340	1357	1118	1340	1313	8,8 %
Wiring products	1049	1044	1068	1225	823	1050	1043	7,0 %
Tapes	1066	933	1056	999	783	979	969	6,5 %
Tools	734	667	828	854	686	693	744	5,0 %
Material handling	544	548	543	531	372	526	511	3,4 %
Technical rubbers	565	498	596	541	244	287	455	3,0 %
Marking products	364	358	378	447	369	353	378	2,5 %
Total (incl. all groups)	15783	14894	16415	15987	12482	14479	15007	

Cost factors play a particularly important role in the motivation of centralized warehousing. With centralized warehousing it is possible to significantly reduce costs associated to maintaining facilities and holding inventories. Centralized warehousing also allows bundling product flows. The resulting economies of scale allow investments in automation and modern warehousing technologies, thus making order processing more efficient. However, traditional factors that favor decentralization are rapid filling of customer orders and better availability of stock (Nozick & Turnquist, 2001). Also the transportation costs tend to fall as the number of warehouses increases because the delivery distances to customers decrease.

5.2.2. The warehousing process

In its current form, the materials handling process can be divided according to the four basic stages of warehousing: receiving, putout, order picking, and shipping. The process flow described in Figure 5-2 shows the standard warehousing procedure during a single order cycle.

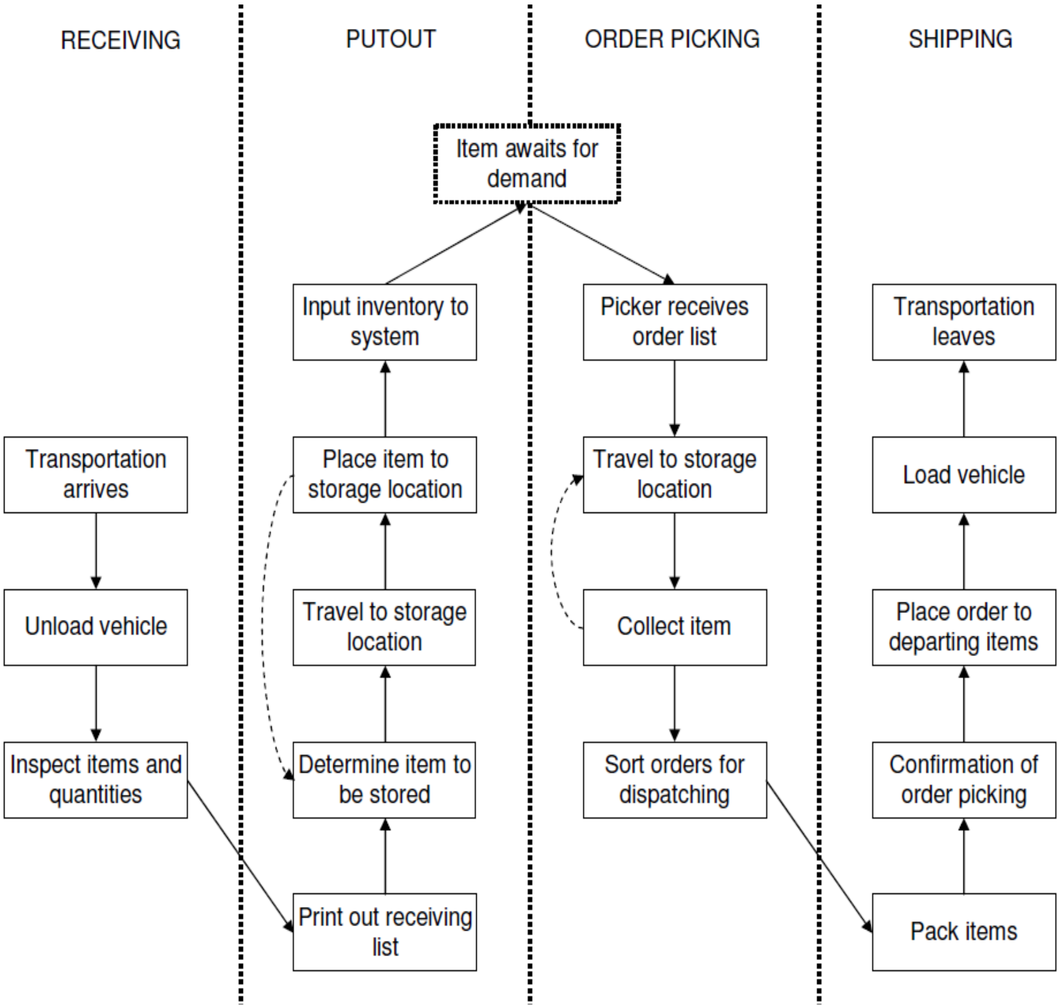

Figure 5-2: Structure of warehousing process in the case company

The inbound warehousing process begins with the arrival of incoming transportation. Based on the transportation contractor, the incoming vehicle is unloaded either by the vehicle operator or the warehouse personnel. Once the items have been unloaded to the receiving dock, they are briefly inspected for physical damages. At this point it is also checked that the type and number of arrived items match with the ordered ones. If no problems occur, the receipt is approved.

The putout process starts when a receiving list is printed out and the given items are located on the receiving bay. The employee typically uses a lift truck to move and place the item to a storage location. The location of each item can be seen on the receiving list. The employee then returns to the receiving bay for the next item. Once the receiving list has been completed the employee updates inventories to the information system and confirms that all receiving operations have been finished.

The order processing part begins when an item is requested on a sales order. The information system automatically creates picking lists from these sales orders which are printed out and handed to the order pickers. The picker travels to the first storage location, collects the requested number of items, and proceeds to the next location. Once all items on the order list have been collected the picker returns to the shipping department.

A common practice is that the picker is also responsible for the shipping of an order. At the shipping department items are sorted out and packed for shipment. The picker then uses the information system to confirm that the order has been finished. Then the picker prints out the shipment address labels, bill of lading, and other necessary documents. Once these steps are finished, items are placed to departing items where they await for outgoing transportation.

In some cases there may appear variations in the sequence of these steps. First case is the cross-docking of an order. This typically happens when the customer of an item is already known at the receiving stage and is especially common for items with order based control. Items being cross-docked are extracted from the received items and straightly moved to the shipping department. This eliminates most of the steps needed during putout and order picking stages.

Another case is faced when an employee must change the order handling sequence to be able to finish an order. For example, if the inventory on a standard picking location is not capable of fulfilling the total volume requested on a picking line, the picker must locate a reserve location. This involves traveling back to a computer in the shipment department, checking available inventory, traveling to the reserve location, restocking the actual pick location, and finally fulfilling the rest of the order line. Observations showed that performing this procedure can take up to three times as much time as a normal picking tour where replenishment is not needed.

5.3 Influence of supplementary services on operations

Physical properties such as the size and shape of an item can significantly complicate materials handling. Industrial hoses comprise a large variety of stock keeping units in Etra's warehousing system. These products are commonly stored by coiling the hose and placing it on a pallet or in a storage shelf. The size of the coiled unit depends on the diameter and length of the hose. Each coil has a standard length when it is received from the supplier. If the item is ordered in a quantity that is not divisible by the standard length, the employee responsible for order handling must cut the hose to a given measure. The leftover piece is saved because throwing it away would be a waste of materials. However, managing these leftover pieces efficiently is one of the constantly faced problems in Etra's warehousing. Item lines where cutting work is involved are troublesome and time-consuming to process because they require specific tools and additional work steps. In some rare cases cutting of the product may become so challenging that the picker decides to send the product to the cutting service which is a separate department in the warehouse. This of course lengthens the time needed to finish the order.

The cutting operation is performed by opening the coil and extending the hose to its full length. The needed pieces are then measured and cut from the hose. Although this sounds simple, the cutting operation takes a lot of time. Some materials can be cut with a normal carpet knife but others require metal cutters and heavier tooling. At the beginning of each picking tour the employee should be able to determine the kind of tooling that will be needed to process the hose, otherwise he may have to return back to the shipping department to retrieve the needed tool. Larger items are usually placed on the warehouse floor for measurement and cutting. This means that the employee spends a lot of the time in a crouching position which is not very ergonomic. Placing items on the floor should also be avoided because certain materials easily absorb dirt and dust. This results in deterioration of product quality which eventually can lead to a customer returning the ordered product.

One of the central challenges in the case company is also to find ways for managing information flows (Hokkanen 6.9.2010, interview). Hoses are especially troublesome because it is difficult to organize their tracking related information. The standard unit of measure in the ERP system is one meter. This means that the system is unable to recognize what type of unit exists in physical inventory. For example, if the system tells that there are 40 meters of a specific item in inventory, it is impossible for a warehouse employee to tell whether this inventory consists of one single hose or two cut pieces that are 20 meters long each. The only way to tell the difference is to travel to the storage location and check the inventory manually.

Finally, it has been difficult to find a convenient storage mode for the hoses. Once opened, a coil becomes harder to handle because it is no longer a tight bundle. It is common to see hoses extending out of their storage locations which not only looks messy but also occupies excessive space. The storage system should be able to retain items of various sizes and still be cost efficient to implement.

5.4 Research data

Research material for the analysis part was gathered from two primary sources. These were a review of case company's ERP system and a participant-observation of operations conducted at the warehouse located in Helsinki. Processing and analysis of research data was primarily conducted in Microsoft Excel.

Data from the central warehouses in Helsinki and Tampere were used as the key source for retrieving order line related information. The data set was restricted to a half year's period starting from March 2010. The decision to choose this time frame for analysis was also partly a result of Etra's decision to move information about central warehousing to a separate division in the ERP system which limited the availability of data from a longer period.

The measurement of warehouse processes was conducted by observing the time warehouse employees were spending on their daily working routines. This was done to estimate the overall cycle time of the warehouse process as well as to find out the distribution of time between different warehouse functions. Before this study was conducted, knowledge about these warehousing attributes was relatively scarce. Investigation of these attributes provides better understanding about the warehouse processes and the results obtained from it can be used, for example, as a basis for warehouse capacity planning.

5.5 Analysis and characterization of data

The following parts summarize the material gathered from warehousing operations in the case company. This is done by analyzing order history information and mapping out order processing activities with their corresponding cycle times. The primary aim is to characterize outbound logistics, discover design and planning opportunities, and quickly crop out the non-feasible design alternatives.

5.5.1. Historical order patterns

Material flow is constituted by the type and volume of products flowing through the warehouse. It can be plotted by analyzing the order set of a warehouse during a given period of time. Warehouse profiles in this section were created to describe the present characteristics of order handling in the case company and suggest solutions for specific order processing problems. To simplify the demonstration of data, the profiles here concentrate on presenting aggregate values from a single product group. However, similar analyses can be repeated fairly effortlessly for any given product range.

One of the initial starting points in warehouse planning was to arrange the warehouse so that each storage aisle consisted of items from a single product group. Some of the reasons for this decision were marketing oriented as the warehouse would be a regular place for customer visits. The product group arrangement was expected to foster visual appearance and simplify storage layout. From the warehousing point of view this arrangement of course has its own implications. Firstly, it is easy for a warehouse employee to memorize the overall location of items. Second, orders containing products from only one item group require little travelling and can be processed quickly in a single location. On the other hand, the time required to process orders with items from multiple groups may become longer because there is a need to switch aisles. Storing similar items next to each other may also cause confusion. For example, some items can be hard to distinguish from each other. To avoid such situations it would be advisable to have item names clearly labeled on the storage position and to not place similar items right up next to each other. There are also restrictions to the product group specific arrangement that must be observed. For example, total weight of items cannot exceed the maximum load capacity of storage shelves.

The order structure has a significant role in defining the work effort required to handle incoming and outgoing materials. Order structure can be described as the average number of item lines per each order. Larger orders typically represent a fairly efficient processing set on their own while the single line orders are more troublesome. In a traditional warehouse it has been noticed that the handling of an order with only one item line takes approximately three times longer than handling an order with more than eight lines (Aminoff et al., 2002). This happens because the average processing time per line is lower for orders consisting of multiple items.

Figure 5-3 represents the distribution of order lines per each order for the case company. The order pattern is characterized by a high number of orders that have either only a single line or orders that consist of more than eight lines. The reason for this can be found in the company's operating strategy. In the case company, roughly 40 percent of the orders in the single line column are backorders. These can typically be handled fairly efficiently through cross-docking. The other end of the distribution is constituted by the accumulated week orders that local warehouses place to the central warehouse.

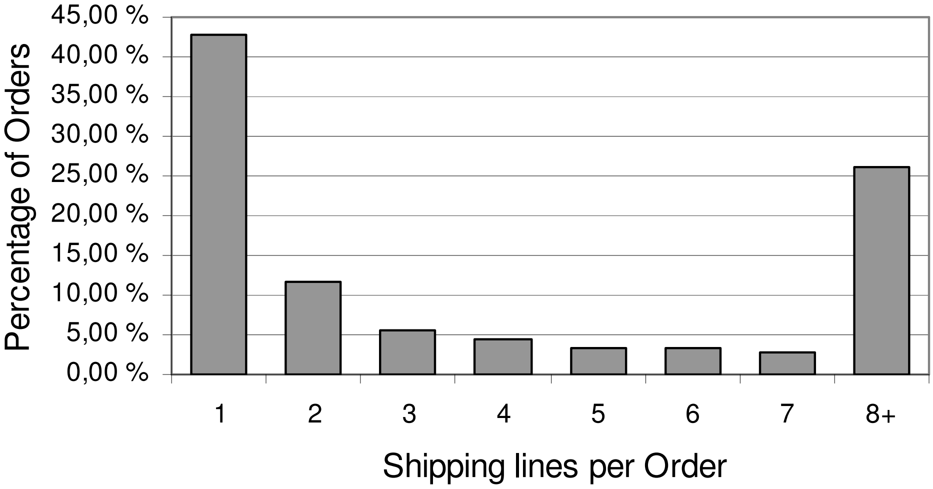

Figure 5-3: Distribution of order lines

The influence of unfavorable order line distributions can be reduced by adopting appropriate operating strategies. A good alternative to handle single line orders is to batch multiple single line orders together. For example, by printing out single line orders in a location sequence, it is possible to create very efficient picking tours. Automation can also provide a way to process orders more efficiently. For example, by having several automated carousel units from which products are picked to a sorting belt, picking speed can be increased tremendously. In this case also the overall time required to handle single line orders reduces because the time needed for manual sorting of items is reduced. One problem, however, is that with large product varieties it may be difficult to find a single automated system that is appropriate for the entire product range.

Figure 5-4 describes the item popularity distribution for the hoses product group in terms of order lines and delivered quantity. The distribution indicates the percentage of picks associated with each percentage of stock keeping units. By observing the delivered quantities it is possible to see the resemblance of the distribution with the classical Pareto distribution where roughly 20 percent of items represent 80 percent of the total quantity delivered. Looking at the order lines, 20 percent of the most popular items represent 60 percent of picking activity. With 50 percent of items it is already possible to satisfy 90 percent of all picks.

Figure 5-4: Item popularity distribution

Dramatic breakpoints in the item popularity distribution may suggest item popularity families. The overriding principle is to assign the most popular items to the most cost-effective locations. These are the most accessible locations that are ergonomic and close to the shipping department. Because we are making observations only on a single product group, popularity distribution also represents fairly well the number of orders that each percentage of items is capable of fulfilling.

Properties such as size, weight and unit loads of an item make it necessary to choose between different storage solutions and material handling technologies. Understanding these properties provides information for making decisions on material handling equipment, the methods that will be used to store materials and the methods that will be used to ship and receive materials. For example, if unit loads are big enough it is typically impossible to move materials efficiently without the help of some assisting technology such as a lift truck. Figure 5-5 describes the distribution of volume per each delivered order line for the case company.

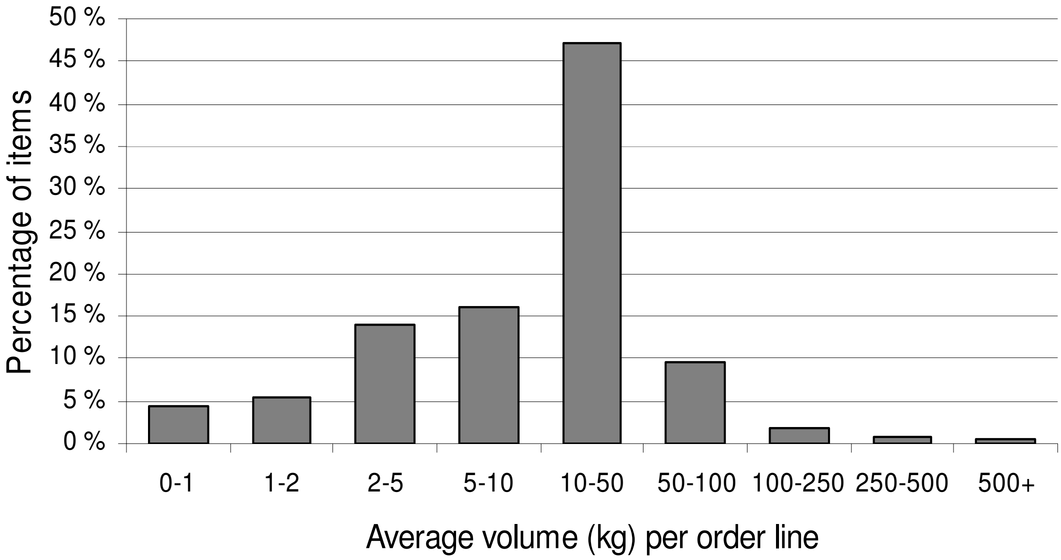

Figure 5-5: Order volume distribution

As demonstrated, the average weight of a single order line lies most typically between 10-50 kilos. Volume distribution can be used to estimate the average unit loads to be handled in a warehouse. The distribution can also be used to illustrate the typical daily order handling activity. For example, items with low average volume per order line are candidates for small item picking, whereas items where average volume per order line is high should be handled in the pallet picking area. Here unit weight and processed quantity were combined to measure total volume of an order line. A more correct measure of volume would be the cube-movement. However, obtaining this information for all items in the case company would have been too complex because it was not available in the existing databases.

Finally, the full/partial unit mix distribution can be used to determine which products require performing cutting work and whether there is a need to separate these items to a different area in the warehouse. The distribution also shows the degree to which products are delivered customer specific. Full issue problems can sometimes be handled by pre-packaging items into most typical order increments. However, with hoses this strategy is an unfeasible alternative because cutting hoses before customer demand is known will most likely result in obsolete inventory. Figure 5-6 shows the handling unit mix distribution for the hoses product group.

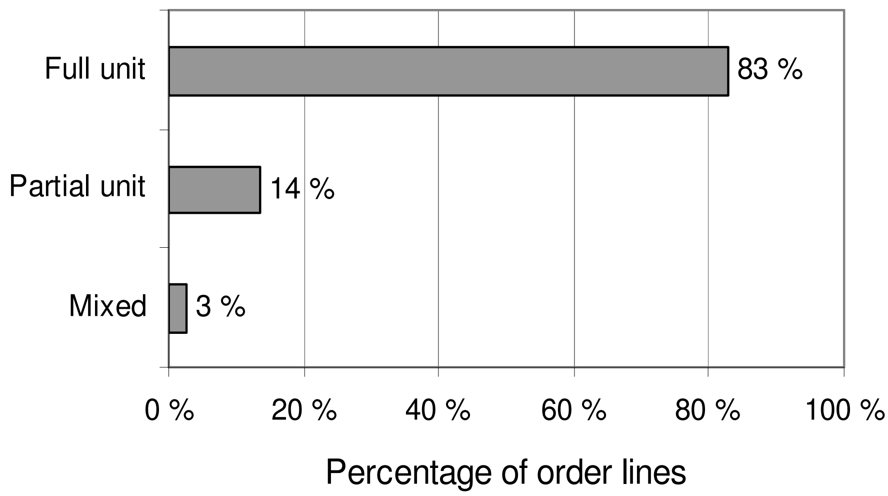

Figure 5-6: Full/partial unit mix distribution

The full unit quantity is the standard length of a hose which varies according to each specific item and its supplier. According to this distribution 84 percent of order lines can be completed in full unit quantities. This leaves 17 percent of line items that require cutting. 14 percent of these lines can be completed by picking one standard sized hose and cutting it into a smaller piece. The remaining 3 percent require delivering both full units and a cut unit.

5.5.2. Distribution of order processing time

A central part of this thesis was the study of order processing under practical conditions. The goal was to find order processing pitfalls, and understand how the overall warehouse workflow in the case company could be streamlined. Observing warehouse functions on the operational level provided also an opportunity to discuss with the warehouse employees and reflect their opinions about the current operating practices.

The study was carried out by observing three different order pickers. They were each given a set of orders and followed while processing these orders. The pickers were allowed to batch orders if they wanted, and thus determine their own picking tours. Although batching did occur sometimes, pickers usually decided to process orders one at a time. In some occasions the order pickers were interrupted and asked for assistance in other duties. In these cases the timing was stopped and continued once the picker returned back to his original work. This was done to keep the focus of study on the effective order processing time.

The analysis data was gathered by observing and writing down the time employees spent on their daily working routines. For this purpose, the order handling process was divided into six phases:

1. Traveling to pick location
2. Material handling
3. Returning to shipping department
4. Shipping operations
5. Order confirmation
6. Moving the order to departing items

Phases 1, 3, and 6 represent the total time of moving around the warehouse during a single processing cycle. The materials handling part, on the other hand, shows the time that is required to extract requested items from storage locations. Shipping operations included sorting items, checking orders for completeness, packing items to appropriate shipping containers, and weighing orders to determine shipping charges. Finally, the order confirmation part is mainly composed of the time an employee spends on a computer typing in order related information and printing out documents such as packaging list, address label, and bill of lading.

The observed sample included a total number of 34 picking lists which contained 73 item lines. The complete list of recorded statistics can be seen in Exhibit 2. When analyzing the results of this study, it should be remembered that the size of the sample is relatively small. Still, the recorder values were close to what had been intuitively expected. This means that the results should be able to describe the current nature of order processing quite accurately.

Figure 5-7 divides the total order processing time into four main activities. Most of the time (33%) was spent on activities related to information handling. This time can be seen as a necessary evil because it is not directly a value adding part in the warehousing function but is still needed to be able to manage processes and keep a track on inventory. Roughly half of the time was spent on movement or transportation (25%) and materials handling (23%). The time required for movements and transportation is mainly determined by the traveling distance, while materials handling was mostly influenced by the type and number of processed items. The rest of the time (19%) was spent on sorting and packing of orders.

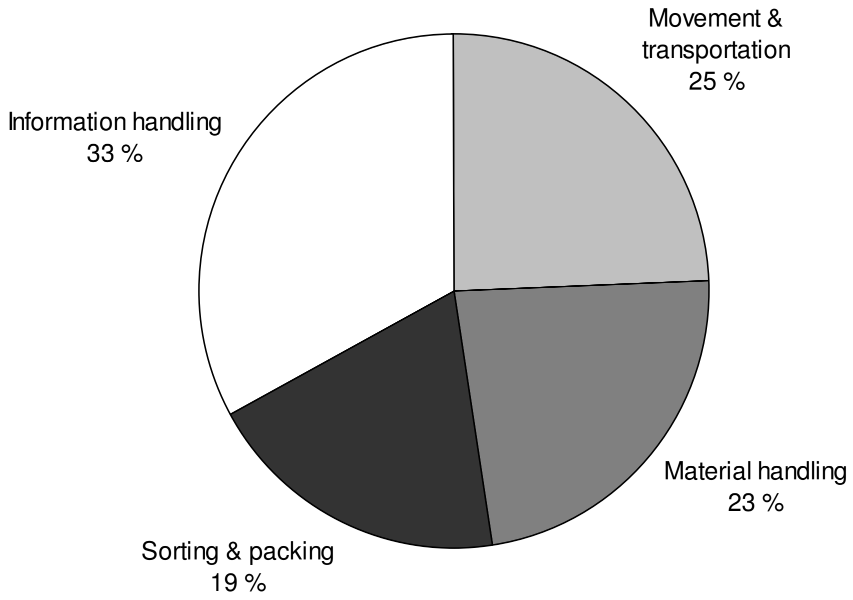

Figure 5-7: Distribution of order processing time

The relative work effort required by various warehousing activities was estimated using average processing times. The research sample was also divided into two groups based on whether the processed order required performing cutting work. The resulting categorization (Figure 5-8) can be used to estimate the average time that is needed to complete each phase in the order handling process. It also allows comparing the average time between orders that require customization activities with those that do not.

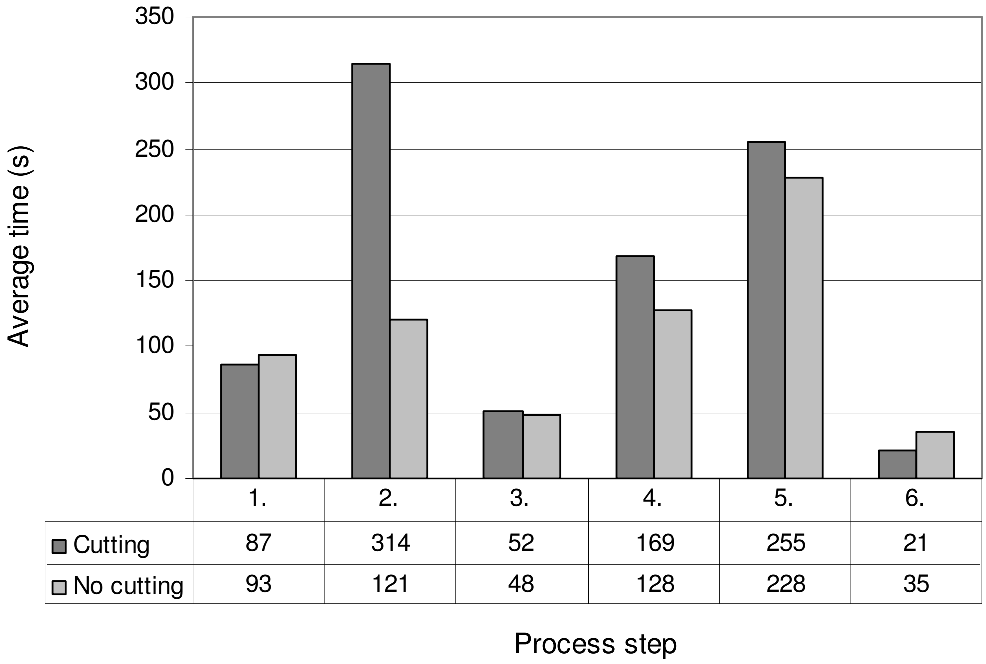

Figure 5-8: Average processing times

The average time for a phase was calculated by summing up recorded time values and dividing this sum by the total number of processed orders. Another possibility would have been to make comparisons based on item line specific averages. However, the number of items per order line as well as the number of lines per order varied a lot. This means that the results from this method would have been accurate only for the first two phases of the process where recorder statistics were item line specific. The values for the rest phases would have been averages based on averages.

The average time to complete an order that required cutting of hoses was 15 minutes. An order that did not require cutting, on the other hand, could be completed in approximately 11 minutes. The reason for this difference can be clearly derived into the materials handling phase where the difference between the two categories is most evident. For the rest of the phases there was significantly less variation between the two groups. It is also worth mentioning that in the collected sample the processed orders contained relatively few lines. It should also be noticed that more frequent order batching or longer orders would most likely result in an increased average time in traveling and materials handling phases.

5.6 Case implications and possible operating strategies

This section summarizes the warehouse design alternatives and demonstrates some of the possibilities that can be used to handle warehousing related problems in the case company. The analysis has been divided into two parts. The first part concentrates on issues in physical order picking and materials handling operations while the second part focuses on information management improvement strategies.

5.6.1. Physical operations

The main principle in cycle time reduction is to ensure that order picking operations are free of interruptions. In general, the observed order pickers in the case company found it extremely frustrating when they had to stop their ongoing order handling because each interruption disconnected them from their picking rhythm. These situations typically occurred when a picker had to re-replenish a standard picking location, change to a different type of truck to reach an item, try to avoid congestion, or travel unusually long distances to fulfill a single item line. In practice it is of course impossible to avoid such disturbances completely. However, it is possible to reduce their frequency of occurrence in order picking. For example, replenishment of the standard picking locations can be removed from order picker's tasks and assigned to a separate warehouse employee. It would also be beneficial to have information about the reserve location readily available so that there is no need to return to the shipping department to re-check it from a computer. For such purposes, mobile data terminals that can be attached to a truck could be used. In the ideal situation information about empty picking locations would be available to the picker already before the picking tour begins. It would also be preferable to have the reserve location as close to the standard picking location as possible so that the additional travel time is not very long. One option is to position the standard picking locations on the ground level and place reserve stock in the shelf space above this location.

The general principle in making order picking operations more efficient is to, change the sequence of activities, improve timing, and eliminate or combine activities where possible. Typical activities in order picking included traveling, documenting, reaching, sorting, searching, and counting items. Means for eliminating and speeding up these activities are outlined in Table 5-3.

Table 5-3: Eliminating order picking work elements (Tompkins et al, 2010)

Work Element	Method of Elimination	Equipment Required
Traveling	Bring pick locations to picker	Stock-to-picker system
		Miniload automated systems
		Horizontal carousel
		Vertical carousel
Documenting	Automate information flow	Computer-aided order picking
		Automatic identification systems
		Light aided order picking
		Radio frequency terminals
		Headsets
Reaching	Present items at waist level	Vertical carousel
		Person-aboard automated systems
		Miniload automated systems
Sorting	Assign one picker per order and one order per tour	
Searching	Bring pick locations to picker	Stock-to-picker systems
	Take picker to locations	Person-aboard automated systems
	Illuminate pick locations	Pick-to-light systems
Extracting	Automate dispensing	Automatic item pickers
		Robotic pickers
Counting	Weigh count	Scales on picking vehicles
	Prepackage in issue increments	

Physical handling of the hoses is one of the product group specific problems in Etra's warehousing. Whenever a cutting operation is needed, time used on materials handling increases dramatically. Moving hoses around, measuring them, and choosing the right tools to perform cutting simply take up a lot of order pickers' time. Currently customers pay the same standard price for any type of cutting service. The costing system of cutting activities should also be delineated more accurately within the product group because the size of the hose and its properties did have an influence on the processing time. One possibility would also be to move cutting activities completely to the cutting department. The cutting department would perform the cutting of the hose and send an impulse to the picker that handling of the order list with that item can begin. This would enhance the time order pickers can spend on actual order picking operations. It would also remove some of the quality issues related to cutting hoses because the cutting department has better tooling and knowledge about cutting various materials.

Inventories in the case company comprise several thousands different items. In such conditions, also storage capacity becomes a typical problem. Goods having a strong impact on the total cost have to be managed carefully while for less important goods it is wise to resort to simple and low-cost techniques. Regarding the hoses product group it has been noticed that smaller products are easiest to store in bin shelves while larger ones can be placed on a pallet that has metal grids welded around it (Hokkanen 6.9.2010, interview).

The overall capacity requirement for storing items depends on the chosen storage method. If fixed location storage is used, the sufficient space is the maximum amount of items that will ever be on hand. For random storage, a good estimate of required capacity will be the average amount of each item; when the inventory level of one item is above average, another item is likely to be below (Tompkins, 2010, 419). One way to estimate storage capacity requirements is to do a periodic review of inventory levels. This is done by looking at the overall inventory levels over a long enough time frame and estimating the average storage need. An example of this methodology using a limited range of products is shown in Exhibit 3. What would still be needed in the case company is a measure that enables transforming these inventory levels into pallet quantities so that the actual number of storage locations needed can be determined.

Allocation of items to storage locations is also important because it influences the frequency employees must reach into difficult storage areas and the time they spend on travelling in the warehouse. Item popularity profiles (see. Figure 5-4) can be used to rank items for this purpose. To increase order picking efficiency it is relevant to have items with high demand frequency close to the shipping department and preferably stored near the pickers waist level where picking can be done most ergonomically.

5.6.2. Information management

A major bottleneck in the shipping operations is the information handling part. This task alone takes roughly one third out of the total order handling time. This is a non-value-adding part in the process because it does not directly improve the value of the product or bring it closer to the customer. It is clear that there is a need to find more effective means of communicating order related information.

The time spent on typing in order related information naturally varies depending on the technology skills of a person. However, one main reason for the long duration of order confirmation stage is the stiffness of ERP system's warehousing module. This is a generally acknowledged problem in the case company which has been considering the possibility of adopting a standalone WMS for tracking information in the central warehouse facility. In its simplest form, the WMS can track product related data and act as an interpreter and message buffer between the order handling process and the existing ERP. In the future the role of the WMS could go beyond the physical boundaries of a warehouse and it could be used for inventory planning and cost management purposes. In this case the objective of the WMS would become to provide a set of computerized procedures that handle the receipt of items into stock and link order processing to logistics management in order to efficiently pick, pack and ship products out of the facility.

An important project in the case company is to update and improve the coherency of information infrastructure. It is not possible to have an efficient order picking system without an effective stock location system. Furthermore, having the basic product information in place is typically a pre-requisite before any new technologies or sophisticated data collection methods can be taken into use. In the current situation it is, for example, extremely hard to estimate actual pallet quantities flowing through the warehouse because some items lack weight and cube information. This information would be valuable especially in warehouse capacity planning and slotting decisions. The item cube information is normally expressed as the amount of square meters that is accommodated by each item unit. If suppliers cannot provide this information then it should be captured at the receiving dock. The easiest way to calculate item cube information is typically to measure the outer dimensions of a packaging unit and divide the resulting cubes by the number of item units that it contains.

By having all the required information in place it may also become possible to skip manual work or entire steps in the order handling process. For example, by using item weight properties in the ERP system, there would be no need to perform manual weighing in the shipping stage. It would also be useful to open separate codes for hoses that have been cut. This would reduce obscurity of inventory because full issue quantities and less than full issue quantities are tracked separately. Finally, warehouse profiling should be a continuous process which is performed regularly to notice possible changes in warehousing trends. For this purpose, it would be good to have warehouse profiling integrated to the company's automated reporting system.

5.7 Validness and generalization of results

The last step in the warehouse design framework which involves selecting the most attractive design approach is left for the consideration of case company's management. As a summarizing remark it should be noticed that there may not exist a planning methodology which is guaranteed to optimize the performance of a warehouse. However, taking existing order data in a company and systematically applying it to the design of a warehouse significantly reduces the need for guesswork and ensures that performed activities at least to some extent match the actual warehousing needs.

The greatest challenge regarding this thesis has been to conduct a study on warehouse operations that do not yet physically exist. When this thesis was finished, the central warehouse of the case company was in its early construction phase. Because no other means for measuring warehouse operations existed, decision making had to rely on contemporary measures such as the ones that were used in this study. This naturally means that some of the processes in the upcoming facility are performed in a somewhat different environment. For example, physical layout, traveling distances, and technology used will not be the same. It is also possible that studied processes in the case company are subject to time because in many firms there is monthly variation in working efficiency.

It must also be noticed that the analysis was mainly concentrated on a single product group. In practice, however, the physical properties of a product as well as the quantity in which products are ordered influence the unit specific cost. This means that the cost of processing an order line differs between various groups of products. For example, a product with a large outer diameter occupies a lot of cube space which means that its storage is more expensive. Such products are often also complicated to handle which makes processing times longer. Customized warehousing activities also take many forms and the study of the cutting operation that was analyzed in this thesis is just one example of how these activities can be measured.

6. Conclusions

The goal of this thesis has been to develop a design framework that can be used to organize and improve order processing activities in a warehousing context where product customization services are an essential part of operations. This chapter presents the most essential results of the study and summarizes the managerial activities that have been suggested during the course of this study.

6.1 Theoretical contribution

The warehouse is evolving into a customer satisfaction center that performs numerous customized and value added services to products before shipment. This has extended the role of warehousing to include services that facilitate more efficient operations in the receiving premises, and therefore, benefit the customer. Whether this means pre-sorting and pre-labeling goods for eventual cross-docking or actual customization of the outbound product often depends on the demands of the customer.

The world of warehousing is changing rapidly under the increased pressure to improve overall supply chain performance. For simple warehouses a standardized planning and control structure suffices but the more complex the warehouse is the more tailor-made solutions are needed. For a warehouse to accomplish its objectives managers must consider the variable warehouse resources and mold them into an effective plan. A successful warehouse maximizes the effective use of resources while satisfying customer requirements. The changing dynamic environment quickly renders existing plans obsolete. Therefore, warehouse planning must be a continuous activity in which the existing plan is constantly being scrutinized to meet anticipated requirements. Having a standardized design procedure would facilitate this effort.

The findings of this paper are important in both theoretical and practical terms. The structured review of literature summarizes the most essential warehouse design elements. Contribution to theory is thus a structured approach to warehouse design which builds upon the framework introduced in chapter 5.1. The design framework shows tools and techniques for each warehouse design phase and helps establishing proper measures for tracking different logistics activities.

Based on literature, there appears to be some consensus on the overall approach that needs to be followed in warehouse design. The framework presented in this study takes the different warehousing design problems and synthesizes them into a step-by-step planning procedure. There can be some debate on the precise steps, as the activities in the design process can be grouped together in various combinations. Similarly, there can be a further debate concerning the sequence of these steps as warehouse design tends to be an iterative process. It is also evident that there is often considerable reliance on the experience of individual warehouse design experts in deciding the tools to be used and in making judgments between various alternative solutions.

In the end, designing a warehouse amounts to choosing its building layout, as well as its equipment and process structure. This often requires a mixture of analytical skills and creativity because most problems encountered during warehouse design are not well-defined and often cannot be isolated to one single cause. The three questions considered most often in warehouse design are how to store items, how to process the items, and how to organize the flow of processes. In principle, the decision maker may choose from a large number of alternatives. However, the analysis in this paper showed that in practice many of the available solutions can be discarded by quantitatively and qualitatively analyzing the physical characteristics of the products, the number of items in stock, and the rate of storage and retrieval requests.

6.2 Managerial implications

The warehouse design framework was also shown to be useful by applying it to a warehouse planning situation in real-life. The empirical case study showed that many of the tools and techniques presented in the warehouse design framework can be useful when planning and organizing warehouse operations. One possibility could also be to use the framework as a checklist to see that all essential steps in the planning process have been taken care of.

A central concept related to warehouse efficiency is the overall cycle time of order processing. Reducing cycle time increases the responsiveness and flexibility of a warehouse but requires identifying bottlenecks in the warehousing process and finding ways to streamline materials handling and order picking activities. Some practical methodologies to achieve more efficient order processing operations were summarized in chapter 5.6.1.

Especially labor force and machine capacity are critical resources in warehouse operations. For this reason, waiting and unnecessary material movements related to these resources should be minimized. Furthermore, results demonstrated in chapter 5.2.2 show that the customization services that are performed in the warehousing context often require more time and resources than would be expected. This implies that management needs to carefully consider the costing structure of these services before they are offered to the customers. It is also worth considering whether value added activities can be completely removed from the order processing function, for example, by moving them to be handled by a separate department in the warehouse.

Also different warehousing systems influence order processing efficiency. The choice of storage and order picking systems is determined by the physical characteristics of the goods, their packaging, and the composition of the outgoing lots. In a simple storage zone warehouse, goods are usually stocked on palletized racks if their processed volumes are high enough while items with lower volumes can be placed in more space effective storage modes such as drawers. Automated systems are feasible if the products can be automatically identified through bar codes or other corresponding techniques. They have low space and labor costs, but require a large capital investment. Hence, they are economically convenient provided that the turnaround rate of goods is high enough.

A major trend in warehouse information handling is to create automatically tracked and paperless processes. Companies that manage to redesign their processes are able to realize significant cost savings and accuracy gains. The observations made in chapter 5.6.2 indicated that there is great potential to reduce warehouse cycle times by automating information flows. For example, weighing orders manually could be replaced by using product property values in the ERP system. Information systems are also essential to control the movement and storage of materials within a warehouse and to track the associated transactions. However, the basic requirement for adopting warehouse technology is that the company has a coherent information infrastructure. Companies whose information systems are scattered and full of errors are most likely to end up with inaccurate warehouse processes. For this reason well organized information handling is important. For example in the case company, creating separate item codes for cut hoses would significantly improve the traceability of inventory.

6.3 Suggestions for future research

The main function of this thesis has been to carry out a preliminary study of warehouse design opportunities in the case company. The research area in this thesis was strictly restricted to order processing operations with attention given to one product group only. To develop a more comprehensive understanding of warehousing, it is suggested that item activity profiling is conducted also for other product groups in the case company. In order to improve planning accuracy and identify possible changes in warehousing trends, it is also a good idea to review the warehouse planning framework when actual process information from the central warehouse becomes available.

As identified by previous warehousing literature, relatively little has been written about the total design process. Due to the high cost of these facilities and the significant consequences of any deficiencies in this area, a need for more comprehensive and systematic warehouse design methodologies continues to exist. From the management point of view, these methodologies should be relatively simple, intuitive, and reliable. They should focus on operational management of warehousing systems, where the different processes in the warehouse are considered jointly to achieve general warehousing objectives.

References

Ackerman, K.B. 1997. *Practical handbook of warehousing*. 4th Edition. Springer.

Aminoff, A. & Kettunen, O. & Pajunen-Muhonen, H. 2002. Research on Factors Affecting Warehousing Efficiency. *International Journal of Logistics.* Vol. 5, No. 1. p. 45-57.

Andersson, D. & Norrman, A. 2002. Procurement of logistics services - a minutes work or a multi-year project. *European Journal of Purchasing & Supply Management*. Vol. 8, No. 1. p. 3-14.

Baker, P. & Canessa, M. 2009. Warehouse design: A structured approach. *European Journal of Operational Research*. Vol. 193, No. 2. p. 425-436.

Baker, P. 2004. Aligning Distribution Centre Operations to Supply Chain Strategy. *International Journal of Logistics Management*. Vol. 15, No. 1. p. 111-123.

Beamon, B.M. & Ware, Tonja M. 1998. A process quality model for the analysis, improvement and control of supply chain systems. *International Journal of Physical Distribution & Logistics Management*. Vol. 28, No. 9/10. p. 704-715.

Berglund, M., van Laarhoven, P., Sharaman, G. & Wandel, S. 1999. Third-Party Logistics: Is There a Future?. *The International Journal of Logistics Management*. Vol. 10, No. 1. p. 59-70.

Bodner, D.A., Govindaraj, T., Karathur, K.N., Zerangue, N.F., and McGinnis, L.F. 2002. A Process Model and Support Tools for Warehouse Design. *School of Industrial and Systems Engineering*. Georgia Institute of Technology.

Burkink, T. 2002. Cooperative and voluntary wholesale groups: channel coordination and interfirm knowledge transfer. *Supply Chain Management: An International Journal*. Vol. 7, No. 2. p. 60 - 70.

Cooper, C.L. & Mulaik, S. 2010. Warehouse Activity Profiling - Identifying Improvement Opportunities in Your Warehouse Operations . *The Progress Group, LLC*.

Cristopher, M. 2005. *Logistics & Supply Chain Management: Creating value-adding networks*. 3rd Edition. Pearson Education.

Croxton, K.L. 2003. The order fulfillment process. *The International Journal of Logistics Management.* Vol. 14, No. 1. p. 19-32.

de Koster, R. & Le-Duc, T. & Roodbergen, K.J. 2007. Design and control of warehouse order picking: A literature review. *European Journal of Operational Research.* Vol. 182, No. 2. p. 481-501.

Faber, N. & de Koster, R.B.M., van de Velde, S. 2002. Linking warehouse complexity to warehouse planning and control structure. *International Journal of Physical Distribution & Logistics Management*. Vol. 32, No. 5. p. 381-395.

Frazelle, E.H. 2002. *World-class warehousing and material handling*. New York: McGraw-Hill

Gademann, A.J.R.M., van den Berg, J.P. & van der Hoff, H.H. 2001. An order batching algorithm for wave picking in a parallel-aisle warehouse. *IIE Transactions*. Vol. 33, No. 5. p. 385-398.

Gu, J. & Goetschalckx, M. & McGinnis, L. 2007. Reasearch on warehouse operation: A comprehensive review. *European Journal of Operational Research*. Vol. 177, No. 1. p. 1-21.

Gunasekaran, A., Patel, C. & McGaughey, R.E. 2004. A framework for supply chain performance measurement. *Production Economics*. Vol. 87, No. 3. p. 333-347.

Hassan, M.M.D. 2002. A framework for the design of warehouse layout. *Facilities*. Vol. 20, No. 13/14. p. 432-440.

Hertz, S. & Alfredsson, M. 2003. Strategic development of third party logistics providers. *Industrial Marketing Management*. Vol. 32, No. 2. p. 139-149.

Higginson, J. K. & Bookbinder, J. H. 2005. *Logistics Systems: Design and Optimisation*. Springer, New York.

Hokkanen, Henri. 6.9.2010. Logistics Director. Etra Oy. Helsinki.

Hoyles, C., Bakker, A, Kent, P & Noss, R. 2007. Attributing meanings to representations of data: The case of statistical process control. *Mathematical Thinking and Learning,*. Vol. 9, No. 4. p. 331 - 360.

James A. Tompkins, John A. White & Yavuz A. Bozer. 2010. *Facilities planning*. 4th Edition. Hoboken, NJ : Wiley.

Jiao, J., Ma, Q. & Tseng M.M. 2001. Towards high value-added products and services: mass customization and beyond. *Technoviation*. Vol. 23, No. 10. p. 809-821.

Johansson, P. & Olhager, J. 2004. Industrial service profiling: Matching service offerings and processes. *International Journal of Production Economics*. Vol. 89, No. 3. p. 309-320.

Jones, D.T., Hines, P. & Rich, N. 1997. Lean logistics. *International Journal of Physical Distribution & Logistics Management.* Vol. 27, No. 3/4. p. 153-173.

Korpela, J., Lehmusvaara, A. & Tuominen, M. 2001. Customer service based design of the supply chain. *International Journal of Production Economics.* Vol. 69, No. 2. p. 193-204.

Koskinen, I. & Alasuutari, P. & Peltonen, T. 2005. *Qualitative research methods in economics (in Finnish)*. Gummerus Kirjapaino, Jyväskylä.

Krajewski, L. J. & Ritzman, L. P. 2005. *Operations management : processes and value chains*. 7th International Edition. Upper Saddle River (NJ) : Pearson Prentice Hall.

Mason-Jones, R. & Towill, D.R. 1999. Total cycle time compression and agile supply chain. *International Journal of Production Economies*. Vol. 62, No. 1-2. p. 61-73.

Mentzer, J.T., Flint, D.J. & Hult, T.M. 2001. Logistics service quality as a segment-customized process. *The Journal of Marketing*. Vol. 65, No. 4. p. 82-104.

Narus, J.A., Reddy, N.M. & Pinchak, G.L. 1984. Key problems facing industrial distributors. *Industrial Marketing Management*. Vol. 13, No. 3. p. 139-147.

Nozick, L.A. & Turnquist, M.A. 2001. Inventory, transportation, service quality and the location of distribution centers. *European Journal of Operational Research*. Vol. 129, No. 2. p. 362-371.

Oliva, R. & Kallenberg, R. 2003. Managing the transition from products to services. *International Journal of Service Industry Management*. Vol. 14 No. 2. p. 160-172.

Petersen, C.G. & Aase, G.R. 2004. A comparison of picking, storage, and routing policies in manual order picking. *International Journal of Production Economics*. Vol. 92, No. 1. p. 11-19.

Petersen, C.G., Siu, C. & Heiser, D.R. 2005. Improving order picking performance utilizing slotting and golden zone storage. *International Journal of Operations & Production Management*. Vol. 25, No. 10. p. 997 - 1012.

Phillips, Ed. 2010. *Warehouse Layout & Design*. http://www.strategosinc.com/warehouse.htm. Cited: 27.05.2010.

Roodbergen, K.J & de Koster, R. 2001. Routing methods for warehouses with multiple cross aisles. *International Journal of Production Research*. Vol. 39, No. 9. p. 1865-1883.

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G.J., Mantel, R.J. & Zijm, W.H.M. 2000. Warehouse design and control: Framework and literature review. *European Journal of Operational Research*. Vol. 122, No. 3. p. 515-533.

Ruben, R.A. & Jacobs, F.R. 1999. Batch Construction Heuristics and Storage Assignment Strategies for Walk/Ride and Pick Systems. *Management Science*. Vol. 45, No. 4. p. 575-596.

Rutner, S.M. & Langley, John C. 2000. Logistics value: Definition, process and measurement. *The Internatonal Journal of Logistics Management*. Vol. 11, No. 2. p. 73-82.

Salanne, I., Päätalo, M. & Musto, M. 2005. Tienpidon vaikutukset kuljetusten täsmällisyyteen. *Tiehallinnon selvityksiä*. 3/2005.

Schneiderman, A.M. 1996. Metrics for the Order Fulfillment Process (Part 2). *Journal of Cost Management*. Vol. 10, No. 3. p. 6-18.

Smith, J.D. 2007. *Storage and Warehousing, in Handbook of Industrial Engineering: Technology and Operations Management*. 3rd Edition. John Wiley & Sons, Inc., Hoboken, NJ.

Tellis, W. 1997. *Application of a case study methodology. The Qualitative Report*, Volume 3, Number 3. http://www.nova.edu/ssss/QR/QR3-3/. Cited: 26.10.2010.

Tho Le-Duc. 2005. *Design and Control of Efficient Order Picking Processes*. Doctoral Thesis. Erasmus University Rotterdam.

Tompkins J.A. 1997. Enhancing the warehouse's role through customization. *WERC: Special Report*. Warehousing education and reseach council.

van den Berg, J.P. & Zijm, W.H.M. 1999. Models for warehouse management: Classification and examples. *International Journal of Production Economics*. Vol. 59, No.s 1-3,. p. 519-528.

van Hoek, R.I. 2000. The role of third-party logistics providers in mass customization. *International Journal of Service Industry Management*. Vol. 11, No. 4. p. 374-387.

Yao, A.C. & Carlson, J.G. 1999. The impact of real-time data communication on inventory management. *International Journal of Production Economics*. Vol. 59, No.s 1-3. p. 213-219.

Yin, R.K. 2003. *Case Study Research: Design and Methods*. Sage Publications, Thousand Oaks.

Exhibits

Exhibit 1: Outbound logistics activity map

Outbound logistics process

#	Step Description	Area	People	OPERATION	TRANSPORT	INSPECT	STORE	DELAY	Comments
1	Await order list	Shipping department	1					x	
2	Check through items on order list	Shipping department	1			x			
3	Setup picking equipment	Shipping department	1	x					
4	Travel to pick location	Storage	1		x				Repeated for all order lines
5	Extract items from pick location	Storage	1	x					Repeated for all order lines
6	Travel to shipping department	Storage	1		x				
7	Sort picked orders	Shipping department	1	x					
8	Pack items	Shipping department	1	x					
9	Weigh items	Shipping department	1	x					
10	Type freight information into system	Computer terminal	1	x					
11	Confirm order picking	Computer terminal	1	x					
12	Print out shipping documents	Computer terminal	1	x					
13	Attach shipping documents to shipment	Shipping department	1	x					
14	Move shipment to departing items	Shipping bay	1		x				

Exhibit 2: Measured process times

Processing date	Order #	Orders	Line #	1.	2.	3.	4.	5.	6.	Cutting work
26.8.2010	105759	1	1	49	279	33	39	127	9	x
26.8.2010	105469	1	1	40	146	55	70	130	20	x
26.8.2010	105684	1	1	59	84	47	365	210	18	
26.8.2010			2	40	30					
26.8.2010			3	45	70					
26.8.2010			4	38	61					
26.8.2010	106024 / 105864	2	1	40	36	24	252	472	15	
26.8.2010			2	18	44					
26.8.2010			1	50	60					
26.8.2010			2	43	11					
26.8.2010			3	15	12					
26.8.2010			4	16	12					
26.8.2010	106151	1	1	39	30	22	87	137	3	
26.8.2010	103376	1	1	11	50	22	76	280	15	
26.8.2010	105489	1	1	20	53	23	231	279	37	
26.8.2010			2	45	33					
26.8.2010			3	39	33					
26.8.2010			4	161	151					
26.8.2010			5	9	30					
26.8.2010			6	3	14					
26.8.2010			7	18	39					
26.8.2010	99277	1	1	56	20	34	60	160	15	
26.8.2010	104427 / 104728	2	1	33	36	44	195	517	46	
26.8.2010			1	158	122					
26.8.2010			2	95	73					
26.8.2010			3	150	42					
26.8.2010			4	12	59					
26.8.2010			5	7	36					
26.8.2010			6	9	27					
26.8.2010			7	14	18					
26.8.2010			8	7	18					
26.8.2010			9	10	6					
26.8.2010			10	7	24					
26.8.2010			11	8	80					
26.8.2010			12	14	25					
26.8.2010	2393450	1	1	19	30	35	0	163	67	
26.8.2010	2392786	1	1	76	37	0	68	151	7	
26.8.2010	2392882	1	1	90	69	0	87	146	32	

Processing date	Order #	Orders	Line #	1.	2.	3.	4.	5.	6.	Cutting work
30.8.2010	106520	1	1	44	51	33	0	152	70	
30.8.2010	99355	1	1	26	423	74	237	278	51	x
30.8.2010	106852 / 106856	2	1	30	35	65	88	313	35	
30.8.2010			1	26	42					
30.8.2010			2	51	33					
30.8.2010	106859	1	1	26	51	1,15	0	217	88	
30.8.2010			2	63	35					
30.8.2010	2398157	1	1	37	140	100	289	304	25	
30.8.2010			2	6	40					
30.8.2010			3	79	107					
30.8.2010			4	50	38					
30.8.2010	106438	1	1	28	16	136	263	296	79	
30.8.2010			2	24	11					
30.8.2010			3	7	45					
30.8.2010			4	27	6					
30.8.2010			5	19	12					
30.8.2010	107094	1	1	49	83	56	19	120	35	
30.8.2010	103883	1	1	24	87	40	206	186	9	
30.8.2010	106670	1	1	40	39	36	105	276	180	
30.8.2010			2	4	28					
30.8.2010			3	29	15					
30.8.2010			4	72	15					
30.8.2010			5	20	12					
30.8.2010	2400970	1	1	45	19	61	0	56	11	

Processing date	Order #	Orders	Line #	1.	2.	3.	4.	5.	6.	Cutting work
6.9.2010	2409459	1	1	31	87	61	354	268	30	
6.9.2010	107907	1	1	99	143	33	103	287	42	x
6.9.2010	107645	1	1	41	125	33	275	316	6	x
6.9.2010	107622	1	1	181	573	54	213	252	7	x
6.9.2010	108186	1	1	36	257	282	309	452	80	
6.9.2010			2	17	177					
6.9.2010	104709	1	1	30	88	50	36	351	12	
6.9.2010	108391	1	1	170	509	80	248	396	11	x
6.9.2010	108044	1	1	62	86	53	309	409	31	
6.9.2010			2	7	21					
6.9.2010	2409640	1	1	57	16	76	45	230	9	

Exhibit 3: Inventory level analysis

Inventory level (meters)

Item	1.3	16.3	1.4	16.4	1.5	16.5	1.6	16.6	1.7	16.7	1.8	16.8	Avg
1	478	244,1	174,1	39,1	376	696	454	314	981	841	681	1011	**524**
2	650	2120	1600	960	480	820	5	0	0	2300	1580	980	**958**
3	0	675	3478	2088	1828	0	0	0	2350	1970	1550	50	**1166**
4	1285	1445	645	1045	525	200	20	978	548	0	0	0	**558**
5	386	336	313	157	67	287	127	87	447	387	297	417	**276**
6	1500	2380	1340	980	180	0	40	40	40	1480	1120	680	**815**
7	834	359	1784	909	3078	2918	2043	3918	3143	3043	2918	2793	**2312**
8	490	440	590	400	285	255	185	380	280	170	210	90	**315**
9	1250	980	860	650	410	200	1910	1310	1100	940	1720	1630	**1080**
10	120	0	0	0	0	0	870	780	720	600	1550	1510	**513**
11	360	120	0	0	0	0	780	690	600	450	1530	1320	**488**
12	2720	1720	360	240	200	1280	1160	1880	1760	2720	2480	2400	**1577**
13	340	43	2275	1875	1825	1275	0	0	0	0	0	0	**636**
14	0	0	1800	1649	1599	924	324	2249	1974	1924	1049	949	**1203**
15	209	129	169	59	119	259	219	179	339	299	189	119	**191**
16	1800	1480	1280	718,5	198,5	0	0	160	40	1160	1160	960	**746**
17	164	34	1200	974	749	474	299	2424	2224	2024	1899	1799	**1189**
18	137,5	787,5	1162,5	481	0	1750	1446	996	446	446	0	0	**638**
19	270	90	48	618	548	518	508	1098	1008	928	888	718	**603**
20	158	138	130	60	158	98	28	18	220	199,4	347,9	275,3	**153**
21	128	98	285,5	235,5	203,5	164	124	84	214	102	44	4	**141**
22	320	360	120	0	560	320	240	440	240	0	1120	920	**387**
23	727	504	1404	1004	854	992	837	563	813	603	453	353	**759**
24	1384	1084	984	784	224	0	0	816	516	291	141	0	**519**
25	221	0	1700	1550	450	200	175	1422	1397	972	897	697	**807**
26	50	0	0	0	3325	2700	2575	4050	3750	3600	3525	2775	**2196**
27	441	916	1291	1116	1061	1001	776	676	576	500	400	371,5	**760**
28	494	244	194	169	516	416	386	801	781	756	731	481	**497**
29	1000	760	600	0	0	0	0	0	0	440	400	302	**292**
30	1330	1290	1010	730	530	410	250	970	770	650	330	650	**743**
31	360	260	10	0	0	250	0	0	330	70	70	0	**113**
32	58	458	458	208	158	1358	1058	850	700	400	300	175	**515**
33	163	93	183	63	53	223	203	3	0	0	0	250	**103**
34	0	0	110	40	30	280	140	100	90	230	160	30	**101**
35	260	260	220	100	60	300	100	260	340	190	430	310	**236**
36	950	900	878	378	128	578	448	348	238	38	32	24	**412**
37	50	700	799	420	270	545	235	35	22	22	22	22	**262**
38	1217	1067	2042	1917	1740	1040	890	1515	1490	1090	1090	915	**1334**
39	50	1000	675	625	475	225	25	645	328	78	1708	1608	**620**
Total	**22355**	**23515**	**32172**	**23242**	**23263**	**22956**	**18880**	**31079**	**30815**	**31913**	**33022**	**27589**	**26733**

Maximum aggregate inventory level = 33022

Minimum aggregate inventory level = 18880

Sum of individual maximum inventory levels = 58104

Average inventory level = 26733