NYNKE FABER

Structuring Warehouse Management

Exploring the Fit between Warehouse Characteristics and Warehouse Planning and Control Structure, and its Effect on Warehouse Performance

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INRICHTEN VAN WAREHOUSE MANAGEMENT PROCESSEN:
Onderzoek naar de afstemming van het ontwerp van de planning en control processen op de karakteristieken van het warehouse en zijn omgeving, en naar de invloed van een optimale afstemming tussen ontwerp en karakteristieken op de prestatie van het warehouse.

Thesis

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Introduction

According to Tompkins (1998), the primary functions of a warehouse are receiving goods from a source, storing them until they are required, picking them when they are required, and shipping them to the appropriate user. Over the years, warehousing has developed from a relatively minor facet of a firm's logistics system to one of its most important functions (Grant *et al.*, 2006). Facing the challenge of providing customers with an increasing assortment of products and reducing holding time of materials and parts, the focus of warehousing has shifted from passive storage towards strategically located warehouses providing timely and economical inventory replenishment for customers (Bowersox *et al.*, 2013; page 224). Warehousing plays a vital role in the supply chain in providing a desired level of customer service at the lowest possible total cost (Grant *et al.*, 2006). Today's warehouses are expected to be more responsive to customer demands than ever before, for example, by providing value-added services such as last minute customization, small-scale assembly, labeling, kitting, and special packaging. With the growing success of e-commerce, warehouses increasingly have to process large numbers of small orders which have to be picked within tight time windows, which further complicates warehouse processes. In response to these developments and in particular to supply chain management initiatives, companies have either concentrated their warehouse operations in one or a few large centralized warehouse(s) with high throughputs, or have decided to outsource their warehouse activities to emergent specialized logistics companies, logistics service providers (LSPs).

All in all, warehouses are facing ever-increasing demands with respect to costs, productivity, and customer service as they become vital for the success of many companies, and simultaneously warehouse processes are becoming more complex due to developments such as value added services, e-commerce, and up-scaling warehouses. Consequently, planning and controlling warehouse processes, also referred to as warehouse management, have become a challenging task. Warehouse management operates within a framework which is defined by decisions on warehouse location and facility design (size, handling systems and lay-out). Research is needed on how to structure warehouse management in order to achieve high performance and to identify related information requirements. Warehouse management is the central theme of this dissertation.

Warehousing is of particular importance for the Netherlands and Belgium, since more than half of all European Distribution Centers (EDCs) are located in this geographic area (BCI, 1997; HIDC/BCI, 2001; HIDC 2009; Kuipers, 1999). Both countries recognize logistics to be an engine of economic growth. The Netherlands and Belgium are rated second and third, respectively, after Germany in the World Bank's 2014 Logistics

Performance Index (LPI), (Arvis *et al*., 2014). These rankings show that these countries have a strong logistics performance.

This chapter has the following structure. Sections 1.1 to 1.4 highlight the key concepts of the research presented in this dissertation: *warehouse functions and warehouse processes* in section 1.1, *warehouse management* in section 1.2, *warehouse management information systems* in section 1.3, and *warehouse performance* in section 1.4. Section 1.5 discusses the research problem, the research objective, the research questions, and the academic and social contribution of the research. Section 1.6 presents an overview of the research design and methods, and section 1.7 provides an outline of this dissertation. Section 1.8 closes this chapter with a declaration of the contributions of the author and other parties to the different chapters of this dissertation.

1.1 Warehouse functions and warehouse processes

A warehouse has traditionally been viewed as a place to hold or store inventory. However, in contemporary logistical systems, warehouse functionality is more properly viewed as mixing and modifying inventory to meet customer requirements, where storage of products is ideally held to a minimum (Bowersox *et al.*, 2013). The warehousing of products occurs for one or more of the following reasons (Grant *et al.*, 2006):

- Achieving transportation economies
- Achieving production economies
- Taking advantage of quantity purchase discounts and forward buys
- Maintaining a source of supply
- Supporting the firm's customer service policies
- Meeting changing market conditions (e.g., seasonality, demand fluctuations, competition)
- Overcoming the time and space differentials that exist between producers and consumers
- Accomplishing least total cost logistics commensurate with a desired level of customer service
- Supporting the just-in-time programs of suppliers and customers
- Providing customers with a mix of products instead of a single product on each order
- Providing temporary storage of materials to be disposed of or recycled (i.e., reverse logistics).

Warehouses decouple supply from demand. They are the points in the supply chain where product pauses, however briefly, and are touched. This consumes both space and time (person-hours), both of which are an expense (Bartholdi and Hackman, 2014).

Bowersox *et al.* (2013) and Grant *et al.* (2006) distinguish four basic warehouse functions that add value to the supply chain. The *breakbulk* function allows for products to arrive in large quantities and then to be shipped in small quantities tailored to the needs of many customers. This adds value as it reduces production costs, purchasing costs, and transport costs upstream in the supply chain. The *storage* function adds value since it allows larger quantities to be produced and transported which is more efficient. It also enables orders to be quickly delivered to customers, which provides a better service level and prevents lost sales. The *consolidation* function implies that the warehouse holds products from various sources, so that customers can order a large product range from a single source. The *customization* function adds value by postponing customized services (i.e., value added services) until the end of the supply chain, reducing upstream inventories. In summary, warehouses store and cross dock inventory in the logistics pipeline and coordinate product supply and consumer demand (Bowersox *et al.*, 2013). In cross docking, received goods have a destination upon receipt, implying they can be sent directly from the receiving docks to the shipping docks. Therefore, no storage is needed.

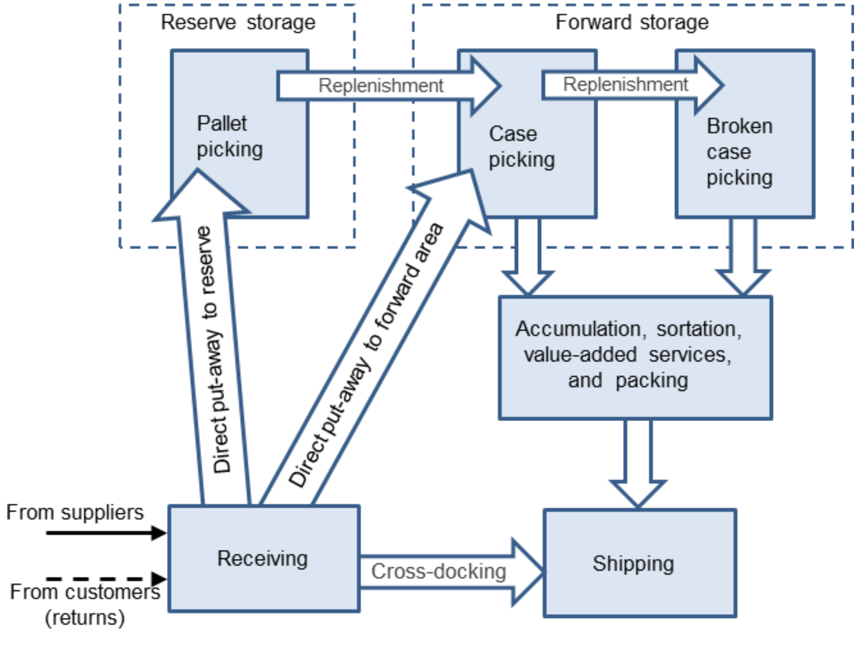

Figure 1.1 Typical warehouse functions and flows (adapted from Le-Duc (2005), and Tompkins *et al.* (2010))

Figure 1.1 shows the typical primary activities in a warehouse. The *receiving* activity includes unloading products from the transport carrier at a receiving dock, identifying the products, verifying quantities, and (randomly) checking the quality of the products.

The *direct put-away* activity involves transferring of (if applicable repacked, i.e., from pallets to cases) incoming products to a location within the storage area. A product kept in stock is also called a stock keeping unit (SKU). Each product or SKU has an identification code that allows it to be tracked for inventory purposes. During the course of a year, the entire inventory of a product or SKU can be replenished multiple times. The storage area of a warehouse may consist of two parts: a reserve area, where products are stored in the most economical way, and a forward area where products are stored for easy retrieval. A forward storage area is *replenished* from a reserve storage area. A wide range of systems can be used to store products, varying from shelf racks to automated storage systems. For an elaborate discussion on storage systems, see Frazelle (2002).

Order picking (pallet/case/broken case) involves obtaining the products requested by a customer order from the storage area. Customer orders consist of order lines, each line for a unique SKU in a certain quantity. When the requested quantity of a SKU is less than the quantity contained within a case for that SKU, it is considered *broken case picking*. If the order requests a quantity of a SKU which is equal to or multiple of the quantity within a case, it is considered *(full) case picking*. *Pallet picking* involves retrieving full pallet loads for customers requesting full pallet quantities. Picking can either be manually or (partly) automated, and it is generally recognized as the most expensive warehouse operation, because it tends to be very labor intensive or very capital intensive (Frazelle, 2002; Tompkins *et al.*, 2010). Many different order-picking system types can be found in warehouses. Often multiple order-picking systems are deployed within one warehouse, e.g., in each of the three storage zones of Figure 1.1. An overview of order-pick systems is given by De Koster, 2004; Le-Duc, 2005; De Koster *et al*., 2007. In the picking process, the requested number of units of a product can be less than the number of units contained within a case (broken case picking), equal to or a multiple of the number of units within a case (full case picking), or as many units as on a pallet (pallet or bulk picking). When picking the products, an order picker may pick one customer order at a time (single order-picking), several customer orders at once (batch picking), or parts of several customer orders (zone-batch picking).

The *accumulation/sortation* of picked products into customer orders is a necessary activity if the orders are picked in batches or come from different storage areas. *Value-adding services*, such as labeling, sampling, kitting, (assembling sets of different products into kits), testing, and repacking may be offered to customize products to customer requirements. The *packing* activity includes checking, packing, and preparing a customer order for shipping. The *cross-docking* activity bypasses the storage and picking activities by transferring incoming products directly from the receiving docks to the shipping docks. The *shipping* activity involves sorting and staging customer orders in a designated dock door area ready to be loaded to the transport carrier and shipped to the customer.

Although warehouses share these typical warehouse activities and a general pattern of material flow, various types of warehouses can focus on different activities or requirements. The literature often distinguishes two types of warehouses based on their prime customers: *distribution centers* and *production warehouses* (Ghiani *et al*., 2004; Roodbergen, 2001; Van den Berg, 2012). A *distribution center* is a warehouse in which products from one or more suppliers are collected for delivery to a number of customers. Customer orders are typically composed of multiple order lines. The number of SKUs may be large, while the quantities per order line may be small, which often results in a complex and relatively costly order-picking process. In distribution centers, the focus is often on optimizing picking processes. A *production warehouse* holds raw materials, semi-finished products, and finished products. Raw materials and semi-finished goods are delivered to a nearby production plant, and finished goods are received from this plant and can be directly delivered from the warehouse to customers or to other warehouses. In production warehouses, products may be stored for long periods. This occurs, for example, when the procurement batch of incoming parts is much larger than the production batch, or when the production batch exceeds the customer order quantity of finished products. If a production warehouse holds finished goods for customers, typically the assortment is limited compared to an average distribution center. Ghiani *et al*. (2004) also classify warehouses by their ownership. A *private warehouse* is operated by the owner of the goods. A *third-party warehouse* is operated by a third-party logistics service provider (LSP) on behalf of one (*dedicated warehouse*) or multiple clients (*public warehouse*). A specific type of public warehouse is a self-storage warehouse that provides temporary storage at a centrally located facility for both private persons and small businesses (Gong *et al*., 2013).

1.2 Warehouse Management defined

This section defines Warehouse Management and Warehouse Management structure as used in this dissertation. Warehouse decisions can be subdivided into long-term, or strategic decisions and short-term, or tactical and operational decisions (Grant *et al.*, 2006). Long-term decisions include defining warehouse objectives supporting supply-chain goals, choosing the facility location, and determining warehouse size, its lay-out, and which technologies to adopt (Baker and Canessa, 2009; Ghiani *et al.*, 2004; Gu *et al.*, 2010). Long-term management decisions are considered fixed when making short-term management decisions. This dissertation focuses on short-term management decisions, and is referred to as Warehouse Management in this research. Warehouse Management operates within the framework defined by long-term management decisions.

In general, Warehouse Management has limited control over the external requirements (like timing, content, and required services of customer orders) imposed on the warehouse. Warehouses are often a part of a larger supply chain or network and as a member of the supply chain or network, the number of shipments demanded from a warehouse and the number of replenishments received at a warehouse are often affected or even controlled by supply chain coordination. Instead, Warehouse Management coordinates the material flow and the utilization of the resources to satisfy these requirements.

Warehouse Management can be subdivided into tactical and operational decisions. First, tactical decisions primarily address how to efficiently plan materials and resources for the short-term period (a week to a few months), within the constraints of the long-term decisions. Analogous to production operations management (e.g., Slack *et al.*, 2010), tactical plans assess the expected overall demand which the warehouse must meet in an aggregated manner; in other words, the expected order quantities are checked against total capacity of space, labor, and equipment, and are then translated into output and required processes. Tactical warehouse plans include inventory replenishment, storage location assignment, workload planning, and transport planning (Ghiani *et al.*, 2004). Inventory replenishment and storage location assignment plans determine which products should arrive and where these should be stored (Strack and Pochet, 2010). Workload and transport planning balance the expected workload over the available resources (labor, equipment, and transport).

Second, at the operational level, actual demand is assessed on a totally disaggregated basis (Ghiani *et al.*, 2004; Slack *et al.*, 2010): resources such as space, equipment (e.g., storage systems, retrieval systems, and internal transport equipment), storage units (e.g. pallets or boxes), labor, and instructions and procedures are allocated among the warehouse working orders. Operational decisions are narrow in scope and short-term focused (a few hours to a few days). At the operational level, many of the resources are given and it is difficult to make large-scale changes in resourcing. The goal of operational decisions is to optimize shop floor activities by avoiding any inefficiency in movement, storage, and information transfer, so that operational costs are minimized while customer orders are delivered in accordance with the expectations of the recipient (e.g., Alpan *et al.*, 2011; De Koster *et al.*, 1999; Roodbergen and De Koster, 2001a; 2001b; Rubrico *et al.*, 2008; 2011; Tsui and Chang, 1992).

All in all, Warehouse Management decisions are the outcomes of the planning and control, and shop floor optimization processes which link operational resources (space, equipment, and labor) with customer demand. Planning means taking the best decisions possible, in accordance with the predetermined objectives. Control means measuring the results, and possibly taking corrective actions when results are not in line with objectives. Shop floor optimization concentrates on the actual loading, sequencing, scheduling, and routing problems in a warehouse. It includes three distinct, though integrated, activities: loading resources, and sequencing and scheduling work orders. In this research, Warehouse Management is defined as follows:

Warehouse Management plans, controls, and optimizes the material flows and the use of the resources in a warehouse in an everyday context, with the objective of delivering goods in accordance with customer demands while minimizing operational costs (that is eliminating unnecessary work and unnecessary movement of people and equipment).

Van den Berg (1999) discusses managing warehouse operations by methods and procedures for tactical planning and shop floor optimization. Compared to Van den Berg (1999), our definition adds the management process *control* to warehouse management, where *control* means measuring outputs and taking corrective actions in response to deviations from plans. Gu *et al.* (2007) view managing warehouse operations as a list of decisions arranged according to warehouse operations: receiving and shipping, storage, and order picking. In their research, they develop a comprehensive overview of warehouse operation decision support models to guide practitioners in applying these models and identifying research opportunities. As such, they do not distinguish between tactical and operational decisions.

In this research, we focus on designing or structuring (the term "structuring" will be used from here on) Warehouse Management in order to obtain high warehouse performance. We view Warehouse Management as a planning and control system which uses inputs, such as people, products, and systems to create outputs, such as orders, customizations, and shipments. Structuring high performance Warehouse Management requires balancing multiple and sometimes conflicting requirements, and involves decisions on a large number of parameters and variables. Eventually, a Warehouse Management structure manifests itself in the way decisions are made about the material flow and the use of resources (space, equipment, and labor) in a warehouse in an everyday context. In this research, Warehouse Management structure is defined as follows:

Warehouse Management structure is the blueprint specifying the way in which Warehouse Management processes are organized. These processes consist of planning, controlling, and optimizing. In the optimizing process, inbound and outbound decision rules are used.

1.3 Warehouse management information systems

In recent years, Warehouse Management has been increasingly supported by computerized information processing systems, called Warehouse Management Systems (WMSs). A WMS is a complex software package that helps manage inventory, storage locations, and the workforce, to ensure that customer orders are picked quickly, packed, and shipped (Bartholdi III and Hackman, 2014; page 33). A WMS focuses on co-ordinating the processes within the warehouse (Verwijmeren, 2004). It supports the day-to-day operations in a warehouse.

Information technology has developed rapidly in the last few decades. Today, computer systems can take many simple or complicated decisions more quickly and more accurately than human operators. Information is available at the moment it is generated, and it is possible to analyze information and compare it with other relevant information before it is presented to the user. Timely and accurate information is a key for managing the increasing complexity of warehouses.

The primary aim of a WMS is to meet the objectives of Warehouse Management: to deliver high service levels and to maximize the use of space, equipment, and labor. It manages the flow of orders and processes by providing inventory and location control, and by directing labor (Mentzer, 2002). The system knows which goods are to be received and shipped, and supports management in determining which tasks need to be performed to process goods. Based on these decisions, it sends commands to human operators and automated material handling systems to execute these tasks (Ramaa *et al.*, 2012; Van den Berg, 2012). Furthermore, the system captures relevant data on orders, shipments, inventory, warehouse lay-out, warehouse staff, vehicles, customers, suppliers, and activities in the warehouse. This allows goods to be tracked and traced, and ensures the quality of warehouse activities (Van den Berg, 2012). Over the last decades, paperless storing and picking has become increasingly popular. In developed economies, new technologies such as radio frequency communication, order picking by voice, and pick-to-light systems have largely replaced paper picking lists (Connolly, 2008). These technologies enable real-time communication between the operator and the WMS, which has two major benefits for WMS applications. Firstly, these applications register all activities in greater detail and offer useful management information from available data, or use the data as input for planning and control policies. Secondly, they support decision-making based on the current situation (Van den Berg, 2012).

In general, information systems can either be tailored to a specific information problem of an organization, or they can be designed as standard software application packages to solve similar information problems for different organizations. Tailor-made systems are designed and built under supervision of the organization itself, while application packages are developed by a software vendor and purchased by organizations coping with similar information problems. With the changing role of warehousing, the development of standard software packages for Warehouse Management has taken flight. A large number of software vendors have developed standard WMSs, which can be configured to support the desired working methods (e.g., Locus of Centric Logistics Solutions, WICS WMS of WICS, or Sattstore WMS of Consafe Logistics). In general, they can also be modified to accommodate future process changes. Tailor-made software is built from scratch and is generally difficult to modify because it is molded for a specific situation. Nevertheless, standard software is not a panacea. If the standard WMS is unable to support the desired working methods, it may be necessary to amend the standard software with customized enhancements, or to design and develop a tailor-made system (Van den Berg, 2012).

The application packages can be divided into integrated systems that provide various functions (e.g., ERP) and best-of-breed systems that are each more specialized in a single function, such as a WMS or a TMS (Transport Management System). If a company chooses best-of-breed systems, it must integrate the separate systems via interfaces, which can be a complex and expensive task. In general, best-of-breed WMSs offer more sophisticated functions, although some ERP-vendors have been developing more sophisticated systems in recent years (Van den Berg, 2009; Gartner, 2013).

We can distinguish a hierarchy of information systems in operating a warehouse (Jacobs *et al.*, 1997; Van den Berg, 2012), see Figure 1.2. At the lowest level, programmable logic controllers (PLCs) control automated material handling systems such as conveyors, sorters, individual cranes, and AGVs. A PLC is a simple rugged computer device that reads input signals, runs control logic, and then writes output signals. For example, a PLC can control an automated crane or a roller conveyor. The PLC receives its input signals from sensors, such as optical sensors or barcode readers, or from the next level, the Material Handling Control System (MHCS). The PLC's output signals control, for example, the engines in the material handling system, or provide feedback to the MHCS. The collaboration of different automated material handling systems in a warehouse (e.g., a conveyor system in combination with an automated storage and retrieval system) is controlled by the MHCS which communicates with the PLCs.

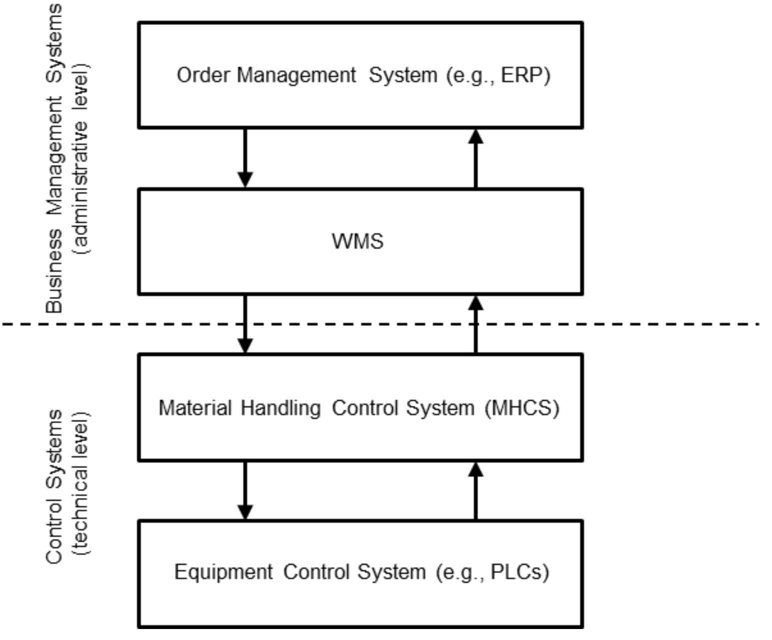

Figure 1.2 Hierarchy of information systems in a warehouse (adapted from Jacobs *et al.* (1997), and Van den Berg (2012))

At the next level, the WMS plans, controls, and optimizes all operations in the warehouse, and interfaces with the MHCS and the order management level. Some WMSs contain an integrated MHCS which allows the WMS to communicate directly with the equipment control system (PLC). This is also the case if a single automated material handling system is used. At the highest level, the order management system is responsible for stock management, registration of customer and purchase orders, and for financial management. All levels have to work closely together to maximize warehouse performance.

In summary, a WMS supports the planning, control, and optimization of all the activities in the warehouse, such as put-away, storage, and order-picking. The system records all activities in detail and generates considerable amounts of data, which provide valuable input for management information.

1.4 Warehouse performance

In general, warehouses aim at simultaneously reducing cost, increasing productivity, and improving customer responsiveness. Measuring warehouse performance provides feedback about how the warehouse performs compared to the requirements, or compared to industry peers. As such, it can also provide feedback on the adequacy and effectiveness of an implemented Warehouse Management structure.

Johnson and McGinnis (2011) discuss two types of warehouse operations performance criteria: financial (i.e., revenue related to cost) and technical (i.e., outputs related to inputs). They argue that technical criteria - based on output generated and resources consumed - tend to give a clearer picture of a warehouse's operational performance than financial measures, because warehouses typically do not generate revenues. The function of warehouses is to support the supply chain. As warehouses are often part of a larger supply chain or network, traditional operational performance objectives such as productivity, quality, delivery, and flexibility (Boyer and Lewis, 2002; Schmenner and Swink, 1998) are more applicable. Technical performance measurement in the warehouse industry includes cases or order lines picked per person per hour, picking or shipment errors rates, order throughput times, and percentage of orders with special requests (Forger, 1998; Van Goor *et al*., 2003). The problem with these key performance indicators (KPIs) is that they are not mutually independent and that each depends on multiple input indicators (De Koster and Balk, 2008). For example, the number of order lines picked per person per hour may be strongly influenced by system automation, assortment size, and warehouse size. To overcome this problem, in this dissertation, Data Envelopment Analysis (DEA) (Charnes *et al*., 1978) is employed. DEA is capable of simultaneously capturing all relevant inputs (resources) and outputs into a single score of performance. This way, DEA measures the relative performance of a set of comparable decision-making units (e.g., warehouses).

Approaches for performance evaluation include simulation, analytical models, and benchmarking (Gu *et al*., 2010). Simulation models evaluate the performance of the warehouse operation over time. They greatly depend on implementation details, and are less amenable to generalization. Analytical models are theoretical models of the existing situation and provide insights into the behavior of warehouse operations, such as throughput, average response time, fill rate, costs, and utilization of space, equipment, and human resources. Benchmarking stems from the search for industry best practices which lead to superior performance (Camp, 1989). Benchmarking forces a warehouse to evaluate and compare its performance to similar warehouses. The critical self-examination during the benchmarking process helps warehouse managers to identify their own inefficiencies and to establish realistic goals for improvement. Where simulation and analytical models measure performance internally using historical data and predictions for the future, benchmarking compares performance externally with data from industry peers.

1.5 Research objective

With the increasing pressure on warehouses to improve overall supply chain performance, the development and implementation of (standard) WMSs have grown considerably. However, selecting a (standard) WMS for a specific warehouse is risky business (Frazelle, 2002). In general, the literature points out that the form and operation of a business information system should be dictated by the management system it supports (Chan and Reich, 2007; Cragg *et al.*, 2007; Henderson and *et al.*, 1996; Van Goor *et al.*, 2003) or at least should be developed simultaneously. This means that insight is needed into how Warehouse Management is structured before a WMS can be selected.

The literature on planning, controlling, and optimizing warehouse operations, i.e., Warehouse Management, has been dominated by analysis-oriented research on isolated subproblems (Baker and Canessa, 2009; Dallari *et al.*, 2009; Gu *et al.*, 2007; 2010; Rouwenhorst *et al.*, 2000). Analysis-oriented research concentrates on developing quantitative methods to model isolated decision-making situations in warehouses in order to achieve some well-defined objectives. In the literature, a range of decision support models and solution algorithms have been established to solve different warehouse planning and optimization problems, but selecting and integrating these models and solutions for a specific warehouse is difficult (Gu *et al.*, 2007; Rouwenhorst *et al.*, 2000). Gu *et al.* (2007) and Rouwenhorst *et al.* (2000) state that a model to guide warehouse operations is lacking and they present a structured overview of the various warehouse operations planning models available in the literature. However, Gu *et al.* (2007) conclude that there continues to be a need for research focusing on the management of warehouse operations, where the different processes in the warehouse are considered jointly, the problems are placed in their dynamic nature, and multiple objectives are considered. In this dissertation, we seek to develop a generic theoretical model for structuring Warehouse Management, where Warehouse Management is considered as a coherent whole of decisions rather than a combination of separate warehouse operations planning models. The generic theoretical model gives relationships between distinctive characteristics of a warehouse (complexity and uncertainty) and structure aspects (planning, control, and optimization). It indicates how Warehouse Management should be structured in different contexts. Such a model offers a starting point to develop a comprehensive framework for warehouse planning and control that aims at integrating various models and algorithms addressing well-defined isolated problems in warehouses. Such a model also constitutes a useful starting point for the development of a framework for functional design models of warehouse management information systems. Thus, insight into structuring Warehouse Management not only helps in selecting and evaluating (standard) warehouse management information systems, but also in designing and evaluating the proper levels of planning, control, and optimization of warehouse operations. This dissertation is a step towards understanding how to structure high performance Warehouse Management, with the aim to build theories on structuring Warehouse Management and to help select and evaluate warehouse management information systems. Therefore, the *objective* of the research presented in this dissertation is:

To develop and test a theoretical model for structuring high performance Warehouse Management.

To reach this objective, this research adopts a contingency perspective (Sousa and Voss, 2008), meaning that Warehouse Management structure must be adapted to the warehouse's situation in order to attain high performance. This perspective suggests that there is no "one structure fits all contexts", but that Warehouse Management structure is context dependent; a specific Warehouse Management structure may perform differently in different contexts. Therefore, warehouses should adapt their Warehouse Management structure to maintain fit with changing contextual factors. Failure to attain a proper fit between structure and environment results in inferior outcomes (typically, the outcomes are some aspects of performance). Sousa and Voss (2008) state that the operations management field is strongly rooted in a contingency paradigm, and that contingency theory (e.g., Donaldson, 2001) can be a very useful theoretical lens to view operations management issues, in particular, in areas where operations management theory is less well developed. To achieve the objective of the research, the following main research question needs to be answered:

How should Warehouse Management be structured to attain high warehouse performance?

As the functional requirements of the warehouse management information system follow from the Warehouse Management structure, the main research question of this dissertation focuses primarily on structuring Warehouse Management. As such, the warehouse management information system is a reflection (or implementation) of the Warehouse Management structure.

Research anchored on a contingency approach examines relationships between contextual variables, the use of practices (or structures), and the associated performance outcomes (Sousa and Voss, 2008). Therefore, we first aim to identify key characteristics of a warehouse (e.g., number of order lines processed per day) and its relevant environment (e.g., demand unpredictability) that drive Warehouse Management structure. Next, in order to examine the relationship between key characteristics and structure, we determine the measurable dimensions of Warehouse Management structure (e.g., planning extensiveness). Because the warehouse management information system is an important aspect of Warehouse Management, we also examine the relationship between contextual variables and the warehouse management information system. We characterize the warehouse management information system with respect to Warehouse Management structure by the level of customization (specificity) to the operational and organizational needs of the warehouse. Thereafter, we research the relationships between the identified key characteristics and the dimensions of Warehouse Management structure, and between the identified characteristics and the specificity of the related warehouse management information system. Finally, to answer the main research question on how Warehouse Management should be structured to attain high warehouse performance, we explore the impact of the relationships between characteristics and structure on warehouse performance. In sum, in order to answer the main research question by applying a contingency perspective, we aim to answer the following six research questions:

1. What characteristics of a warehouse and its relevant environment can be identified in relation to warehouse planning and control? (Chapter 2 and 3)
2. What dimensions of Warehouse Management structure can be identified? (Chapter 3)
3. How can a warehouse management information system be characterized with respect to warehouse planning and control? (Chapter 3)
4. How do warehouse characteristics affect Warehouse Management structure and the related warehouse management information system? (Chapter 2 and 3)
5. How can warehouse performance be operationalized in order to serve as a means to judge the adequacy of an implemented Warehouse Management structure? (Chapter 4)
6. How does fit between Warehouse Management structure and warehouse characteristics impact warehouse performance? (Chapter 4)

The research of this dissertation is of importance to science as well as to society, in particular, to warehouse organizations. The contribution to science is to expand the knowledge of warehouse planning and control, and the related warehouse management information system. Warehouse organizations can benefit from the knowledge obtained by this research to better structure Warehouse Management, and to select and evaluate warehouse management information systems.

1.6 Research design and methods

This research focuses on relationships between warehouse characteristics and Warehouse Management structure, and their effects on warehouse performance. The first research question on identifying key warehouse characteristics, will be answered by first conducting an exploratory study to understand the empirical complexity of Warehouse Management, and then by reviewing the literature. Exploratory studies can help to identify the concepts and the basis for measurement, and are very appropriate for early stages of research (Malhotra and Grover, 1998). Exploratory research with many unknown elements can be performed by means of a case study design, using either a single case study or multiple case studies (Yin, 2003). We conduct a multiple case study, because we aim to explain the variation in managing warehouse operations by key warehouse characteristics. In general, case studies help the researcher to understand why certain characteristics or effects occur, or do not occur. In the multiple case study, warehouse management information systems (WMSs) are considered as the implementation of Warehouse Management structures in practice. The Warehouse Management structure is represented by the related WMS. Therefore, a case in this study consists of a warehouse and its WMS. We develop propositions linking warehouse characteristics to Warehouse Management structure, and identify warehouse characteristics that influence the choice of the warehouse management information system (i.e., standard or tailor-made).

The multiple case study is followed by a literature study to further identify key warehouse characteristics (research question 1), and to decompose Warehouse Management structure into its constituent elements (research question 2). The literature on production management is chosen as a main starting point because of its similarity to Warehouse Management and in particular because it has quite an elaborative history. It may therefore contain useful insights and perspectives to inspire research on Warehouse Management structure. In addition, we use interviews with warehousing experts to identify dimensions of Warehouse Management structure. We also study the literature on information systems in general and warehouse management systems (WMSs) in particular to characterize warehouse management information systems (research question 3).

We conduct an explanatory study using a survey to answer the fourth research question on the effects of the warehouse characteristics on Warehouse Management structure and on the related warehouse information system. Explanatory research implies that the research is intended to explain, rather than simply describe, the phenomena studied (Maxwell and Mittapalli, 2008). We use the survey method because surveys provide a broad view of a phenomenon, and hypothesized relationships between variables can be tested by applying statistical techniques. The theoretical basis of this study is built on the propositions drawn from the multiple case study in combination with a review of the literature. First, hypotheses are formulated on the relationship between warehouse characteristics and the dimensions of Warehouse Management structure, and second, on the relationship between warehouse characteristics and the warehouse management information system characterization. The hypotheses are tested in a survey among 215 warehouse managers.

The fifth research question on defining and operationalizing warehouse performance is answered by conducting a literature review. In this dissertation, multi-factor performance and benchmarking are used to compare warehouses based on Data Envelopment Analysis

(DEA) calculations. Other authors such as Hackman *et al.* (2001), Ross and Dröge (2002; 2004), McGinnis (2002), and De Koster and Balk (2008) have also used DEA in warehouse benchmarking. We conduct another explanatory study to answer the sixth research question on the impact of fit among Warehouse Management structure and warehouse characteristics on warehouse performance. Hypotheses are formulated and tested in a survey among 111 warehouses (distribution centers).

1.7 Outline of this dissertation

This chapter has introduced the research described in this dissertation. It has set out the motivation for this research and has described the research problem and methodologies. Furthermore, the key concepts of the research have been introduced. The remainder of the dissertation is structured along four chapters, two of which have been published as papers in academic journals. Chapter 2 presents the results of the multiple case study to gain insight into the context of Warehouse Management structure and the various constructs. Chapter 2 forms the basis for answering the first research question. It was published in the International Journal of Physical Distribution & Logistics Management (Faber *et al.*, 2002). Because warehousing and especially warehouse technology, including warehouse management information systems, have changed over the last decade, Chapter 2 concludes with an up-to-date commentary on the findings of the paper at the time. In Chapter 3, the warehouse characteristics, the dimensions of Warehouse Management structure, and the related warehouse management information system characterization are further developed using the literature. The impact of the warehouse characteristics on Warehouse Management structure and on the related information system is examined, using a comprehensive questionnaire. Chapter 3 was published in the International Journal of Operations & Production Management (Faber *et al.*, 2013). Chapter 4 tests how the fit among Warehouse Management structure and warehouse characteristics affects warehouse performance. This chapter concludes with a model for structuring high performance Warehouse Management. Finally, Chapter 5 concludes this dissertation by evaluating the research, drawing conclusions on the research questions, and giving directions for further research. Figure 1.3 presents the outline of this dissertation.

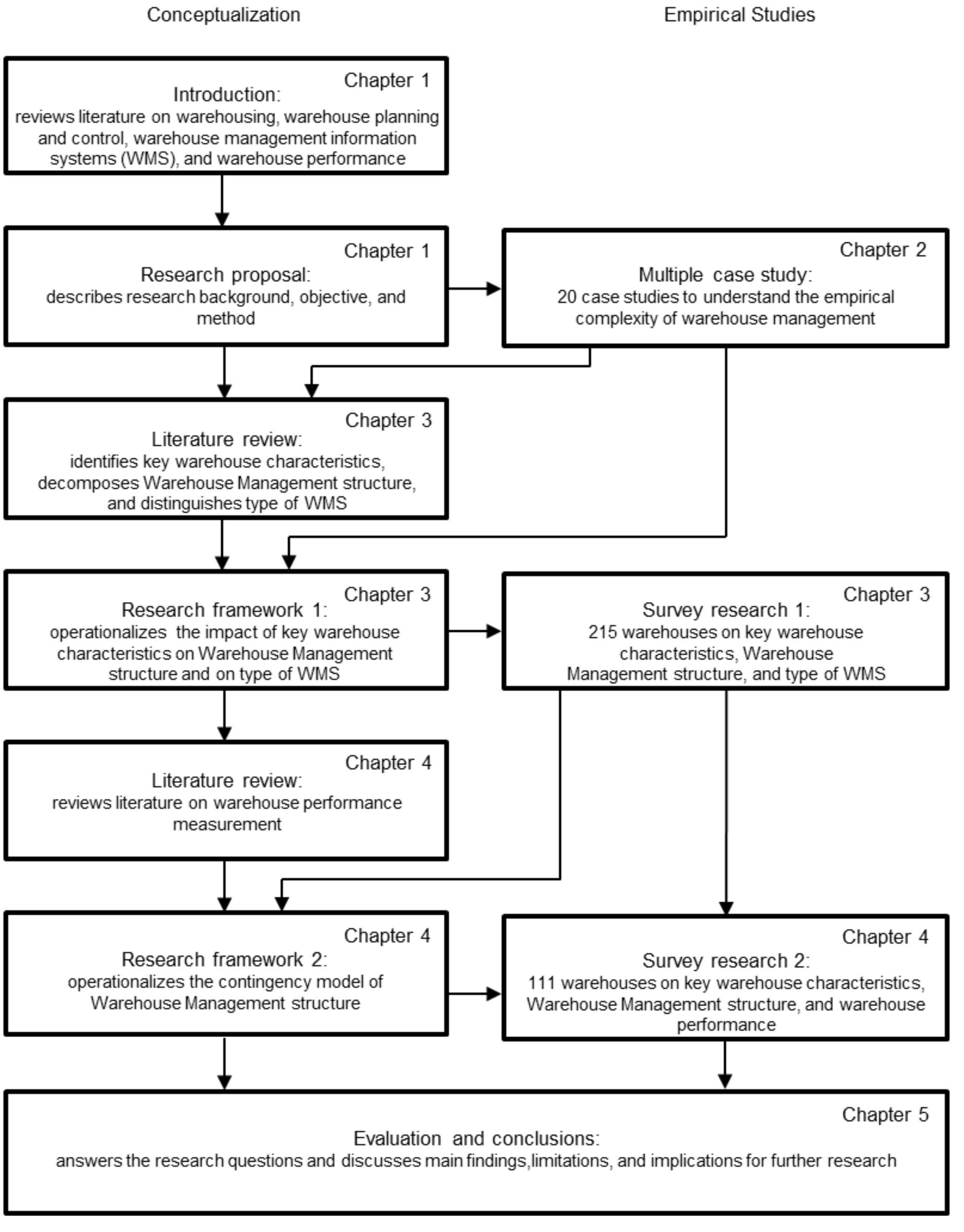

Figure 1.3 Outline of this thesis

1.8 Declaration of contribution

This section states the contribution of the author to the different chapters of this dissertation and also acknowledges contributions of other parties, where relevant.

Chapter 1: The majority of the work in this chapter has been done independently by the author of this dissertation. Feedback from the promoters and other members of the doctoral committee has been received and included.

Chapter 2: The author of this dissertation is a co-author of the paper[1] included in sections 2.2 to 2.6 of this chapter. The paper was mainly written by the third author. The author of this dissertation formulated the research question, conducted the data analysis, and interpreted the findings. The main source of data consisted of case descriptions made up by student groups of the Erasmus University who visited several warehouses in the Netherlands as part of a course for a master in Supply Chain Management. In addition, the author of this dissertation collected case study descriptions of these warehouses available in (Dutch language) trade journals. The case selection was done by one of the promoters. The work of the update study on the findings and conclusions of the paper, included in section 2.7 and 2.8, has been done independently by the author of this dissertation. Feedback from the promoters has also been implemented.

Chapter 3: The author of this dissertation is the first author of the paper[2] included in Chapter 3, and the promoters are the two co-authors. The author formulated the research question, performed the literature review, developed the hypotheses, designed the questionnaire, collected the data with the help of students of the Erasmus University, conducted the data analysis, interpreted the findings, and wrote the paper. Obviously, at several points during the process, each part of this paper was improved by implementing the detailed feedback provided by the promoters. Especially in the data analysis and interpreting the findings phases of the research, feedback and assistance was given by the promoters.

Chapter 4: The author of this dissertation is the first author of the working paper[3] included in Chapter 4, and the promoters are the two co-authors. The author formulated the research question, performed the literature review, developed the hypotheses, conducted the data

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[1] Faber, N., De Koster, M.B.M., and Van de Velde, S.L. (2002), "Linking warehouse complexity to warehouse planning and control structure: an exploratory study of the use of warehouse management information systems", International Journal of Physical Distribution & Logistics Management, Vol. 32 No. 5, pp. 381-395.

[2] Faber, N., De Koster, M.B.M., and Smidts, A. (2013), "Organizing warehouse management", International Journal of Operations and Production Management, Vol. 33 No. 9, pp. 1230-1256.

[3] Faber, N., De Koster, M.B.M., and Smidts, A. (2015), "Survival of the fittest: the impact of fit between warehouse management structure and warehouse characteristics on warehouse performance", Working paper, Erasmus University Rotterdam, Rotterdam, June 2015 .

analysis, interpreted the findings, and wrote the paper. Prof. dr. B.M. Balk assisted in understanding the mathematical method of Data Envelopment Analysis. At several points during the process, each part of this chapter was improved by implementing the detailed feedback provided by the promoters. Especially, the promoters provided feedback and assistance at the data analysis and interpreting findings phases of the research. Also, feedback from other members of the doctoral committee has been included.

Chapter 5: The majority of the work in this chapter has been done independently by the author of this dissertation. Feedback from the promoters and other members of the doctoral committee has been received and included.

2

Linking warehouse complexity to warehouse planning and control structure: an exploratory study of the use of warehouse management information systems[4]

2.1 Outline Chapter 2

In this chapter, we present the paper "Linking warehouse complexity to warehouse planning and control structure: an exploratory study of the use of warehouse management information systems", published in the International Journal of Physical Distribution & Logistics Management (Faber *et al.*, 2002). This research was conducted to gain empirical insight into the nature of complexity of Warehouse Management and to identify key warehouse characteristics affecting Warehouse Management structure. In the research, Warehouse Management structure is represented by the implemented WMS software. Since warehouse technology, including WMS software, has changed over the last decade, follow-up research has been conducted to update the findings. That is, the literature has been reviewed, a WMS expert has been interviewed, and a larger and more recent sample has been used to update the findings. This chapter has the following structure. Sections 2.2 to 2.6 are based on the original paper, section 2.7 includes the contemporary update, and section 2.8 gives a short reflection on the first research question of this dissertation.

2.2 Introduction

As a result of global competition and supply chain concepts, including a focus on integral inventory control, warehousing has become a critical activity in the supply chain to outperform competitors on customer service, lead-times, and costs (De Koster, 1998). Warehouses are now (re-)designed and automated for high speed, that is, high throughput rate, and high productivity, to reduce order processing costs. More and more, they change to flow-through warehouses (Harmon, 1993), where products remain for a short period of time only.

Timely and accurate information about products, resources and processes are essential to operationalize a planning and control structure that effectively and efficiently achieves the high performance of warehouse operations required in today's marketplace. A warehouse management information system (WMS) provides, stores, and reports the

[4] Faber, N., De Koster, M.B.M., and Van de Velde, S.L. (2002), "Linking warehouse complexity to warehouse planning and control structure: an exploratory study of the use of warehouse management information systems", International Journal of Physical Distribution & Logistics Management, Vol. 32 No. 5, pp. 381-395.

information necessary to efficiently manage the flow of products within a warehouse, from time of receipt to time of shipping. Some of the benefits that a WMS can provide include increased productivity, reduction of inventories, better space utilization, reduced errors, support of customer EDI requirements, and value added logistics compliance programs. Not surprisingly, the Gartner Group recently stressed that a warehouse without a WMS puts itself at a competitive disadvantage.

Up to about ten years ago[5], nearly all WMSs in use were tailor made. With the changing role of warehouses, more and more standard WMSs are becoming available: in the USA, there are at least 100 different WMSs (Randall, 1999), and in the Benelux, where 55 per cent of all Japanese and US owned centralized European distribution centers are located, there are at least 50 (Dusseldorp, 1996). Furthermore, the number of implementations of standard WMSs and the offered functionality, while still limited, is growing fast; the number of implementations grew by 30 per cent in 1998, and this growth rate is expected to continue in the near future (Dohmen, 1998).

The Gartner Group recently pointed out that standard WMSs offer many advantages over tailor-made systems: they are less costly in acquiring, implementing, and maintaining, have shorter implementation times, and are proven software solutions. As always, standard software has its limitations; whichever WMS is selected to achieve the best possible fit with the warehousing processes, a WMS imposes its own logic on a warehouse's operations and organization. Implementing a standard WMS therefore remains largely making compromises between the way a warehouse wants to work and the way the system allows the warehouse to work. In many instances, these compromises are minor and have no or only a small negative effect on the performance of the warehouse. In some instances, however, these compromises would lead to a significant degradation of warehouse performance, and in these cases it would be better to acquire a customized WMS, tailored to the operational and organizational needs of the warehouse. The wrong choice of WMS, that is, standard or tailor-made, may therefore lead to a competitive or a cost disadvantage. The key question is then, of course, whether a warehouse should implement and adopt a tailor-made or standard WMS. This practical question was the main motivation for our research study.

To answer the question, we need to understand the relationship between the construct warehouse complexity and the construct warehouse planning and control structure. In particular, the construct warehouse complexity cannot be observed directly, but it includes many measurable and non-measurable aspects. Warehouse complexity refers to the number and variety of items to be handled, the degree of their interaction, and the number, nature, i.e., the technologies used, and variety of processes (including the number and variety of orders and orderliness and the types of customers) necessary to fulfill the needs and

[5] Please note that this research was conducted in 1999. WMSs and the WMS market have changed considerably over the last decade. In section 2.7 an update is given.

demands of customers and suppliers. Warehouse planning and control structure refers to the management functions that plan, direct, coordinate, and control the flow of goods through the warehouse, from the time of receiving to the time of shipping. It is very strongly related to the WMS in use. A standard WMS is a realizer of a generic, standardized planning and control structure – the WMS leads and the planning and control structure follows. With a tailor-made WMS it is the other way around; the planning and control structure leads and the tailor-made WMS follows; in this case, the WMS is an enabler of a tailor-made planning and control structure. We stipulate, therefore, that the WMS in use is the predominant aspect of a warehouse's planning and control structure.

Warehouse complexity affects the planning and control structure through the comprehensiveness of the work to be done. In highly complex warehouses, feeding organizational actors with the right type of information and knowledge at the right time is difficult. Nonetheless, a complex warehousing operation requires a control structure that has a great deal of information, data, and knowledge about products, processes, customers, and resources readily available.

Since virtually nothing is known about the relationship between warehouse complexity and planning and control structure and there is no a priori theory, we carried out an exploratory field study to collect data and information about these two constructs in different types of warehouses of varied complexity with different planning and control structures. In view of the central role of the WMS in the warehouse planning and control structure, we put much emphasis on the implementation, adoption, day-to-day use, maintenance, and after-sales service of the different WMSs. Clearly, the intent of the study was not to collect data and information to test and validate hypotheses, but to first develop an understanding of the empirical reality. The next step was to analyze the data and the information gathered. This empirical base led to the building of a theory linking warehouse complexity and warehouse planning and control structure.

The organization of this paper is as follows. In section 2.3, we discuss the scope, generic functionality and a classification of standard WMSs. In section 2.4, we describe our research methodology, including the sample selection, the research structure, and data collection approaches. Section 2.5 constitutes the heart of the paper, where we formulate our propositions. Section 2.6 concludes the paper with directions for future research.

2.3 WMSs

In this section, we discuss the scope, the common functionality, and the classification of WMSs.

2.3.1 The scope of WMSs

A warehouse management system (WMS) provides the information necessary to manage and control the flow of products in a warehouse, from receiving to shipping. Since a warehouse is a node in the flow of products serving or steered by other business functions, such as purchasing and sales, a WMS must communicate with other management information systems about issues including order acceptance, procurement, production control, finance, and transportation. Note that more and more of these systems are integrated in a single comprehensive so-called enterprise resource planning (ERP) system. To control material handling and moving within a facility, a WMS also has to communicate with technical systems, like AS/RS control, PLC and radio frequency systems. Figure 2.1 shows the interactions between a WMS and its environment.

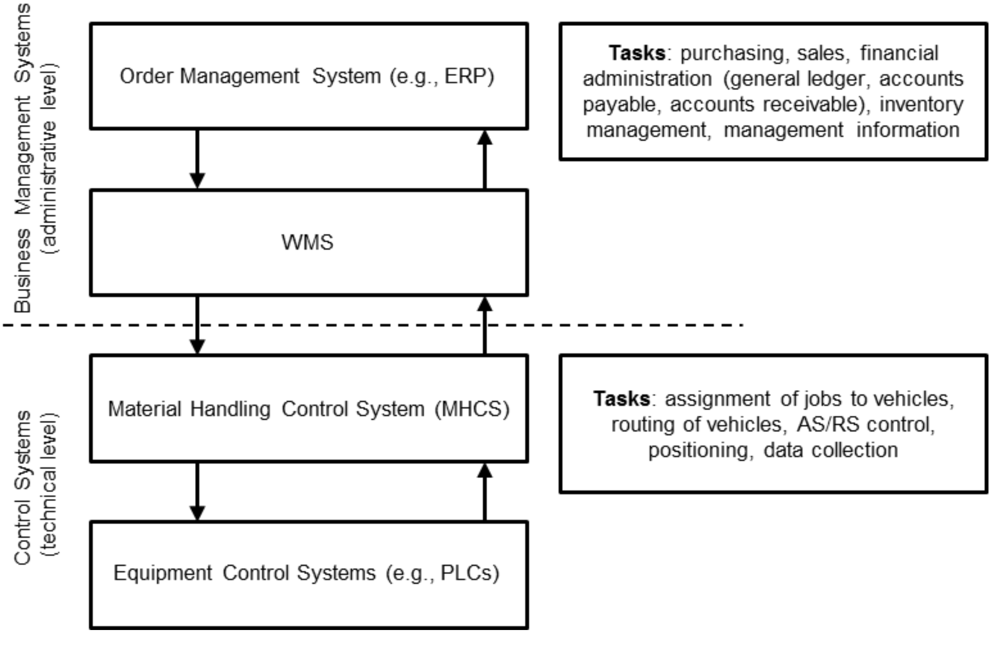

Figure 2.1 WMS in relation to other management information and technical systems

There is a clear difference in functionality and scope between a WMS and an ERP system. The latter has a focus on planning over a horizon of several weeks and covers virtually all functionality in the organization. A WMS is a short-term planning, shop-floor control, system for warehousing and cross-docking (sometimes transport) activities only. The similarity in information, planning, and control requirements of so many warehouses triggered and stimulated the development of standard WMSs. These standard WMSs were often developed from a custom-made system for one specific warehouse, and over time more and more features and functionality were added to meet the needs of other warehouses. The market of standard WMSs is still young and immature, and the number of implementations of any standard WMS is quite limited. Research carried out by the Warehousing Research and Education Council (WERC) among 200 warehouse and IT managers in the USA showed that no standard WMS has a market share of more than 10 per cent and that the top eight have a total market share of less than 40 per cent (McGovern, 1999; Gurin, 1999). Not surprisingly, the after-sales service is often quite meager, leaving room for improvement.

In contrast to a standard WMS, a tailor-made WMS is tailored to the specific requirements and problems of a specific warehouse. The development of such systems is usually outsourced, but sometimes it is carried out by the organization's own information technology (IT) department, possibly in cooperation with a software developer.

2.3.2 Functionality

Jacobs *et al*. (1997) classify the warehousing functions of a state-of-the-art WMS in three clusters:

(1) inter-warehouse management functions
(2) warehouse management functions
(3) warehouse execution control functions

Baan, an enterprise resource planning software developer and vendor, has adopted this classification; see Baan (1998). For a brief discussion of the functions in each cluster, we refer to the Appendix A.

2.3.3 Classification of WMSs

Following Dusseldorp (1996), we distinguish three types of WMSs:

(1) *Basic WMSs*. A basic WMS supports stock and location control only. The goods can be identified by using scanning systems. Furthermore, the system determines the location to store the received goods and registers this information. Storing and picking instructions are generated by the system and possibly displayed on RF-terminals. The warehouse management information is simple and focuses on throughput mainly.
(2) *Advanced WMSs*. 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.

(3) *Complex WMSs*. A complex WMS can optimize the warehouse or group of warehouses. Information is available about where each product is (tracking and tracing), where it is going to and why (planning, execution and control). To optimize the warehouse, different complex storage strategies, replenishment strategies, cycle counting strategies, and picking strategies are used. A complex WMS is able to interface with all kinds of different technical systems (AS/RS, sorter, AGV, RF, robots, and data collection systems). Furthermore, a complex system offers additional functionality, such as transportation planning, dock door planning, value added logistics planning, and sometimes simulation to optimize the parameter setting of the system and to optimize the warehouse operations as a whole.

2.4 Research methodology

2.4.1 The sampling procedure

In the period 1997-1999, we analyzed the implementation, adoption, use and maintenance of recently implemented WMSs at 20 different, modern warehouses in the Benelux. All WMSs had been implemented between 1992 and 1999. Eight warehouses used tailor-made WMSs, whereas the other 12 warehouses used eight different standard WMSs. These 12 warehouses obtained their WMSs through the largest vendors of standard WMS software in the Benelux. In order to have a variety of warehouses in our sample, we included mail order warehouses, manufacturing warehouses, end product (both consumer and industrial products) wholesalers, food retailers, and logistic service providers (both with public and dedicated warehouses). Furthermore, we selected the warehouses for which case study descriptions, albeit sometimes superficial, were available in (Dutch language) trade journals.

It is not likely that our sample of warehouses is fully representative of the entire warehouse population, although we included a wide variety of warehouses in our sample. Furthermore, our sample was biased towards larger, more modern and more innovative warehouses, for which case descriptions have appeared in trade journals. However, no sample can be declared to be entirely representative without knowing the entire population, which is an impossible task. Furthermore, the type of bias here may make the empirical research more valuable, since it concerns warehouse forerunners, not laggards.

2.4.2 Research principles and assumptions

Focusing on the initial choice between a standard and a tailor-made WMS, we assume that all standard WMSs are of the same quality and all tailor-made WMSs are of the same quality. Hence, we do not explicitly take into account the differences among the WMSs. In practice, quality varies, and one WMS system is simply more suitable for one type of warehouse than another. This means that there might be another bias in our empirical data as a result of poor WMS vendor or WMS developer selection by the companies; after all, certain problems might not have occurred with a different WMS. In our sample, this potential bias did not seem to be present. All people interviewed, but two, were content or very content with their WMSs. The high degree of satisfaction is likely explained by the big effort put in making the software, and thereby the warehouse operations, a success once a WMS was selected. After all, once a WMS has been selected, there is hardly a way back. The two companies that were not content were nonetheless thinking of acquiring and implementing new WMSs. Also, we explicitly told our respondents that our study was not about the selection of a WMS vendor or developer. In our questions about the implementation, the performance, and the day-to-day use of the WMS, we focused on generic aspects of standard or tailor-made software, not on specific aspects of the WMS system. We therefore believe, that this type of bias, played only a minor role in our analysis.

Finally, we made no attempt to carry out a cost/benefit analysis of investments in standard or tailor-made IT on the basis of traditional investment appraisal techniques, such as return on investment, internal rate of return, net present value, and payback approaches; see, for instance, Hochstrasser and Griffiths (1991), Willcocks (1994) or Trunk (1998). Not only is it problematic to evaluate information systems, because of their intangible benefits, it is also not clear which of these traditional appraisal techniques is the most appropriate. Our primary appraisal technique was the measurement of the fit between the type of WMS and the organizational needs; see also Kannellis *et al*. (1997). This fit was determined by the degree of management satisfaction with the system with respect to the implementation, functionality, daily use, and the service received.

2.4.3 Information and data collection approach

For each warehouse, we obtained our data and information from three sources: in-depth interviews with the logistics or operations manager; interviews with the WMS vendor or developer; and case study descriptions in trade journals, if available. A logistics or operations manager is usually a suitable respondent, in view of his/her involvement in the implementation and use of the WMS and his/her broad perspective of the performance of warehousing operations. The different information sources enabled some form of triangulation to cross-validate the results.

In our in-depth structured interviews, we focused on two types of data and information: about the planning and control structure, and particularly about the WMS system in use; and about the products, processes, resources, storage and handling technologies, and the lay-out, being aspects of warehouse complexity. The interviews were held using a questionnaire with open questions about the planning and control structure and the warehouse complexity.

With respect to the planning and control structure in use, we focused on five aspects:

(1) *The organization structure*. What is the extent of decentralization, the type of formal control (a priori performance measurement), the number of layers in the organization, and the spans of control?
(2) *The type of WMS*. Is it tailor-made, largely standard, or hybrid? Is it basic, advanced, or complex? How is it interfaced with other information systems? We call a WMS ``standard'' if, besides interfaces (which are nearly always tailor-made), less than 20 per cent of the functionality is tailor-made.
(3) *The implementation of the WMS*. Information was gathered about the implementation methodology, if any, the implementation lead time, and the level of satisfaction.
(4) *Daily use of the system*. Here, we focused primarily on the fit between the WMS and the warehouse processes.
(5) *Maintenance and after-sales service*. Maintenance and after-sales service concerns the quality of the vendor's or developer's helpdesk support; the warranty agreements; the documentation; and the implementation of new releases and upgrades.

With respect to warehouse complexity, we specifically focused on:

- *The type of warehouse*. Is it a privately owned, public or dedicated warehouse?
- *The lay-out, and size of the warehouse*. This includes, for instance, the size of the warehouse in square meters but also the number of workers on the shop floor.
- *The warehouse (hardware) systems*. Here we focused on equipment and systems for moving, handling, storing, and retrieving goods, such as robots, automatic storage and retrieval systems, palletizers, conveyors, overhead conveyors, order picking trucks, RF systems, pallet racks, shelf racks, flow racks, block stacks and carousels. We also checked whether there were special storage conditions, for instance, concerning temperature and humidity.
- *The product-market combinations*. This concerns the types of products processed by the warehouse (sizes, weights, storage and handling conditions, customs aspects, etc.), the number of stock-keeping units (SKUs), the characteristics of the markets serviced by the warehouse, the maximum and average number of daily orders and order lines, the variety in order handling, and the types of customers.
- *Processes*. This information is about the nature as well as the size of the processes: the storage strategy; the order batching and picking strategy (if any);

special processes, such as cross-docking, value-added logistics, customs clearance, and the handling of returned products.

2.5 Results[6]

In this section, we report on our analysis of the empirical data obtained from the warehouses involved in our exploratory study. In section 2.4.1, we report on our most notable and striking empirical findings concerning WMSs. These are formulated as generalizations and do not have explanatory theories to explain them. For this reason, they are not further discussed.

In section 2.4.2, we present a theory, and formulate four propositions, that link the construct warehouse complexity to the construct warehouse planning and control structure. This subsection is the heart of our paper, and includes our main contribution.

2.5.1 Empirical generalizations

Our main empirical findings concerning the use of WMSs are:

- *The WMS market is quite immature*. It appeared that the number of implementations of any WMS is quite limited.
- *The quality of after-sales service is poor*. Many warehouse managers complained about the reachability and quality of the helpdesk; for instance, the business hours of one warehouse had no overlap with the opening hours of the WMS helpdesk in the USA. New releases were a source of big and unexpected problems, too. They often contain (too) many bugs and even miss crucial functionality or features that were available in the previous versions. Finally, there are often disagreements about the warranty agreements and service contracts. Of course, these problems have everything to do with the relative immaturity of the WMS market.
- *The implementation of a tailor-made WMS is longer, more problematic, and more costly than that of a standard WMS*. Although the implementation of standard WMSs may take up to six months (Cooke, 1997), tailor-made WMSs take even longer.
- *The use of both standard and tailor-made WMSs is in general successful*. Only two warehouses reported that their WMS was unsuccessful. This is in line with the earlier mentioned WERC research, where 10 per cent of the respondents indicated that their WMS was a failure.

[6] Please note that these results relate to research conducted in 1999. WMSs and the WMS market have changed considerably over the last decade. In section 2.7 an update on these results is given.

2.5.2 Warehouse complexity vs warehouse planning and control structure

As pointed out earlier, the construct warehouse complexity refers to the number and variety of items to be handled, the degree of their interaction, and the number, nature, and variety of processes. It affects the planning and control structure through the comprehensiveness of the work to be done. In highly complex warehouses, feeding organizational actors with the right type of information and knowledge at the right time is difficult. Nonetheless, a complex warehouse requires a planning and control structure that has a great deal of information, data and knowledge about products, processes, customers, and resources readily available.

The number of order lines processed per day and the number of SKUs are both measurable aspects of warehouse complexity. The number of SKUs is both an explicit and an implicit warehouse complexity measure. Implicit, because it largely determines the variety in storage and handling technologies and processes; the higher the number of different SKUs stored, the more variation in physical storage and handling systems will be needed (think of different systems for fast and slow moving items, or for large and small items), also leading to a greater variation in handling processes and storage and handling technologies. The number of order lines is also an explicit and an implicit measure of warehouse complexity. The number of order lines is related to the number of customer orders. If the number of order lines increases, customer orders are likely to show a greater variety, which also means a greater variety in areas where the corresponding items have to be picked and ways the items have to be handled, packed or shipped. Hence a greater variety in processes and technologies.

Figure 2.2 presents a diagram which shows the position of each warehouse on the basis of the number of SKUs and the number of order lines. The warehouses with a standard WMS are numbered S1 through S12; the warehouses with a tailor-made WMS are numbered T1 through T8. Product diversity, in terms of size, weight, storage conditions, packaging, slow/fast movers, expiry date, together with the number of SKUs increase along the supply chain; production warehouses usually hold a few hundred to a thousand products, while distribution centers may hold ten thousands and more. The same holds for the daily number of order lines that have to be picked and shipped from the warehouse. Not surprisingly, distribution centers are usually more complex than production warehouses.

Figure 2.2 suggests that two indicators only; namely, the number of daily order lines and the number of SKUs are sufficient determinants of warehouse complexity. This is quite surprising, as we initially expected that more factors would play a role. Figure 2.2 and our explanation of the connection between warehouse complexity on the one hand and the number of order lines processed and the number of SKUs on the other hand, support Proposition 1 (*P1*).

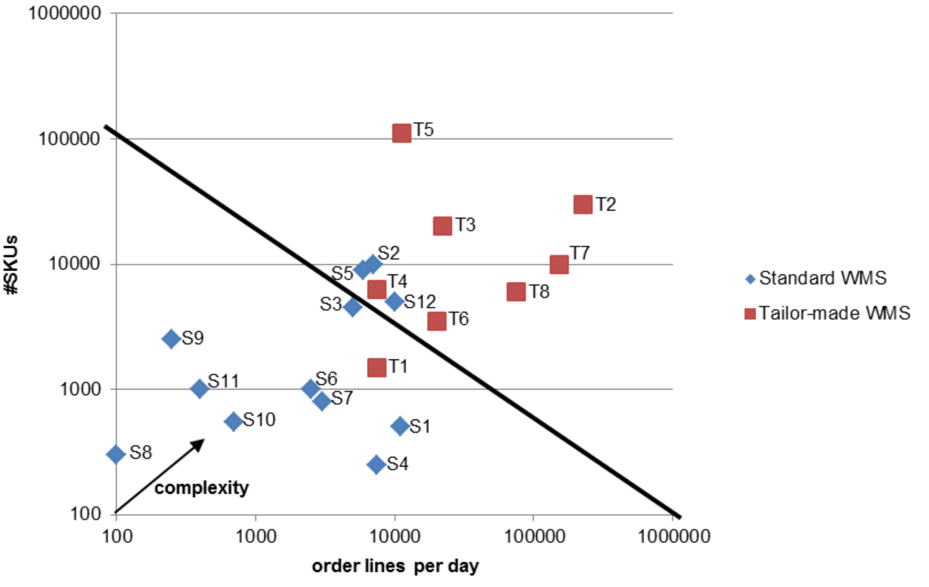

Figure 2.2 The investigated warehouses, grouped by the number of daily order lines and the number of SKUs

P1. The number of order lines processed per day and the number of (active) SKUs are the two main measurable variables of warehouse complexity.

The warehouses below the slanted line in Figure 2.2 all use a standard WMS, except T1. The warehouses in this area are relatively simple, and nearly all seem to be content with their WMSs. T1 uses a standard WMS for product receipt and storage and tailor-made software for interfacing to the manufacturing control system and for the highly mechanized order picking process. A similar statement goes for S5 that uses a standard package, but only for a few (four) functions. All planning functions, including transport, are tailor-made.

The warehouses above the slanted line in Figure 2.2 mainly use tailor-made WMSs. S2, S3 and S12 are exceptions. For S2, the European distribution center of a US mail-order company of collector items, only a fraction of its 10,000 products are active. It operates in a niche market, with no direct competition. The storage and handling systems involve no automation at all; only pallet racks and ordinary warehouse trucks are used. For these reasons, a standard WMS would suffice.

Warehouse S3 is a distribution center of a supermarket chain. This supermarket chain finds the optimization of the supply of its supermarkets more important than the optimization of the warehousing operations. The warehouse uses a simple control structure, including fixed locations and a bulk-near-pick picking strategy. The warehouse has quite a poor performance, and warehouse management believes that a better planning and control structure would reduce the number of shop-floor workers and increase performance considerably. The current WMS is to be replaced in the near future. Warehouse S12 is the most recent one and is currently still in the start-up phase. The relationship suggested by Figure 2.2 and our explanation for its existence, together with the discussion of the three exceptions, lead to *P2*.

P2. The more complex a warehouse, the more specific the planning and control structure.

On the other hand, a simple warehouse can apparently benefit from the advantages of a standard WMS, including a shorter implementation time and less cost. This observation suggests *P3*.

P3. The simpler a warehouse, the more standardized the planning and control structure.

Implementing a standard or tailor-made WMS in an existing warehouse will always lead to the redesign or adaptation of some warehouse processes, or to a less efficient control structure. The empirical data suggest that warehouses that were designed in close concert with the possibilities and limitations of an already selected standard WMS had a better performance, in terms of shorter implementation lead times, less tuning and fewer teething problems, than warehouses that have a control structure which was designed at a later stage. This suggests *P4*.

P4. The more the design of a new-to-be-built warehouse takes place in close concert with the design of the planning and control structure, taking into account the limitations and possibilities of possible standard WMSs for the new-to-be-built warehouse, the more competitive the warehouse will be.

After all, as pointed out in section 2.2, if a standard WMS is selected after the design of the new-to-be-built warehouse, there is a risk that the warehousing operations are molded around the standard WMS, and that warehouse performance is hampered by it.

2.6 Conclusions[7]

The world of warehousing is changing rapidly under the increased pressure to improve overall supply chain performance. As a result, it is recognized that a WMS plays a crucial role in the planning and control structure to achieve the desired high warehouse performance.

The main result of our empirical study is the formulation of four useful and researchable propositions about the relationship between warehouse complexity and warehouse planning and control structure that are potentially applicable in practice. The theory stipulated is useful for answering the question whether a given warehouse should implement and adopt a standard or a tailor-made WMS.

A direction for future research is the deduction and generation of hypotheses, based on these propositions, and to put them to the test in practice. In view of the relationship suggested by Figure 2.2, one such a hypothesis seems to follow in an obvious way from *P1*:

> *Warehouses with more than 10,000 SKUs or more than 10,000 order lines processed per day require a tailor-made WMS to remain competitive.*

Here competitiveness might be translated into one or more measurable indicators, such as above-average profit or above-average productivity. However, such a hypothesis seems to be too fugitive to be useful, since standard WMSs are evolving rapidly and are becoming more and more powerful, which means that the slanted line in Figure 2.2 is shifting to the right.

Also, the distinction between standard and tailor-made may soon prove to be too rigid. Although standard WMSs are becoming more powerful, it is impossible to capture all conceivable systems functionality; see also Kjaer and Madsen (1995). Future research might focus on the usefulness of tailorable WMSs; tailorable information systems are deferred information systems, which allow users to configure the system in accordance to their social, organizational and cultural context. These systems are expected to rise rapidly (Cooke, 1997). In this respect, a tailorable system is a hybrid between a tailor-made and a standard WMS.

2.7 Update on findings and conclusions of the original study in 2002

Warehouse technology, in particular storage and retrieval technology, has changed over the last decade. There has been a development towards further system automation, like automated vehicle based storage and retrieval systems such as Kiva, Autostore, and other

[7] Please note that these conclusions relate to research conducted in 1999. In section 2.7 an update on these conclusions is given.

systems, and systems with flexible storage and retrieval capacity (Baker and Halim, 2007; Bloss, 2011; 2014; Connolly, 2008). The Aberdeen Group (2012) concludes that the trend of real-time processing and event driven warehousing has arrived and is growing. In line with these developments, we expect standard WMSs to have become more powerful over the last decade, and that they can support more complex warehouses. To show the development in a larger and recent sample of warehouses, Figure 2.3 presents the same type of diagram as Figure 2.2 for the database of 215 warehouses from Faber *et al.* (2013), see also Chapter 3. In this figure, the variables *Number of order lines* (X-axis), *Number of SKUs* (Y-axis), and *Information System Specificity* (only standard WMS and tailor-made WMS) from this database are used. See Appendix B and D, respectively.

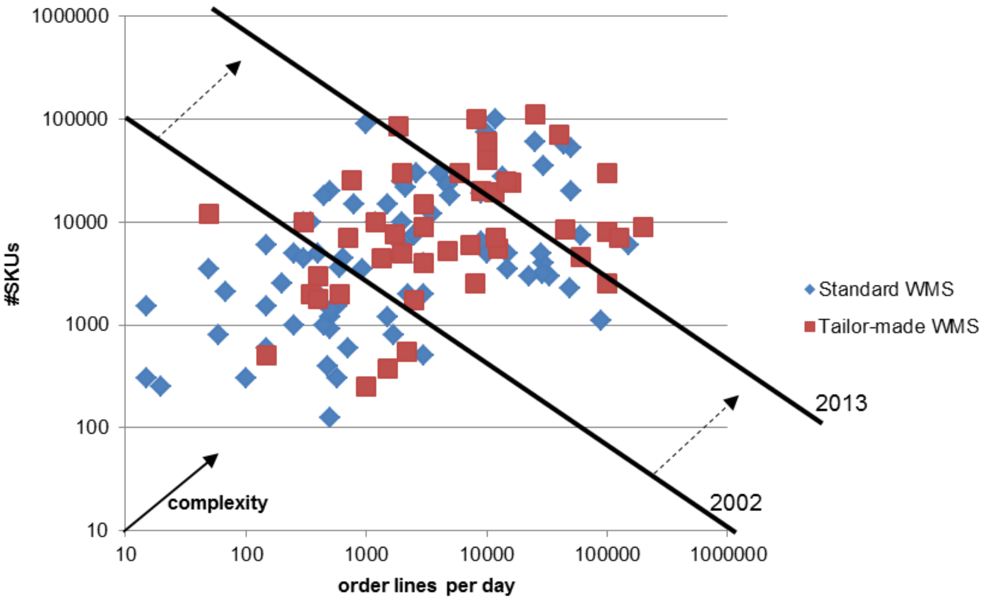

Figure 2.3 Warehouse complexity and the use of standard or tailor-made WMS

As conjectured in section 2.6, Figure 2.3 shows that standard WMSs have shifted to the right over time since the original study was carried out (2002). Apparently, standard WMSs now support complex warehouses with specific planning and control structures. The warehouses in the database of 2013 show that new or revised tailor-made WMSs are still being used and that standard WMSs are not expected to take over the tailor-made WMS market completely. A recent survey study of Logistiek.nl (2015) indicates that 32 per cent of the warehouses use a tailor-made WMS. Especially large and complex warehouses appear to use tailor-made WMSs. A WMS expert, interviewed to provide an up-to-date perspective on the results of the original study of 2002 (see Appendix I), states that the choice between standard and tailor-made is driven by the business strategy. When logistics is considered a main differentiator, a tailor-made WMS is the preferred solution (e.g., Amazon, Docdata, Ocado). However, when a low-cost strategy is pursued even by a complex warehouse, a standard WMS is an obvious solution (e.g., DHL). Furthermore, Figure 2.3 shows that simple warehouses are still primarily supported by standard WMSs. Based on these combined findings, we conclude that standard WMSs have become more powerful over the last decade but have not completely replaced tailor-made WMSs.

With respect to the main empirical findings of the original study concerning the use of WMSs (see section 2.5.1), we first discuss the developments in the standard WMS market over the last decade. Autry *et al.* (2005) state that the number of warehouses investing in technologies that enhance decision-making, such as a WMS has grown. Also, according to Gartner (2013), the marketplace for WMSs is still growing and becoming more global. North America and Western Europe represents 79 per cent WMS licenses, but license rates are expected to be higher for emerging markets than for established markets by 2015 (Gartner, 2013). The WMS market is even more fragmented than in 2002. Bartholdi and Hackman (2014) indicate that there are hundreds if not thousands of WMS vendors in the world, e.g., over 300 WMS vendors in the US alone, and only a few companies have a significant global presence. Gartner (2013) breaks down the WMS market into four types of vendors: application megasuite vendors (i.e., ERP vendors), SCM/logistics suite vendors, specialist WMS vendors, and WMS component vendors. The WMS market has been dominated by specialist WMS vendors, especially for more complex warehouses. Gartner (2013) expects ERP vendors (i.e., Infor, Oracle and SAP) to continue to add depth to their WMS solutions and become viable alternatives for increasingly complex warehouses. Gartner (2013) also concludes that the WMS applications are mature and approaching parity, but innovation continues. Distinguishing characteristics among WMS vendors are and will be to what extent they articulate a vision on where WMSs will be in the future, and to what extent they exhibit an innovative culture (Gartner, 2013). The interviewed WMS expert (see Appendix I) confirms that new innovative oriented market entrants (e.g., parties focusing on using mobile platforms to host WMS and related supply chain functionalities) are challenging established WMS vendors. Furthermore, Gartner (2013) expects the WMS industry to move toward more vertical-specific functionality, such as capabilities for apparel distribution for hung goods, expanded multitenant capabilities for 3PL providers, and forward and reverse logistics that are particular to retail, high-tech and service parts supply chains. In sum, the WMS market has matured over the last decade but has also become more fragmented. New market entrants and application megasuite vendors are challenging established WMS vendors.

Second, in the original study of 2002, the quality of after-sales service of WMS vendors was considered to be poor. The study by Logistiek.nl (2015) shows that complaints are still heard, specifically about long response times to user requests (39 per cent) and lack of innovations (23 per cent). In general, WMS vendors are relatively small businesses and have problems to react quickly to customer requests. Fortunately, due to technology development, standard WMSs are nowadays more flexible and users can make small adjustments themselves. Also, in-the-cloud technology makes it easier for WMS vendors to offer their customers the latest improvements (software upgrades).

Third, in the original study it was found that the implementation of a tailor-made WMS is longer, more problematic, and more costly than that of a standard WMS. Based on the interview with the WMS expert, it is not expected this has changed over the last decade. Especially, the testing phase in developing tailor-made software leads to extended implementation times.

Fourth, the original study indicated that the use of both standard and tailor-made WMSs is in general successful. Based on the study by Logistiek.nl (2015), customer satisfaction seems to have dropped. Only 12 per cent of the respondents assessed their WMS as successful. Two thirds indicated that the functionality of their WMS falls short, and more than 40 per cent of the respondents complained about the lack of flexibility of their WMS to be able to adjust to new business requirements. All in all, it seems that WMS users have become more demanding over the last decade.

2.8 Key warehouse characteristics

The first research question of this dissertation concerns identifying key characteristics of a warehouse and its relevant environment that drive Warehouse Management structure. The study presented in this chapter focused on the internal complexity of a warehouse as key warehouse characteristic; the relevant external environment was not considered yet. In the management sciences literature, there is consensus among researchers on two important organizational contextual (i.e., situational) factors: complexity (other terms used: variety, detail complexity or static complexity) and uncertainty (other terms used: environmental dynamism or dynamic complexity) (e.g., Duncan, 1972; Bozarth *et al.*, 2009; Frizelle and Woodcock, 1995; Hatch, 1997; Miller and Friesen, 1983; Premkumar and Zailani, 2005; Van Assen, 2005). Complexity is a consequence of the 'inner' boundary of the environment, i.e., the organization itself, whereas uncertainty is a consequence of the external environment of the organization. Complexity has been the topic of frequent discussions in a wide variety of management sciences literature (de Leeuw *et al.*, 2013). In this dissertation, we choose to model warehouse complexity by the number and diversity of the elements of the internal warehouse system (Hatch, 1997), see also Chapter 3. Also, we view warehouse complexity as a (measurable) fact. That is, warehouse planning and control should be adapted to the level of warehouse complexity. Uncertainty refers to the degree to which the factors of a warehouse’s environment are subject to change. Uncertainty causes a lack of predictability for directing and controlling warehouse activities. In Chapter 3, the literature is reviewed to further identify key characteristics that drive Warehouse Management structure. Next to warehouse complexity, environmental uncertainty will be given attention as key warehouse characteristic.

3

Structuring Warehouse Management[8]

3.1 Introduction

The warehouse is today playing a more vital role than it ever has in the success (or failure) of businesses (Frazelle, 2002). Warehouses play a critical intermediate role between supply chain members, affecting both supply chain costs and service (Kiefer and Novack, 1999). In an attempt to rationalize supply chain processes and to manage them more efficiently, many companies have set up centralized production and warehouse facilities over the last decades (HIDC/BCI, 2001). This has resulted in larger warehouses responsible for the distribution to a greater diversity of more demanding customers in a vaster region and, consequently, with more complex internal logistic processes (see the survey of ELA/AT Kearney, 2005).

As a consequence, managing complex warehouses effectively and efficiently has become a challenging task. An important question therefore is how Warehouse Management, as a cluster of planning and control decisions and procedures, is structured in order to meet today's challenges. Warehouse Management encompasses the control and optimization of complex warehouse and distribution processes (Ten Hompel and Schmidt, 2006), and it depends on the tasks to be performed and on the market the warehouse operates in. In the area of production management, it is commonly accepted that the produced volume and product variety (i.e., task complexity) and the rate of change of the external environment (i.e., market dynamics) are the main drivers of the planning and control structure (see, e.g., Bertrand *et al*. 1990; De Toni and Panizzolo, 1997; Hatch, 1997; Peterson and Silver, 1979; Van Assen, 2005). However, systematic research into the drivers of the warehouse planning and control structure, i.e., Warehouse Management structure, seems to be lacking. Rouwenhorst *et al*. (2000) and Gu *et al*. (2007; 2010) conclude in their reviews of warehouse planning and control literature that analysis-oriented research on isolated subproblems is dominant in the current literature. This study takes the first step in exploring the drivers of Warehouse Management structure.

Warehouse processes that need to be planned and controlled include: inbound flow handling, product-to-location assignment, product storage, order-to-stock location allocation, order batching and release, order picking, packing, value-added logistics activities, and shipment (Ackerman and La Londe, 1980; Frazelle, 2002). Particularly

[8] Faber, N., De Koster, M.B.M., and Smidts, A. (2013), "Organizing warehouse management", International Journal of Operations and Production Management, Vol. 33 No. 9, pp. 1230-1256.

storage and order picking are complex, often labor-intensive processes that determine warehouse performance for a large part.

Our first contribution is to define and make measurable the core characteristics of Warehouse Management structure. To the best of our knowledge, there is currently hardly any literature that clearly captures Warehouse Management structure as a coherent whole. Because this study is just a first step in exploring the dimensions of Warehouse Management structure, we consider Warehouse Management structure at a high level of aggregation. We propose and define the constructs necessary to do this, focusing on both planning and control activities within the warehouse, and on the decision rules used to schedule and optimize the inbound, storage, and retrieval processes in the warehouse.

Second, we establish and test the drivers of Warehouse Management structure. Following the literature on production systems (e.g., Van Assen, 2005), we distinguish task complexity and market dynamics as the main drivers of the warehouse planning and control activities and of the decision rules used. Task complexity measures the depth and breadth of the tasks a warehouse has to perform and is internally oriented. Market dynamics measures the rate of change of the external environment in which a warehouse operates. In general, we expect that a more complex warehouse task results in more complex decision rules for scheduling and optimizing inbound, storage, and outbound activities. Warehouse planning and control depends both on the complexity of the warehouse task and on the dynamics of the market. We test these propositions in our study.

Our third contribution relates to a specific aspect of Warehouse Management: the warehouse management (information) system (WMS). Information systems play a significant role in managing complex processes (LeBlanc, 2000). We assess the degree to which the drivers of Warehouse Management structure impact the specificity of the information system. Establishing the dependency of the WMS's specificity on these drivers may help managers to decide on the most effective information system to suit the warehouse management's needs. Since many standard warehouse management software systems are available on the market (Loudin, 1998; Randal, 1999), selecting one can be a difficult task.

We carried out a survey to test our theory and collected data on 215 warehouses and distribution centers in the Netherlands and Flanders (Belgium). Warehousing is of particular importance to the Netherlands and Flanders due to their geographical location with deep-sea ports (Rotterdam and Antwerp), major European air-cargo hubs (Schiphol and Zaventem), and direct connections via water (barge and short-sea), road, and rail to a large part of industrial Europe. More than half of all European Distribution Centers (EDCs) are located in this region (BCI, 1997; HIDC/BCI, 2001; Kuipers, 1999). The level of performance of warehousing operations in the region is generally high, represented in high labor productivity and low error rates (see OECD, 2006). High costs of land and labor, and increasing labor shortages are forcing companies to invest in people and automation systems with a relatively long-term investment horizon.

The organization of this paper is as follows. In sections 3.2 and 3.3, we develop our constructs and formulate our hypotheses. In section 3.4, we describe our research methodology, including the sample selection and data collection approaches and the measures of the constructs. Section 3.5 describes the results of the data analysis and hypotheses testing. Section 3.6 concludes the paper.

3.2 General framework for Warehouse Management

3.2.1 Warehouse Management

Analogous to production management (see Bertrand *et al.*, 1990), the objective of Warehouse Management is to efficiently and effectively coordinate all warehouse processes and activities (Harmon, 1993; Tompkins *et al.*, 2003). Warehouse Management includes all planning and control procedures to operate the warehouse. Planning and control is concerned with managing the ongoing activities of the operations so as to satisfy customer demand (Slack *et al.*, 2001). The main purpose of planning and control is to ensure that operations run effectively and produce products and services as they should (Slack *et al.*, 2001). Whereas planning involves deciding what should be done and how, control is the process of ensuring that the desired output (plan) is obtained (Anthony and Young, 1984; Van Goor *et al.*, 2003). Planning is therefore proactive and control is reactive. Together, plans and controls regulate outputs. Within planning, we distinguish a tactical and an operational level. At the tactical decision level, warehouses draw up plans to make efficient use of resources and to fulfill market demand. However, due to the highly dynamic environment, the tactical planning horizon for many warehouses is only days or weeks rather than months. At the operational level, decision rules are used to sequence, schedule, and optimize planned activities (Slack *et al.*, 2001).

In the literature, the dimensions of Warehouse Management have not yet been explored. Based on the above literature and interviews with experts, we propose to broadly define Warehouse Management as a combination of the planning and control systems and the decision rules used for inbound, storage, and outbound flows. We now consider each aspect in more detail.

Tactical planning system. A plan is a formalization of what is intended to happen at some time in the future (Slack *et al.*, 2001). Plans or norms specify a desired output (expressed in quantity, quality, cost, timing, etc.) at some future time. The most important tactical issues in warehouses include: stock planning, storage-location assignment planning, transport planning, and capacity (personnel and equipment) planning. For a comprehensive overview of these and other planning processes, see Van den Berg (1999) and Van den Berg and Zijm (1999).

Stock planning decides which products are kept in storage in what quantities, and determines when shipments arrive. Intelligent stock planning may reduce warehousing costs. Storage location planning decides the location types (for example, shelf, pallet, high-bay or block-stack) and the zones within these storage areas where the products will be stored. An effective storage-location assignment plan may reduce the need for space and the mean travel time for storage/retrieval and order picking. Capacity planning and transport planning determine the required personnel, equipment, and transport capacities.

Making such tactical plans is time consuming and should only be done if they lead to performance improvements. Therefore, the number of tactical plans may vary per warehouse. We define the construct Planning Extensiveness by the number of tactical plans a warehouse explicitly draws up.

Inbound, storage and outbound decision rules. Tactical plans determine which products arrive in what quantities, where these should be stored and how much personnel, equipment, and transport is needed to process the products and orders. Tactical plans define a framework for the operational planning level (Van den Berg, 1999). Operational decisions typically deal with the sequencing, scheduling, and routing of order picking and storage/retrieval operations. There are many different rules that can help operations make these decisions and improve performance (Chen *et al.*, 2010; Rouwenhorst *et al.*, 2000). For an overview of decision rules focusing on storage and order picking, see De Koster *et al.* (2007) or Wäscher (2004).

The complexity of the decision rules implemented in a warehouse differs per warehouse. Complexity is a well-defined construct in management literature (e.g., Alter, 2002; Hatch, 1997; Huber, 1984). The complexity of a system depends on the number of differentiated components of the system, the number of interacting components, and the nature of the interaction between components (Alter, 2002). We therefore define the construct Decision Rules Complexity as the number of different types of decision rules used for inbound, storage, and outbound activities and the perceived complexity of these rules.

Control system. When plans are implemented, things do not always happen as expected (Slack *et al.*, 2001). For example, customers may change their minds about what they want and when they want it, suppliers may not deliver on time, machines may fail, inventory records may be inaccurate, and staff may be absent due to sickness. Control is the process of coping with these changes (Slack *et al.*, 2001). It relates to the feedback and corrective action function of the management system. By monitoring what actually happens and making the necessary changes, control makes the adjustments which allow operations to achieve the objectives that were laid down in the plan (Slack *et al.*, 2001).

Thus monitoring, analyzing, reporting, and intervening are core functions of the control system. For this purpose, information about the progress and realization of the plans is essential (Anthony and Young, 1984). The time to respond to deviations and changes is limited. Therefore, in this study, we consider the speed at which data is transformed into information by the control system as the most important dimension of control. Accurate and timely information on the shop floor is essential to control operations.

Information can be recorded and presented on paper, online, or in real-time if radio-frequency technology is used with mobile terminals and scanners, or with voice response. As the speed of the transformation of data into information increases, the control system becomes more sophisticated. However, the degree of sophistication of the control system must be justified economically, i.e., the higher accuracy and the lower stock-outs must outweigh the extra costs of the control system. As a consequence, the sophistication of the control system differs per warehouse. We define the construct Control Sophistication as the speed of transforming data into information used by warehouse employees to decide and act upon.

Based on the above-mentioned dimensions of Warehouse Management, we define Warehouse Management structure as a combination of Planning Extensiveness, Decision Rules Complexity, and Control Sophistication.

3.2.2 Warehouse management (information) system

In most warehouses, information systems support Warehouse Management. Such information systems can be either built specifically for a warehouse (tailor-made) or bought off-the-shelf (standard software package). Software is primarily focused on broad or specific functionality (Lynch, 1985). A software product with broad functionality supports a large number of different processes in an organization (e.g., an ERP system). Although ERP systems can be configured to the customer's processes, the fine-tuning is complex (Somers and Nelson, 2003) and configuring the system involves making compromises and has its limits (Davenport, 1998). Software products with specific functionality support a smaller number of processes in an organization but with more intensity (e.g., WMS). The specificity of the information system differs per warehouse. We define the construct Information System Specificity by distinguishing six different types of information systems with an ascending degree of specificity.

3.2.3 Drivers of Warehouse Management structure

The basic premise of our study is that the best approach to structure Warehouse Management depends on the specific characteristics of the warehouse. Traditional contingency theorists such as Burns and Stalker (1961) and Lawrence and Lorsch (1967) suggest that effectiveness derives from structuring an administrative arrangement appropriate to the nature of an organization's environment. In the operations management literature, it is also a generally accepted assumption that the environmental context influences the appropriateness of the structure of the planning and control system (Sousa and Voss, 2008). Van Goor *et al.* (2003) state that the characteristics of the market, the products, and the processes determine the way supply chains are managed; and according to Fisher (1997) and Lee (2002), the choice of a supply chain control depends on the product type and the predictability of the market.

The need to consider the environmental context is obvious and widely accepted in literature. With regard to Warehouse Management structure, the environment refers to the immediate operating environment that is beyond the control of management in the short run. Therefore, we focus on narrowly defined parts of the environment rather than overall industry parameters. Analogous to Van Assen (2005), in this study, the warehouse operations environment consists of the external warehouse environment (i.e., the market) and the internal warehouse system.

The core concept that captures the effects of the organization's environment on its performance is uncertainty (Thompson, 1967). Researchers in organizational theory identify two major dimensions of uncertainty: complexity and dynamism (Duncan, 1972; Hatch, 1997; Miller and Friesen, 1983; Premkumar and Zailani, 2005). Complexity refers to the number and diversity of the elements in an environment (Hatch, 1997). The warehouse system can be characterized by the products (SKUs) that have to be stored and picked, the processes to store and pick these products, and the orders that request the delivery of these products. Complexity increases as the number and diversity of SKUs, order lines, and processes increase. In general, if the number of SKUs increases, more storage space (often different type and control logic) will be needed and more products have to be registered and managed in the warehouse information system. Some warehouses have a greater number and/or variety of processes and some of these activities are labor intensive and have substantial impact on order throughput time. The number of order lines is a good indicator for the total amount of work in order picking and thereby for the total amount of work to be done in the warehouse. In general, the majority of warehouse work is in order picking (Drury, 1988). We conceptualize environmental complexity with regard to Warehouse Management structure as the complexity of the task a warehouse has to perform. Thus, we define the construct Task Complexity by:

- the number of different products (SKUs) handled in the warehouse
- the number and variety of the processes carried out by the warehouse
- the number of order lines processed by the warehouse per day

Task Complexity affects Warehouse Management structure through the comprehensibility of the work to be done.

Environmental dynamism is characterized by the rate of change and technology innovation in the industry as well as the uncertainty or unpredictability of the actions of competitors and customers (Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Thompson, 1967). At the level of the immediate operating environment, Warehouse Management interacts directly with customers. Other factors relevant to the warehouse's goal setting, such as competitors, suppliers, government, technology, economy, and labor have a less direct influence on Warehouse Management structure and, for this reason, are not considered in this study. We conceptualize environmental dynamism with regard to Warehouse Management structure as the dynamism in the customer market. We define the construct Market Dynamics by

- the unpredictability of market demand
- the rate of change in the taste and preference among customers

Unpredictability of market demand refers to the difficulty of forecasting customer behavior (Khandwalla, 1977). It is difficult to know just how customers will react to very new products and services, and to anticipate the various problems that might occur. The rate of change in customers' preferences refers to the turbulence of the market. Warehouses that operate in more turbulent markets are likely to have to continually modify their products and services in order to satisfy customers' changing preferences. A dynamic market also manifests itself in frequent assortment changes. Market Dynamics affects Warehouse Management structure through the predictability of the work to be done.

The consideration of Task Complexity and Market Dynamics provides a sound starting point to study the drivers of Warehouse Management structure. Our full research model is shown in Figure 3.1. Task Complexity and Market Dynamics are expected to strongly affect how Warehouse Management is organized. Structuring Warehouse Management takes shape in three dimensions (Planning Extensiveness, Decision Rules Complexity, Control Sophistication), and is reflected in warehouse management's Information System Specificity.

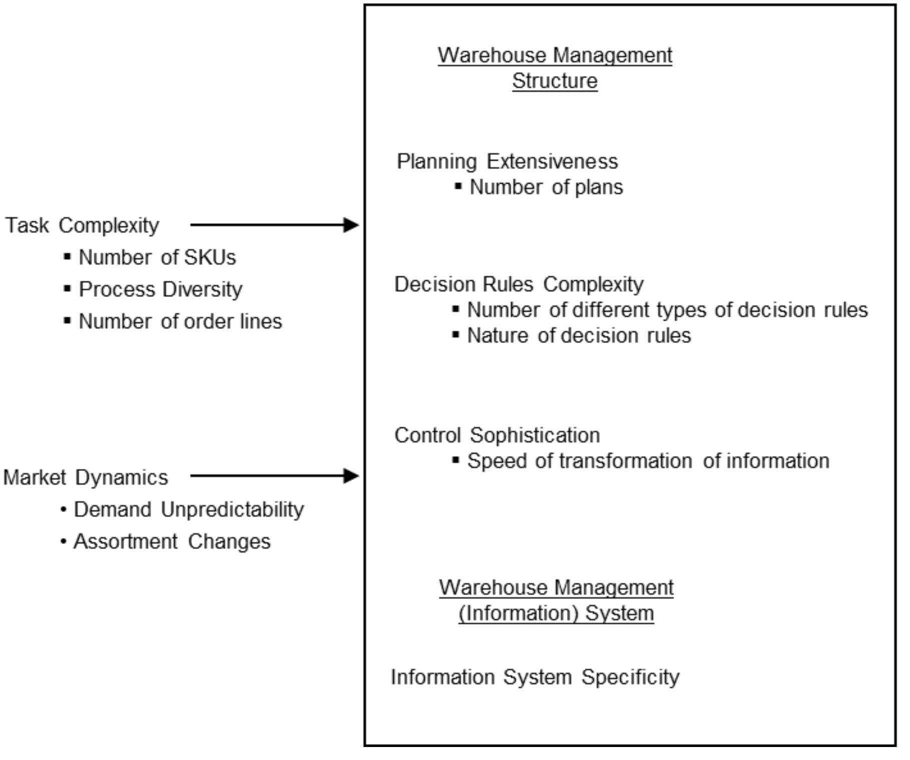

Figure 3.1 Research model

It should be noted that Warehouse Management structure is not solely determined by these two main drivers. In reality, many other elements must be in place for Warehouse Management structure to be successful. These include an educated and well-trained workforce, appropriate alliances with customers and suppliers, well-designed strategic planning processes, well-designed lay-out and systems, well-designed work processes, etc. Task Complexity and Market Dynamics were selected for this study because they play a key role in designing and managing warehouse systems.

To our knowledge, the relationship between the dependent constructs Planning Extensiveness, Decision Rules Complexity, Control Sophistication, and Information System Specificity and the independent constructs Task Complexity and Market Dynamics has not been addressed in the literature.

3.3 Hypotheses

The task a warehouse has to perform is complex if the number of SKUs, process diversity, and number of daily order lines are high. As the complexity of a system increases, managing the system becomes harder (Van Assen, 2005). Each resource has to be aligned to perform the warehousing activities. This can be done efficiently only if the resources and the relationships between these resources are coordinated in a timely, complete, and reliable fashion (Van Assen, 2005). This means that tactical and operational planning is necessary. The first hypothesis of our study is:

H1. The more complex the warehouse task, the more extensive the planning.

It can be expected that the decision rules (i.e., operational plans) used to schedule and optimize activities in the warehouse will be complex when the task is complex. For example, a large number of SKUs generally implies that many of them will need different storage and order picking logic and conditions (think of size, weight, physical condition, packaging, and product carriers like totes or pallets), all laid down in decision rules. If the number of SKUs, process diversity, and number of order lines is small, we expect the decision rules to be simple. The second hypothesis of our study is:

H2. The more complex the warehouse task, the more complex the decision rules.

If the warehouse task is complex, the organizational structure can be adapted to deal with this (Espejo and Watt, 1988), and management may delegate responsibilities downward in the organization to reduce complexity (Mintzberg, 1983). However, the lower levels of the organization have to justify their decisions by regularly reporting progress and results to management. We therefore expect a more complex warehouse task to require more comprehensive and thus, more sophisticated instruments to control the task. The third hypothesis of our study is:

H3. The more complex the warehouse task, the more sophisticated the control system.

Based on a sample of 20 production and distribution warehouses, Faber *et al.* (2002) found that complex warehouses (measured by the number of order lines processed per day and the number of active SKUs), use tailor-made software solutions whereas simple warehouses use standard software solutions to support Warehouse Management. Hence, we expect that if the warehouse task is complex, it will be difficult to find a standard software solution because the situation is too specific. In such situations, only a tailor-made, specific solution or a standard, specific software package with substantial customization will be effective. A simple warehouse task can be supported by standard, broad solutions or even by no automated information system. The fourth hypothesis of our study is:

H4. The more complex the warehouse task, the more specific the functionality of the information system.

Major characteristics of a dynamic market are demand unpredictability and frequent assortment changes. Extensive tactical planning is not effective in a highly dynamic environment because plans have to change constantly. Short-term planning or coordination by feedback (Perrow, 1967), i.e., negotiated alterations in the nature or sequence of tasks, would be more effective in this situation. In contrast, if the market is stable, extensive planning is advisable in order to make efficient use of warehouse resources (personnel, machines, transport, and stock locations) and to minimize stock. These arguments lead to the fifth hypothesis of this study:

H5. The more dynamic the market of a warehouse, the less extensive the planning.

As decision rules are internally oriented, externally driven unpredictability of demand and assortment changes will have much less influence on the complexity of decision rules. Thus, we do not propose an influence of Market Dynamics on Decision Rules Complexity.

Some operations are reasonably predictable and usually run according to plan. In these situations, the need for control is minimal (Slack *et al.*, 2001). Dynamism affects the reliability of the information and the assumptions that are used in planning. The higher the rate of change, the more momentarily available information is (Van Assen, 2005). The internal reporting system has to process and deliver information rapidly to keep up with changes. Also, in a dynamic market, online information exchange with partners (suppliers and/or customers) in the supply and demand chain is needed to respond to market changes. The sixth hypothesis of our study is, therefore:

H6. The more dynamic the market of a warehouse, the more sophisticated the control system.

The six hypotheses of this study are summarized in Figure 3.2. All hypotheses are directional, which means the relationships are positive or negative. We carried out a survey to test our hypotheses.

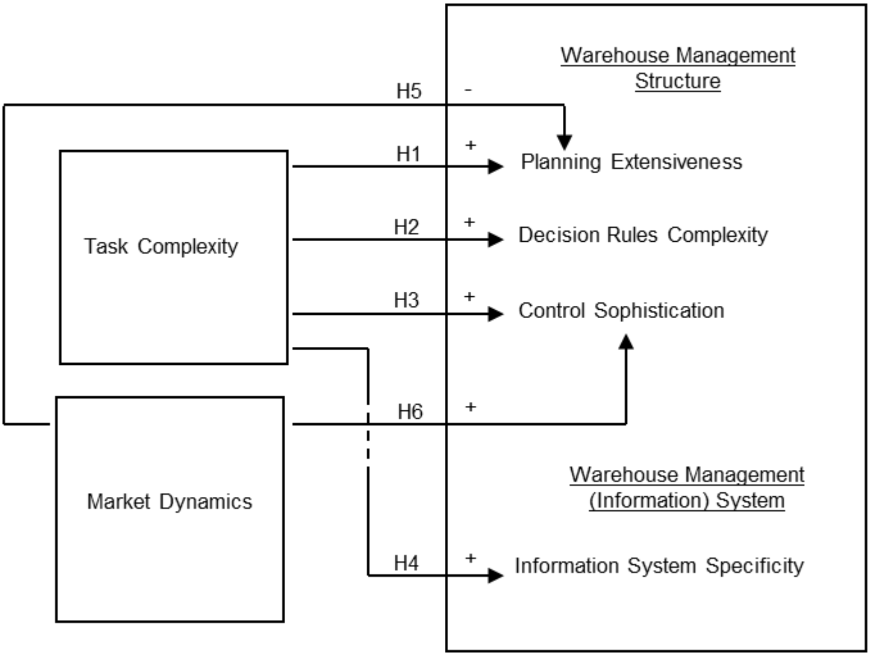

Figure 3.2 Hypotheses

3.4 Method

3.4.1 Data collection and sample

Data were collected by means of a survey among warehouse managers. The final questionnaire consisted of 55 questions divided into ten sections (general data, warehouse type, assortment, order lines, processes, market situation, planning, decision rules, control, and information systems). The questionnaire was extensively pretested for clarity and for assessing the length of the interview. A face-to-face pretest with two warehouse managers of different warehouses indicated that we had to improve the wording of a number of questions and response categories. Later on, we tested the improved questionnaire by telephone on two other warehouse managers representing two more warehouses. This led to some minor changes in the questionnaire.

A single database on warehouses in the Netherlands does not exist. We aimed at a complete representation of medium and large warehouses. We constructed a database by cooperating with HIDC, the Holland International Distribution Council, who owns a database of all multinational warehouse operations in the Netherlands (HIDC/BCI, 2001). We extended the database with the membership lists of well-known logistics associations in the Netherlands (www.NDL.nl, www.FENEX.nl, IMCC and VLM) and Flanders (Belgium) (www.VIL.be, www.warehouseandlogisitcs.com and www.brucargo.be). All, except two of these lists, were available on the Internet. The remaining two were disclosed at our request. The database was further completed with recent lists of attendees of workshops and conferences on warehouse management. We targeted warehouses representing various industry sectors, with different positions in the supply chain (varying from production-related warehouses - i.e., storing not only finished products but also raw materials and components - to wholesale and retail warehouses), and different outsourcing relations. After eliminating duplicate listings and incomplete addresses, our sample population consisted of 765 warehouses, which provides good coverage of the medium and larger warehouses in the Netherlands and Flanders. These warehouses were approached in two waves.

The first wave of 250 warehouses gathered from the HIDC database and lists of attendees of workshops and conferences was contacted by telephone and asked to collaborate. Obtaining answers to the questions was an elaborate job. For one thing, the targeted managers were very busy, and a single contact sometimes required about three to four calls to complete the questionnaire (several calls were required to ensure that the managers had prepared the questionnaire which contained many questions on factual data). One hundred and one warehouses were willing to participate. The most often-heard argument for nonresponse was that the questionnaire was too time consuming.

Due to the rather small absolute sample size of the first wave, in the second wave, we approached 515 warehouses, based on the membership lists of logistics associations in the Netherlands and Flanders, by sending a cover letter and the questionnaire by e-mail. Two steps were taken to increase response. First, the survey instrument and process were made as user friendly as possible by using various media, i.e., a web-based questionnaire on the Internet, an electronic questionnaire, and a hardcopy. Second, we approached all non-responding addressees a second time by e-mail. The most often-heard argument for nonresponse was lack of time. In the second wave, 114 warehouses filled in the questionnaire. If deemed necessary, follow-up calls were made to verify responses, solve ambiguities, or to ask the respondent to check objective data. After carefully checking the responses of both waves for completeness and eligibility, 215 completed questionnaires could be used for this study, representing a response rate of 28 percent. Given the low response rates for surveys in the logistics industry in general (Muilerman, 2001), this response rate is good.

Because the respondents represent an organization, they must be knowledgeable about the main constructs (Huber and Power, 1985). We requested a logistics or warehousing executive, preferably the warehouse manager, to complete the questionnaire. The warehouse manager is probably one of the few people with sufficient knowledge about the data in our questionnaire. For this reason, we had to use a single respondent. Table 3.1

shows that we were quite successful in contacting the preferred informant: 85% of the respondents are senior warehouse managers and 15% are logistics staff members. Table 3.1 also shows other demographic data such as warehouse types, general industry classification, and number of warehouse employees.

Respondent's position		Type of warehouse		Sector		Number of warehouse employees	
Senior Manager	85.1%	Production Warehouse	10.2%	Automotive	5.6%	< 10	14.0%
Logistics Staff	14.9%	Distribution Center insourced	58.1%	Healthcare	3.3%	11 - 20	15.8%
		Distribution Center outsourced	31.7%	Pharmaceutical	3.3%	21 - 30	13.0%
				Defence/Police	4.2%	31 - 50	13.5%
				Food retail	5.1%	51 - 70	10.7%
				Agricultural products/ Food products	7.4%	71 - 100	10.2%
				Information and Communication Technology	11.2%	101 - 160	11.2%
				Industrial products	18.1%	161 - 250	6.0%
				Other products (mainly consumer products)	28.4%	251 - 370	1.9%
				Public warehouses	13.5%	371 - 520	2.3%
						520 - 700	1.4%
Total	100%	Total	100.0%	Total	100.0%	Total	100.0%
						mean	78
						std. deviation	106

Table 3.1 Sample description

Table 3.1 shows that our sample covers a wide variety of industries, from automotive to retail, and it represents all types of warehouses. The average number of full-time direct employees is 78, the average number of stored SKUs per warehouse in our sample is 14,000, and the average number of shipped order lines is over 10,000 per day. Although our research is limited to the Netherlands and Flanders, warehousing practices in these regions are not different from elsewhere in Western Europe. In fact, many companies run multiple similar facilities elsewhere in Western Europe (Quak and De Koster, 2007). Overall, we conclude that the response is large enough and sufficiently diverse to draw meaningful conclusions for medium and large warehouses.

3.4.2 Measures

Keller *et al.* (2002) provide a directory of all multi-item scales published in leading logistics journals from 1961 to 2000. Most scales for the constructs included in this study were not available in the literature. Hence, we developed our own measures for these constructs. An important issue in this regard is whether constructs are considered reflective or formative (Diamantopoulos and Winklhofer, 2001). The choice of a formative versus a reflective specification depends on the causal priority between the measurable items and the latent variable (see Jarvis *et al.*, 2003).

In operationalizing the constructs of our study, we closely followed the recommendations of Churchill (1979) and particularly Rossiter (2002), who updates and elaborates the Churchill paradigm of scale development. Each construct was defined, and four experts in the domain of warehouse management (two academics and two warehouse managers) provided specific items to measure these constructs. After several discussion rounds, our experts concluded that all constructs in our study are formative. Fundamental to formative constructs is that all items of the construct contribute to the construct; omitting an item is omitting a part of the construct. Therefore, we kept items in our construct even if they did not correlate strongly with other items in that particular construct. The resulting indicators per construct are presented and discussed below. A compilation of the constructs and their measures is summarized in Appendices B, C and D.

- *Task Complexity* (TC) is measured by summing up the standardized scores of:
- *Number of SKUs* (TCa). This variable is measured as the log of the number of SKUs since the effect of the number of SKUs on Task Complexity is expected to be skewed (Faber *et al.*, 2002; De Koster and Balk, 2008).
- *Process diversity* (TCb). Following Faber *et al.* (2002) and Schoenherr *et al.* (2010), this variable is measured by both the number of special processes and the number of modes in which processes can be carried out in the warehouse. Instead of measuring the number of all the different processes, we only measure the number of special processes. Nearly all warehouses perform processes such as

receiving, storage, internal replenishment from bulk to pick areas, order picking, and shipping, but some warehouses also perform special processes. Examples include product repacking, return handling, customs clearance, cycle counting for stock integrity, cross-docking, and value adding activities. We measure the number of special processes on a binary scale with five special processes as a split value; five is a fairly large value since most warehouses have at least some special processes. Warehouse processes can be carried out in different modes. For example, storing products in a shelf area differs substantially from storing products in a pallet area with regard to procedures, product carriers, and material-handling equipment used. The same is true for order picking in such areas. Complexity is driven by the average number of modes in which processes are carried out. We measure this average number of modes on a binary scale with three as a split value; three is a relatively small value, justified by a low average number of modes per process in most warehouses.

- *Number of order lines* (TCc). This variable is measured as the log of the number of order lines since the effect of the number of order lines on Task Complexity is expected to be skewed (Faber *et al.*, 2002).

To measure Market Dynamics (MD), we used Miller and Friesen's (1983) perceptual measures for dynamism. Here, Market Dynamics is measured as the sum of the standardized scores of:

- *Demand Unpredictability* (DU). This variable is measured as the sum score of three questions asking for perceived demand predictability in the very short, in the short, and in the long run, each measured on a three-point scale (predictable, limited predictability, and difficult to predict).
- *Assortment changes* (AC). The frequency and amount of assortment change is measured on a three-point scale (hardly, to a limited extent, and to a great extent).

Warehouse Management structure is measured by three constructs:

- *Planning Extensiveness* (PE). We measure this construct by the number of tactical plans that are explicitly drawn up in the warehouse (ranging from 0 to a maximum of four plans).
- *Decision Rules Complexity* (DC). We measure the number of different types of decision rules (DCa) by counting activities that are systematically executed using decision rules. We distinguished 12 activities (see Appendix C for the full list). We measure the nature of the decision rules (DCb) by asking the respondent's

opinion on the perceived complexity of both inbound and outbound rules, each measured on a three-point scale (ranging from simple to complex). The score for Decision Rules Complexity is obtained by summing the standardized scores of both parts (DCa, DCb).

- *Control Sophistication* (CS). This construct is measured by two indicators: the sophistication of the internal reporting system and the online information exchange with partners (using e.g., EDI). The sophistication of the reporting system is the degree to which data in a warehouse are recorded and monitored online (CS1, CS2), and the reaction time to unforeseen situations (CS3). The aspects are all measured on a binary scale. Online information exchange (scheduling information, plans, orders, etc.) with business partners is the degree of online information sharing with suppliers and customers, respectively on a yes/no scale (CS4, CS5). The total score is the sum of all aspects of the reporting system and online information exchange with partners.

Information System Specificity (IS). This is measured by distinguishing six different types of information systems with an ascending degree of specificity, ranging from no automated system to a tailor-made system (see Appendix D for precise levels).

At the construct level, we assume all subdimensions to contribute equally to a construct.

3.5 Results

To assess the relationship between warehouse characteristics and Warehouse Management structure, we performed a series of regression analyses. The correlations between the variables specified in Table 3.2 are the input for the regressions. The results are shown in Table 3.3. The regressions were conducted both at the construct level (see results on upper part of Table 3.3) and at the subdimension level (results on lower part of Table 3.3). At the subdimension level, we conducted stepwise regression among the five independent variables and we present results only for variables for which $p < .10$ (two-tailed). We chose a higher p-value because of the exploratory character of this study. We also tested for interaction effects between the main constructs. These turned out to be not significant for any of the dimensions of Warehouse Management structure.

H1 predicted a positive relationship between Task Complexity and Planning Extensiveness, whereas *H5* predicted a negative relationship between Market Dynamics and Planning Extensiveness. The results in Table 3.3 confirm a significant and positive effect of Task Complexity (standardized regression coefficient $\beta = 0.29$, $p < 0.001$) and a negative effect of Market Dynamics ($\beta = -0.14$, $p < 0.038$). Table 3.3 shows that Task Complexity and Market Dynamics explain approximately 10% of the variance in Planning

Extensiveness. However, the regression analysis in the lower part of Table 3.3 shows that 21% of the variance in Planning Extensiveness is explained by the subdimensions. Especially “number of order lines” has a strong positive effect on Planning Extensiveness.

	TC	TCa	TCb	TCc	MD	DU	AC	PE	DC	CS	IS
Task Complexity (TC)	1.00										
Log no. of SKUs (TCa)	0.81[a]	1.00									
Process diversity (TCb)	0.66[a]	0.33[a]	1.00								
Log no. of order lines (TCc)	0.72[a]	0.45[a]	0.12	1.00							
Market Dynamics (MD)	0.08	0.09[b]	0.14[c]	-0.04	1.00						
Demand unpredictability (DU)	-0.17[c]	-0.05	0.03	-0.34[a]	0.70[a]	1.00					
Assortment changes (AC)	0.29[a]	0.18[b]	0.16[c]	0.28[a]	0.70[a]	-0.03	1.00				
Planning Extensiveness (PE)	0.28[a]	0.07	0.18[b]	0.38[a]	-0.10	-0.27[a]	0.12	1.00			
Decision Rules Complexity (DC)	0.44[a]	0.28[a]	0.28[a]	0.39[a]	-0.01	-0.14[c]	0.12	0.35[a]	1.00		
Control Sophistication (CS)	0.21[b]	0.18[b]	0.14[c]	0.14[c]	0.07	0.00	0.09	0.11	0.27[a]	1.00	
Information System Specificity (IS)	0.33[a]	0.18[b]	0.22[a]	0.35[a]	0.08	-0.03	0.14[c]	0.18[b]	0.23[a]	0.23[a]	1.00
n=	212	215	215	212	213	214	214	215	215	212	213
min=	-2.55	1.3	2	1.18	-1.86	3	1	0	-1.66	5	0
max=	2.02	5.41	4	5.3	2.03	9	3	4	2.42	10	5
mean=	0	3.63	2.98	3.16	0	5.74	2.48	2.63	0	7.66	2.71
std dev=	1	0.74	0.8	0.92	1	1.74	0.54	1.22	1	1.48	1.8

[a] $p < 0.001$; [b] $p < 0.01$; [c] $p < 0.05$

Table 3.2 Correlations

	Planning Extensiveness (PE)			Decision Rules Complexity (DC)			Control Sophistication (CS)			Information System Specificity (IS)		
	β	***t***	***p***	**β**	***t***	***p***	**β**	***t***	***p***	**β**	***t***	***p***
Construct level analysis												
Task Complexity (TC)	0.29	4.41	0.000	0.44	7.00	0.000	0.20	2.96	0.003	0.33	5.00	0.000
Market Dynamics (MD)	-0.14	-2.08	0.038	-0.05	-0.71	0.477	0.04	0.54	0.587	0.04	0.60	0.553
R^2	0.10			0.19			0.04			0.11		
n=	210			210			207			208		
Subdimension analysis	**β**	***t***	***p***	**β**	***t***	***p***	**β**	***t***	***p***	**β**	***t***	***p***
Task Complexity (TC)												
Log no. of SKUs (TCa)	-0.17	-2.29	0.023				0.19	2.75	0.007			
Process diversity (TCb)	0.18	2.70	0.007	0.23	3.69	0.000				0.17	2.55	0.011
Log no. of order lines (TCc)	0.38	5.13	0.000	0.37	5.91	0.000				0.33	5.10	0.000
Market Dynamics (MD)												
Demand unpredictability (DU)	-0.16	-2.37	0.019									
Assortment changes (AC)												
R^2	0.21			0.21			0.04			0.15		
n=	210			210			207			208		

Table 3.3 Regressions

A detailed examination of the relationship between Market Dynamics and Planning Extensiveness indicates that the two subdimensions of Market Dynamics appear to work in opposite directions. As expected, the subdimension “demand unpredictability” has a significant negative effect on Planning Extensiveness (correlation = -0.27; $p < 0.001$, Table 3.2), which means that if demand is more difficult to predict, planning will be less extensive. Contrary to our expectation, the subdimension “assortment changes” appears to affect Planning Extensiveness marginally positively (correlation = 0.12, $p < 0.074$, Table 3.2). This means that if the assortment of the warehouse changes often, tactical planning will be more extensive. This result seems to suggest that changes in the assortment of a warehouse are predictable. Our initial expectation was based on theories that mainly focus on production situations in which changes in the assortment are considered unpredictable, thus increasing uncertainty (see for example, Fisher, 1997). Indeed, frequent product changes may be rather unpredictable in a production environment. However, when information about product changes and new products is exchanged between production and distribution, a distribution center should be able to predict the changes in the assortment. This even encourages distribution centers to put more effort into planning to cope with these changes.

Support for this interpretation can be found when comparing the production warehouses and the distribution centers in our sample with respect to the effect of the subdimension “assortment changes” on Planning Extensiveness. Production warehouses store and distribute raw materials, semi-finished and finished products in a production environment. Distribution centers store products between point-of-production and point-of-consumption and are located close to the products’ markets. In other words, production warehouses are located upstream, whereas distribution centers are located downstream in the supply-and-demand chain. We therefore expect a negative effect of assortment changes in production warehouses. Although we have to be cautious since the number of production warehouses is relatively small in our sample (n = 22), the results of a separate regression (see Table 3.4) for production warehouses show a significant negative effect ($\beta = -0.45$; $p < 0.027$). This means that the more the assortment changes, the less extensive is the planning. Changes in the assortment are difficult to predict and therefore difficult to plan for in production warehouses. In distribution centers (n = 193), no significant effect of assortment changes on Planning Extensiveness shows up in Table 3.4 because the effects of the other variables, especially “number of order lines” are more dominant. The results of correlation analyses (see Table 3.5) show a significant positive correlation (correlation = 0.18, $p < 0.015$)) between “assortment changes” and Planning Extensiveness for distribution centers, and a negative correlation (correlation = -0.38, $p < 0.083$) for production warehouses. Our results indicate that because distribution centers are located downstream in the supply chain, assortment changes can be predicted and planned.

	Production Warehouses			Distribution Centers		
	Planning Extensiveness (PE)			Planning Extensiveness (PE)		
	β	***t***	***p***	**β**	***t***	***p***
Construct level analysis						
Task Complexity (TC)	-0.12	-0.64	0.530	0.32	4.65	0.000
Market Dynamics (MD)	-0.60	-3.20	0.005	-0.10	-1.40	0.162
R^2	0.39			0.11		
n=	21			189		
Subdimension analysis	**β**	***t***	***p***	**β**	***t***	***p***
Task Complexity (TC)						
No. of SKUs (TCa)				-0.14	-1.85	0.066
Process diversity (TCb)				0.18	2.60	0.010
No. of order lines (TCc)				0.40	5.07	0.000
Market Dynamics (MD)						
Demand unpredictability (DU)	-0.46	-2.48	0.023	-0.15	-2.08	0.039
Assortment changes (AC)	-0.45	-2.42	0.027			
R^2	0.38			0.22		
n=	21			189		

Table 3.4 Regression production warehouses vs distribution centers

	Production Warehouses			Distribution Centers		
	Planning Extensiveness (PE)			Planning Extensiveness (PE)		
	r	*p*	n	*r*	*p*	n
Assortment changes (AC)	-0.38	0.083	22	0.18	0.015	192

Table 3.5 Correlation “assortment changes” and Planning Extensiveness

Table 3.4 shows, in addition, that Market Dynamics drives Planning Extensiveness (β = -0.60, $p < 0.005$) in production warehouses, and that Task Complexity drives Planning Extensiveness (β = 0.32, $p < 0.001$) in distribution centers. Distribution centers appear to process significantly more order lines (mean = 11715, SD = 27585) than production warehouses (mean = 881, SD = 766) ($t = 3.47$, $p < 0.001$), which explains the stronger effect of Task Complexity on Planning Extensiveness in distribution warehouses.

H2 predicted a positive relationship between Task Complexity and Decision Rules Complexity. Table 3.3 shows that 19% of the variance in Decision Rules Complexity is explained by Task Complexity. The results in Table 3.3 confirm a significant and positive effect of Task Complexity ($\beta = 0.44$, $p < 0.001$): the more complex the warehouse task, the more complex are the decision rules. As expected, Market Dynamics has no significant effect on Decision Rules Complexity ($p < 0.477$).

H3 and *H6* predicted an effect of both Task Complexity and Market Dynamics on Control Sophistication. The results in Table 3.3 confirm hypothesis 3 ($\beta = 0.20$; $p < 0.003$) and rejects hypothesis 6 ($\beta = 0.04$; $p < 0.587$). A more complex warehouse task requires more sophisticated control, while a more dynamic market does not affect control. Only 4% of the variance in Control Sophistication can be explained by Task Complexity. We conclude that Task Complexity and Market Dynamics do not explain the variances in Control Sophistication; other factors may play a role, and further research is needed here.

H4 predicted that warehouses with a complex task need a more customized and tailor-made information system. Table 3.3 shows that the Information System Specificity is indeed significantly and positively affected by Task Complexity ($\beta = 0.33$, $p < 0.001$). 11 percent of the variance in Information System Specificity is explained by Task Complexity. We conclude that a more specific and customized information system is required once a warehouse task becomes more complex. As expected, Market Dynamics has no effect on Information System Specificity.

We tested for several control variables, such as industry sector and respondent's position, by adding variables to the subdimension regression of Table 3.3, applying a Chow (*F*-change) test for increase in explained variance. We only found significant effects of industry sector for three warehousing dimensions, i.e., Decision Rules Complexity (*F*-change = 2.72; $p < 0.007$), Control Sophistication (*F*-change = 2.11; $p < 0.036$), and Information System Specificity (*F*-change = 3.11; $p < 0.002$). No effect of industry sector was found for Planning Extensiveness ($p > 0.24$).

A more detailed analysis reveals that Information System Specificity (IS) is significantly higher than average for the sector Public warehouses (p < 0.001). A possible explanation for why public warehouses use significantly more specific information systems (72% have implemented a WMS) could be that logistic-service providers serve multiple clients in such warehouses (on average 4.4 within a single facility; De Koster and Warffemius, 2005) which all require specific processes. Such a diversity of processes is, in general, not sufficiently supported by generic warehouse management systems (WMSs). This could also explain the significantly higher-than-average Decision Rules Complexity (DC) in public warehouses ($p < 0.013$). In addition, Decision Rules Complexity (DC) is significantly lower ($p < 0.018$) than average for the Healthcare/Pharmaceutical sector. This might be due to a smaller-than-average diversity in outbound processes. In this sector, all shipments are in small quantities, picked from storage systems, fit for piece picking. A greater diversity can be often observed in the dedicated systems in other industry sectors, since next to piece picking, box and pallet picking also takes place. Finally, Control Sophistication (CS) is significantly lower for Defence/Police warehouses ($p < 0.002$) and for Industrial products warehouses ($p < 0.038$). For Defence/Police warehouses, especially online information exchange with business partners is particularly low. This could be explained by the important role of security and data protection in such warehouses. Warehouses with industrial products are located upstream in the supply chain. As lead times generally increase upstream in supply chains, this implies that such warehouses have a longer planning horizon and do not have to respond in real-time to changes and unforeseen situations.

To summarize, we find clear support for *H1*, *H2*, *H4*, and *H5*, but weak support for *H3*, and no support for *H6* (see Figure 3.3). For *H1* and *H5*, we found different effects for production warehouses and distribution centers. *H1* is supported by distribution centers, but not by production warehouses; and *H5* is supported by production warehouses, but not by distribution centers. With regard to Market Dynamics, the subdimension "demand unpredictability" behaves as expected, but the effect of the subdimension "assortment changes" seems to be different in distribution centers than in production warehouses. The variable "assortment changes" does not seem to be a characteristic of a dynamic market in distribution centers. Importantly, most subdimensions of the independent constructs have significant effects and differ in size. This indicates the importance of measuring the constructs in a detailed manner and analyzing the subdimensions separately.

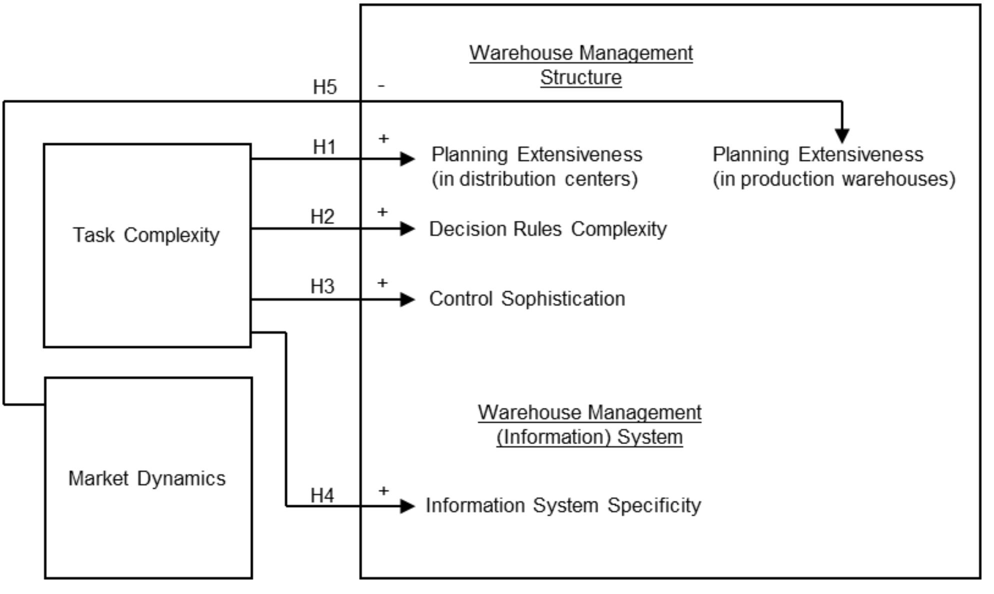

Figure 3.3 Results

3.6 Conclusions and future research

In this paper, we proposed and defined Warehouse Management structure by three constructs: Planning Extensiveness, Decision Rules Complexity, and Control Sophistication. We developed a model linking the two main drivers of Warehouse Management structure, Task Complexity and Market Dynamics, and tested this model in a large sample of warehouses. In the process, we developed new measures for most constructs.

We empirically find that Warehouse Management structure is largely driven by Task Complexity and to a much lesser extent by Market Dynamics. Our results show that the more complex the warehouse task is, the more extensive is the planning and the more complex are the decision rules. Furthermore, a complex warehouse task leads to a more sophisticated control system. Our fifth hypothesis ("The more dynamic the market of a warehouse, the less extensive the planning") is weakly supported by the data. This is mainly due to the role of the subdimension "assortment changes" in the Market Dynamics construct. Assortment changes appear to have a different effect in distribution centers than in production warehouses. Whereas the subdimension "demand unpredictability" indeed leads to less extensive planning, frequent assortment changes lead to more extensive planning in distribution centers. In hindsight, this makes sense as changing assortments is regular business (think of regular promotions, seasonal products) in many distribution centers, and stock and location plans have to anticipate this. Furthermore, we find that distribution centers process significantly more order lines per day than production warehouses. This phenomenon, together with the opposite effect of "assortment changes", explains why Planning Extensiveness is driven by Market Dynamics in production warehouses and by Task Complexity in distribution centers. Our sixth hypothesis ("The more dynamic the market of a warehouse, the more sophisticated the control system") is not supported by the data. Apparently, only Task Complexity plays a dominant role.

We expected to find the choice of the warehouse management (information) system (measured by Information System Specificity) to be driven by Task Complexity. Indeed, the data confirm our fourth hypothesis that the more complex the warehouse task is, the more specific is the functionality of the information system. Other factors than Task Complexity obviously play a role in the warehouse management (information) system choice. For example, logistics service providers do not base their WMS choice on a single warehouse but on the various warehouses they operate. Warehouse Management structure is strongly related to the specificity of the information system: all three dimensions (Planning Extensiveness, Decision Rules Complexity, and Control Sophistication) correlate positively with the specificity of the software system. This was to be expected as generic software systems do not sufficiently support complex requirements.

In this research, we contributed to the study of structuring Warehouse Management by developing new measures for most constructs. We provided an extensive and detailed operationalization of each construct and its subdimensions. Most of these measures were developed using objective facts about the warehouse and the insights and observations of expert informants, usually the senior warehouse manager.

Future research should be conducted to further validate the measures. Our operationalization could be used as a starting point for developing measures in similar contexts such as transshipment terminals and crossdock operations. Further research could also test whether the current operationalizations (dimensions and subdimensions) are general enough to be applied outside of the warehouse context, for instance, in production.

Our research focused on warehousing in the Netherlands and Flanders. It would be interesting to test our hypotheses in warehouses in non-Western countries. A priori, we do not expect significantly different results. In addition, it might be interesting to extend the sample with more production warehouses to more robustly test for differences between production warehouses and distribution centers. In our study, we still find a substantial variability in responses to Task Complexity and Market Dynamics. In follow-up research, in-depth case studies might provide additional insight into the implementation of the subdimensions of Warehouse Management structure.

Our proposed operationalization provides means to systematically study other aspects of warehousing. Most notably, how Warehouse Management structure affects warehouse performance. In particular, it would be interesting to research whether a (mis)match between the independent variables, Task Complexity and Market Dynamics, and the way Warehouse Management is structured impacts warehouse performance. Such a study would complement current studies on warehouse performance (e.g., De Koster and Balk, 2008; De Koster and Warffemius, 2005; Hackman *et al.*, 2001) that did not test drivers. Detailed case studies could provide more insight into the motivations and reasons for apparent mismatches. Such reasons might be diverse. Think of warehouses with physical constraints (e.g., space shortage, outdated systems, poor lay-out) that have not been able to timely adapt to changes in the environment or tasks. Furthermore, it would be interesting to study the impact of differences in warehouse management (information) system and the choice of warehouse management (information) system on performance.

Finally, this study could help warehouse managers to benchmark their warehouse against the independent constructs developed in this paper. Knowledge of scores on these indicators can help managers effectively structure Warehouse Management and assist them with their choice of warehouse management (information) system; in particular, whether a standard system will do, or whether a system with specific functionalities will be more appropriate.

4

Survival of the fittest: the impact of fit between Warehouse Management structure and warehouse characteristics on warehouse performance[9]

4.1 Introduction

Today's competitive and increasingly complex market place has highlighted the value-added potential of logistics (Mentzer *et al.*, 2004). Concepts such as supply chain management, collaborative planning, forecasting and replenishment (CFPR), and e-logistics and e-fulfillment pursue a demand-driven organization of the supply chain with small inventories and reliable short response times throughout the supply chain. Warehouses play a critical intermediate role among supply chain members in realizing these concepts, affecting both supply chain costs and service (Kiefer and Novack, 1999). The focus of warehousing has shifted from passive storage to strategically located warehouses providing timely and economical inventory replenishment for customers (Bowersox *et al.*, 2013). Warehouse performance is pivotal for a company's logistic success (Quak and De Koster, 2007).

The importance of measuring and comparing overall warehouse performance has been recognized in the literature (De Koster and Balk, 2008; Hackman *et al.*, 2001; Hamdan, 2005; Johnson and McGinnis, 2011; Kiefer and Novack, 1999; Tompkins *et al.*, 2003; Zimmerman *et al.*, 2001). Also, research has been conducted on the effect of different warehouse characteristics, such as ownership, country of origin, region location, lay-out, size, and level of automation, on warehouse performance (e.g., Andrejić *et al.*, 2013, Banaszewska *et al.*, 2012; De Koster and Balk, 2008; Hamdan and Rogers, 2008). Likewise, Johnson and McGinnis (2011) examined the relationship between different warehouse operational practices (e.g., use of pick-to-light, use of barcoding, temporary labor) and warehouse performance. However, little work is available on the performance impact of the way in which warehouse operations are managed. The objective of this paper is to develop a model for structuring high performance warehouse operations management. We follow Sousa and Voss (2008) by taking a contingency perspective on operations management, meaning the structure-performance relationship is context dependent. Common to all contingency approaches is the proposition that performance is a consequence of the fit between structure and context (Donaldson, 2001).

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[9] Faber, N., De Koster, M.B.M., and Smidts, A. (2015), "Survival of the fittest: the impact of fit between warehouse management structure and warehouse characteristics on warehouse performance", Working paper, Erasmus University Rotterdam, Rotterdam, June 2015.

Warehouse operations management, henceforth referred to as Warehouse Management, generally refers to the planning, control, and optimization of warehouse processes (Ten Hompel and Schmidt, 2006). The processes that need to be planned, controlled, and optimized include inbound flow handling, product-to-location assignment, product storage, order-to-stock location allocation, order batching and release, order picking, packing, value added logistics activities, and shipment (Ackerman and La Londe, 1980; Bowersox *et al.*, 2013; Frazelle, 2002). The way in which Warehouse Management is structured manifests itself in the way decisions are made about the material flow and the use of resources (space, equipment, and labor) in a warehouse in an everyday context. A contingency perspective employs a reductionist approach (Sinha and Van de Ven, 2005), meaning that we have to decompose Warehouse Management structure into its constituent elements. We use therefore the dimensions of Warehouse Management structure identified by Faber *et al.* (2013), i.e., planning, control, and decision rules used to optimize warehouse processes, to assess Warehouse Management structure.

In this paper, we hypothesize that warehouse performance is positively affected by a fit between Warehouse Management structure and its context (or environment). We conduct an empirical study using the survey method to examine the proposed model and its associated hypotheses. In our study, we base warehouse performance measures on existing literature (De Koster and Balk, 2008), and adopt the data envelopment analysis (DEA) approach (Charnes *et al.*, 1978) and cross efficiency evaluation (CEE) (Sexton *et al.*, 1986) to measure warehouse performance. DEA and CEE are particularly appropriate for this study because they integrate a variety of performance metrics into a single comparative (relative) score of performance. Faber *et al.* (2013) empirically found that Warehouse Management structure is influenced by the warehouse type (i.e., production warehouse or distribution center), the complexity of the warehouse task (i.e., the complexity of warehouse processes, assortment and order lines), and to a lesser extent by the dynamics of the market. These context factors will thus be taken into account in assessing warehouse performance. In sum, we adopt a contingency approach and provide evidence that a fit between Warehouse Management structure (i.e., planning, control, and decision rules), and warehouse characteristics (i.e., task complexity and demand unpredictability), has a positive impact on warehouse performance. We focus on the large majority of warehouses that have a distribution function (i.e., distribution centers - DCs).

With this paper we contribute to warehouse research by empirically showing that fit, as measured by the interaction between warehouse context and Warehouse Management structure, leads to higher warehouse performance. Although Faber *et al.* (2013) researched the drivers of Warehouse Management structure, they did not examine whether the fit between these drivers and Warehouse Management structure improves warehouse performance. The current paper explicitly investigates such fit, and tests its impact on performance, thereby extending the findings of Faber *et al.* (2013) and translating them to insights for managers. Additionally, this study shows that contingency theory provides a useful theoretical lens through which the effect of Warehouse Management structure on performance can be studied. From a managerial perspective, developing an understanding of the relationships between warehouse performance, Warehouse Management structure, and warehouse characteristics helps firms in deciding on their own optimal model for planning and controlling warehouse processes, and in selecting an appropriate warehouse management information system to support it.

The paper is structured as follows. In the next section, we provide the theoretical and conceptual background in support of our hypotheses, followed by sections describing how data from actual DC settings are collected, discussing the measures of the constructs of the study, and reporting the results of the data analysis, respectively. In section 4.6, we develop a model for structuring high performance Warehouse Management. The final section ends with conclusions and suggestions for future research.

4.2 Background and hypotheses

A contingency research approach rests on two assumptions. First, there is no one best way to organize; in our case this means that there is no universally appropriate Warehouse Management structure that applies equally to all DCs in all circumstances. Second, the most effective organizational structure should be appropriate for the environmental conditions facing the organization. The major theoretical view on such organizational contingencies is contingency theory (Lawrence and Lorsch, 1967; Thompson, 1967; Woodward, 1958). In its most rudimentary form, this theory states that organizations adapt their structures to maintain fit with changing contextual factors. Failure to attain a proper fit between structure and environment results in inferior outcomes (typically, the outcomes are some aspects of performance). Already in the early days of contingency theory, performance was incorporated in the theory. For example, one of its pioneers, Woodward (1965), argued that where the organizational structure fits the organizational technology this caused superior performance compared to those organizations whose organizational structure is in misfit to the technology. Also, Lawrence and Lorsch (1967), who initiated the term contingency theory, demonstrated that organizations whose structures fitted their environment had higher performance. In Dubin's (1976) terms, the "law of interaction" in contingency theory states that organizational performance depends on the fit between organization context and its structure and process. Many of the principles of contingency theory have permeated other fields of study, such as strategic management, operations management, learning, marketing, and information systems.

Central to contingency theory is the concept of fit between structural and environmental characteristics (contingencies) of organizations (Donaldson, 2001). According to Donaldson (2001), three main elements form the core paradigm of structured contingency theory: (1) there is an association between contingency and the organizational structure; (2) contingency impacts the organizational structure; and (3) there is a fit of some level of the structural variable to a level of the contingency, where a high fit leads to effectiveness and a low fit leads to ineffectiveness. More specifically, Sousa and Voss (2008) state that contingency studies involve three types of variables: (1) contingency variables, which represent the context; (2) response variables, which represent the organizational or managerial actions taken in response to contingency factors, and (3) performance variables, which measure the effectiveness of the organization. Donaldson (2001) emphasizes that effectiveness in contingency theory has a wide-ranging meaning that includes efficiency, profitability, and employee satisfaction. Applying the contingency perspective in our study, we thus propose that the performance of a distribution center is dependent upon the fit between Warehouse Management structure and warehouse context.

As noted above, the fit-performance relationship has been investigated empirically in contingency theory research from the earliest studies onward (Donaldson, 2001). Performance variables in contingency studies are the dependent measures and represent specific aspects of effectiveness that are appropriate to evaluate the fit between structure and context variables for the situation under consideration.

In the contingency literature, there is no undisputed way to measure management structure and context of operations. Blackburn (1982) states that given the number of proposed structural dimensions and the variety of their definitions, identifying a definitive set of organizational dimensions or managerial actions is difficult without its specific context and objectives. This implies that each application of contingency theory should thus specify the structures that fit its contingency, so that fits and misfits are unique to that application (Donaldson, 2001). Faber *et al.* (2013) studied and identified relevant context features of DCs that affect Warehouse Management structure. They concluded that Warehouse Management structure for DCs is contingent on two main warehouse characteristics: Task Complexity and Demand Unpredictability. Task Complexity is defined as the number and diversity of tasks a DC has to perform and affects Warehouse Management structure through the comprehensibility of the work to be done. Demand Unpredictability refers to a warehouse's immediate environment that is uncontrollable by management and affects Warehouse Management structure through the predictability of the work to be done. Faber *et al.* (2013) also decomposed Warehouse Management structure into three structural dimensions: Planning Extensiveness, Decision Rules Complexity, and Control Sophistication. Planning Extensiveness is related to the time and resources put into preparing tactical plans, such as stock, storage location assignment, transport, and capacity (personnel and equipment) plans. Warehouses draw up tactical plans to make efficient use of resources and to fulfill market demand. Tactical plans define a framework for the operational planning level. Decision Rules Complexity refers to the complexity of operational decisions typically dealing with sequencing, scheduling, and routing of order picking and storage/retrieval operations. Control is the process of coping with changes to plans and schedules, and Control Sophistication relates to the speed of the feedback and corrective action function of the management system. For the purpose of the current study, we argue that the structural dimensions and context variables developed by Faber *et al.* (2013) capture structure and context as defined in contingency literature and are therefore appropriate for studying the drivers of warehouse performance. More specifically, Faber *et al.* (2013) found the following context-structure relationships between warehouse characteristics and Warehouse Management structure dimensions:

- The higher the Task Complexity, the more tactical plans are prepared (i.e., higher Planning Extensiveness).
- The higher the Task Complexity, the more, and the more complex decision rules are used to schedule and optimize warehouse activities (i.e., higher Decision Rules Complexity).
- The higher the Task Complexity, the more sophisticated the control system is (i.e., higher Control Sophistication).
- The higher the Demand Unpredictability, the fewer tactical plans are prepared (i.e., lower Planning Extensiveness).

Contingency theory holds that the effect of Warehouse Management structure (i.e., levels of Planning Extensiveness, Decision Rules Complexity, and Control Sophistication) on warehouse performance depends on its contingencies (Task Complexity and Demand Unpredictability). Thus, fit of Warehouse Management structure to contingencies leads to higher performance. This implies that when contingencies change, the Warehouse Management structure should also change to fit the new level of the contingencies to avoid loss of performance. Therefore, based on the findings of Faber *et al.* (2013), see Chapter 3, we specifically hypothesize:

H1. Fit between Task Complexity and Planning Extensiveness will positively influence Warehouse Performance. Here fit means that a higher Task Complexity requires a higher Planning Extensiveness.

H2. Fit between Task Complexity and Decision Rules Complexity will positively influence Warehouse Performance. Here fit means that a higher Task Complexity requires a higher Decision Rules Complexity.

H3. Fit between Task Complexity and Control Sophistication will positively influence Warehouse Performance. Here fit means that a higher Task Complexity requires a higher Control Sophistication.

H4: Fit between Demand Unpredictability and Planning Extensiveness will positively influence Warehouse Performance. Here fit means that a higher Demand Unpredictability requires a lower Planning Extensiveness. Thus, Demand Unpredictability and Planning Extensiveness are negatively related to influence Warehouse Performance positively.

Other factors relating to a DC may also affect warehouse performance, independent of its context and structure. We distinguish three main control variables: sector, ownership (whether the DC is insourced or outsourced), and operations type (finished goods production DC, spare parts DC, wholesale DC, retail DC). Our full conceptual framework is shown in Figure 4.1. This diagram conceptually links the areas of interest of this study.

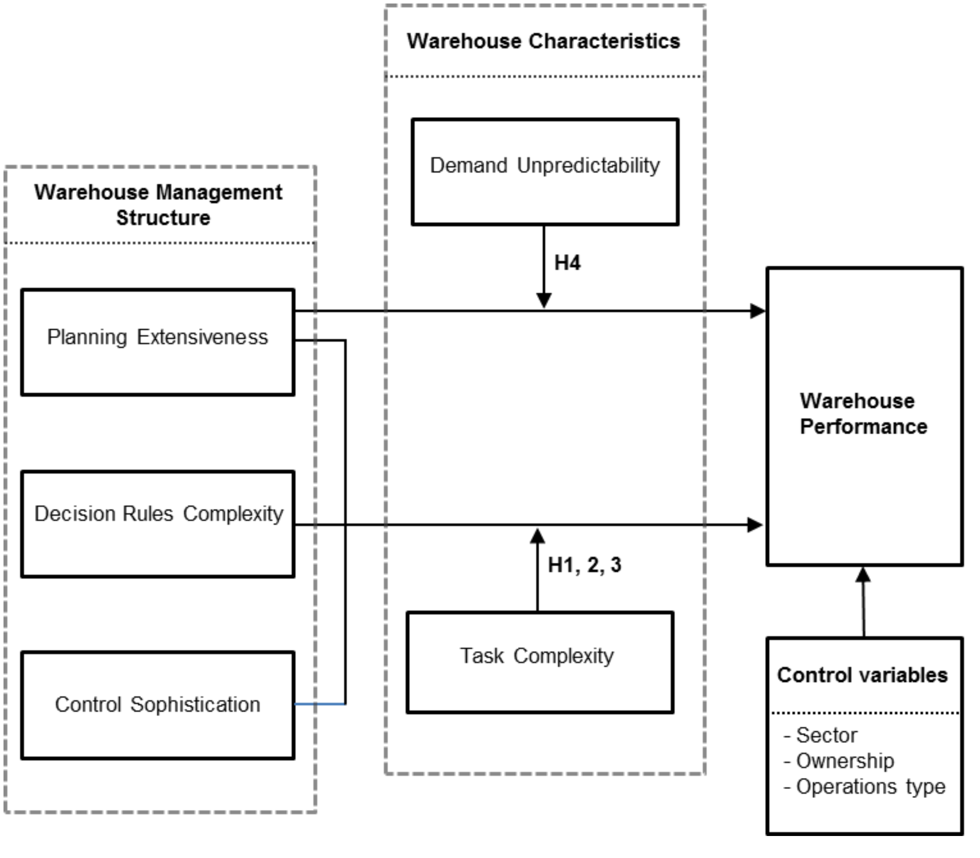

Figure 4.1 Conceptual framework of the performance implications of fit among Warehouse Management structure and warehouse characteristics (warehouse context)

4.3 Data collection and sample

To test our hypotheses, we use a subset of the database of 215 warehouses from Faber *et al.* (2013). They approached 765 warehouses in the Netherlands and Flanders to fill out a questionnaire regarding warehouse characteristics, Warehouse Management structure, and warehouse performance. In this study, we focus on warehouse performance data that were not used in the research of Faber *et al.* (2013).

Since we are interested in medium and large DCs only, nine very small DCs (fewer than five direct FTEs and fewer than 1000 stock keeping units (SKUs), or fewer than 60 order lines per day), incomparable in performance, were removed from the database, as were 21 production warehouses. We also excluded DCs that could not (i.e., Defense and Police DCs; n = 8) or did not answer all performance questions (n = 66). In this study, we use data from 111 completed questionnaires.

T-tests indicate that the subset of 111 DCs does not differ in Warehouse Management structure and warehouse characteristics variables from the 66 DCs that did not respond to the performance questions. Considering sector, the 111-database contains fewer ICT warehouses, 4.5 % versus 24.2%, and more industrial products DCs, 19.8% versus 3%. As to operations type, the 111-database contains more wholesale DCs, 19.8% versus 7.6%. We found no differences with regard to ownership.

Although this research is limited to the Netherlands and Flanders, distribution practices in both countries are not different from elsewhere in Western Europe. In fact, many companies run multiple similar facilities in Western Europe (Quak and De Koster, 2007, p. 1104). Since the database used by Faber *et al.* (2013) is sufficiently representative and the subset of 111 DCs does not differ from that database with respect to Warehouse Management structure or warehouse characteristics, we conclude that the current response is appropriate to draw meaningful conclusions for medium and large DCs. The average number of full-time (FTE) direct employees in the sample is 72 (SD = 85), the average number of stored SKUs per DC is 13,631 (SD = 23,396), and the average number of shipped order lines per day is 12,044 (SD = 23,886). See Table 4.1 for more descriptives of the sample.

Ownership	%	Operations type	%	Sector	%	No. direct FTEs	%	Size in m^2	%
DC insourced	63	Finished goods production DC	52.3	Automotive	6.3	< 10	10.8	< 1000	2.7
DC outsourced	37	Spare parts DC	6.3	Healthcare and Pharmaceutical	4.5	11 - 20	15.3	1000 - 3000	4.5
		Wholesale DC	19.8	Food retail	4.5	21 - 30	14.4	3000 - 5000	9.9
		Retail DC	21.6	Agricultural/Food products	7.2	31 - 50	15.3	5000 - 10,000	18.9
				ICT	4.5	51 - 70	11.7	10,000 - 20,000	27.0
				Industrial products	19.8	71 - 100	8.1	20,000 - 50,000	27.0
				Other products (mainly consumer products)	35.1	101 - 160	13.5	> 50,000	9.9
				Public warehouses (multiple categories)	18.0	161 - 250	8.1		
						251 - 600	2.7		
Total	100	Total	100	Total	100	Total	100	Total	100

Table 4.1 Sample description (n = 111)

4.4 Construct measures

4.4.1 Measuring warehouse characteristics and Warehouse Management structure

We measure the constructs Task Complexity (TC), Demand Unpredictability (DU), Planning Extensiveness (PE), Decision Rules Complexity (DRC), and Control Sophistication (CS), following Faber *et al.* (2013), see Chapter 3. A compilation of the warehouse characteristics constructs and their measures is summarized in Appendix B. Appendix C summarizes the Warehouse Management structure constructs.

4.4.2 Measuring warehouse management fit

The key concept in this study is fit, more specifically warehouse management fit. We define warehouse management fit as the appropriateness of the level of Planning Extensiveness, Decision Rules Complexity and Control Sophistication to the level of Task Complexity and Demand Unpredictability as found by Faber *et al.* (2013), see Chapter 3. In this paper (Chapter 4), we hypothesize that warehouse management fit predicts warehouse performance in such a way that a better warehouse management fit leads to a higher performance. Fit, although intuitive from a theoretical perspective, is an elusive concept for empirical research. Venkatraman (1989) provides an overview of various forms of fit, statistical methods used for analysis, and the implicit assumptions made in the theoretical formulation and empirical analysis. Although his study was conceptualized in the context of strategy research, it is applicable in other disciplines as well. Venkatraman (1989) identifies six different perspectives of fit. Given the variety of perspectives of fit that can be adopted, it is important that the selected interpretations are appropriate for the specific context (Venkatraman, 1989). The hypotheses of this study explicitly addresses the effect of fit between warehouse characteristics variables and Warehouse Management structure variables on warehouse performance. As recommended by Venkatraman (1989), we adopt the 'Fit as Moderation' perspective to measure warehouse management fit, because of the high degree of specificity of the theoretical relationships and the criterion-specificity (i.e., warehouse performance) of the hypotheses of this study. The moderation perspective assumes that the impact of a predictor variable (in this research: Warehouse Management structure) has on a criterion or outcome variable (in this research: warehouse performance) is dependent on the level of a third variable, the moderator (in this research: warehouse characteristics). See Figure 4.2.

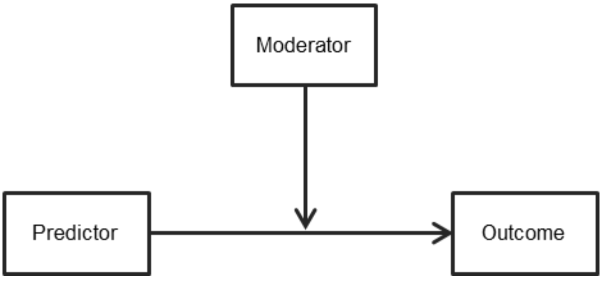

Figure 4.2 Diagram of the conceptual moderation model (source: Field, 2013)

In other words, the effect of Warehouse Management structure on warehouse performance is contingent on warehouse characteristics variables (Task Complexity and Demand Unpredictability). A linear model is assumed such that the moderator (warehouse characteristic) determines the sign and magnitude of the linear effect of the predictor (structural variable: Planning Extensiveness, Decision Rules Complexity, or Control Sophistication) on the outcome (warehouse performance). In the 'Fit as Moderation' method, the fit between the predictor and the moderator is the primary determinant of the criterion variable (outcome). In this method, fit is tested by the cross product (i.e., interaction effect) of two variables. A statistically significant interaction term indicates that the two variables (in this research: Warehouse Management structure and warehouse characteristics) exhibit a fit, and that this fit influences a dependent variable (in this research: Warehouse Performance). A positive interaction term implies that an increase (decrease) in a warehouse characteristic variable makes the slope of the structural variables in predicting warehouse performance more positive (negative). In line with hypotheses 1, 2, 3, and 4, respectively, we test the impact of warehouse management fit on performance by four interaction terms:

1. The cross-product of the standardized scores of Task Complexity and Planning Extensiveness (TCxPE).
2. The cross-product of the standardized scores of Task Complexity and Decision Rules Complexity (TCxDRC).
3. The cross-product of the standardized scores of Task Complexity and Control Sophistication (TCxCS).
4. The cross-product of the standardized scores of Demand Unpredictability and Planning Extensiveness (DUxPE).

4.4.3 Measuring warehouse performance

Warehouse performance is mostly measured by means of the Data Envelopment Analysis (DEA) method (Andrejić *et al.*, 2013; Banaszewska *et al.*, 2012; De Koster and Balk, 2008; Hackman *et al.*, 2001; Hamdan, 2005; Hamdan and Rogers, 2008; Hollingsworth, 1995; Johnson and McGinnis, 2011; Zimmerman *et al.*, 2001). DEA is a non-parametric linear programming technique that is capable of simultaneously capturing all relevant inputs (resources) and outputs into a single score of efficiency, and is therefore regarded as an appropriate tool for warehouse benchmarking (Cooper *et al.*, 2004). DEA measures the relative efficiency of a set of comparable decision-making units (DMU). DMU is commonly used in the DEA literature to refer to the organizations under examination. An efficient DMU means that no other DMU can either produce the same outputs by consuming fewer inputs, known as the input-orientated approach; similarly, it cannot produce more outputs by consuming the same inputs, known as output-orientated approach. Coelli *et al.* (2003) and Fried *et al.* (2008) provide a partial list of the many applications of DEA.

When determining the necessary input and output factors, all the important aspects that determine the operational efficiency must be included. Furthermore, each input and output must have a defined unit of measure that is meaningful and measurable. In the DEA literature, different input-output models have been developed to benchmark warehouse operations. At the conceptual level, most authors agree that the core inputs are labor, size, and equipment, representing the resources. With respect to the outputs, consensus only seems to exist on produced order lines.

In our study, we measure Warehouse Performance using DEA variables selected by De Koster and Balk (2008). The input factors of their model are labor, size, and equipment. They operationalize the input factor equipment by the degree of automation and the number of different stock keeping units (SKUs), representing equipment investments. The output factors of the internal operation of a DC are mainly to be measured in terms of production output, quality, and flexibility (De Koster and Balk, 2008). Where De Koster and Balk (2008) use three indicators for production output: order lines, value added logistics, and special processes, we use two indicators in our study: order lines and special processes. Here value added logistics is interpreted as a special process and for this reason not seen as separate output. In line with De Koster and Balk (2008), we distinguish two additional output factors: quality and flexibility. The input-output model we use in our study is shown in Figure 4.3. A compilation of the DEA input variables and their measures are summarized in Appendix E. Appendix F summarizes the DEA output variables.

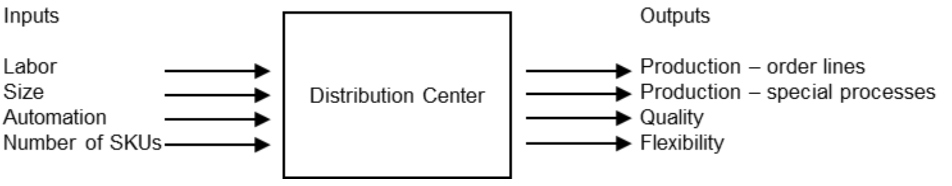

Figure 4.3 Input-output model of a distribution center

In a DEA, positivity and isotonicity conditions must be met, which means that an increase in an input should increase one or more outputs (Bowlin, 1998). Table 4.2 presents the Pearson correlation coefficients between the input and output factors of our DEA model. Although some of the input and output variables are measured at an ordinal scale, the number of classes is quite large (6 – 9; see Appendix E and F) and we have therefore interpreted them on an interval scale in the computation. In spite of the fact that SKUs are significantly correlated to only one output factor (i.e., Flexibility, $p < 0.10$), all relationships of SKUs to outputs have the correct sign and we therefore maintain the model of De Koster and Balk (2008).

	Mean	SD	Order lines	Special processes	Quality	Flexibility
Labor	72.4	85.3	0.75^{***}	0.20^{**}	-0.10	0.14
Size	4.8	1.4	0.29^{***}	0.26^{***}	0.07	0.25^{***}
Automation	3.7	1.3	0.33^{***}	0.18^{*}	0.29^{***}	0.04
SKUs	13,631.4	23,395.8	0.14	0.12	0.06	0.16^{*}
Order lines	12,044.4	23,885.7				
Special processes	5.4	2.3				
Quality	98.5	2.6				
Flexibility	7.4	1.1				

Note: Significant at: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

Table 4.2 Means, SDs, and Pearson correlation coefficients between DEA input and output variables (n = 111)

We use the original Charnes, Cooper, and Rhodes (CCR) (Charnes *et al.*, 1978) input-oriented approach for the DEA calculations (see Appendix G). The maximum efficiency score is 100%, which means that the DC is efficient. An inefficient DC has an efficiency score of between 0 and 100%. Input orientation of the model means that an inefficient DC with a score of x% should be able to achieve its output with only x% of its input resources.

The DEA results indicate that 17% of the DCs (i.e., 19 DCs) operate efficiently. The mean efficiency score for the sample of this study is 0.65 with a standard deviation of 0.21.

The basic DEA model has some limitations. First, it does not distinguish between efficient DCs. Consequently, the distribution of efficiency scores is highly skewed. Second, it allows for unrestricted weight flexibility, which may result in identifying a DC with an unrealistic weighting scheme to be efficient (Eren Akyol and De Koster, 2013). Such DCs perform well with respect to few input/output measures, but do not or hardly act as peer to other DCs in the sample (in our sample this is the case for five DCs: DC11, DC22, DC 33, DC 56, and DC125, see Table 4.3).

DC	DEA Efficiency	No of times acted as peer
5	1.00	35
11	**1.00**	**0**
12	1.00	29
22	**1.00**	**1**
23	1.00	52
33	**1.00**	**0**
40	1.00	6
47	1.00	6
53	1.00	10
56	**1.00**	**0**
69	1.00	5
85	1.00	45
91	1.00	36
97	1.00	55
103	1.00	6
105	1.00	43
108	1.00	56
110	1.00	10
125	**1.00**	**3**

Table 4.3 Efficient DCs according to DEA

In order to overcome these limitations, Sexton *et al.* (1986) propose the Cross Efficiency Evaluation (CEE) model, which can identify good overall performers and distinguish between efficient DCs. The CEE model calculates the efficiency of each DC using the optimal input and output weights of all other DCs obtained from the DEA model. An 111 x 111 Cross Efficiency Matrix (CEM) is constructed using the cross efficiencies of all DCs. In the CEM, the element in the ith row and the *j*th column represents the efficiency of DC*j* evaluated with respect to the optimal weights of DC*i*. The elements in the diagonal consist of DEA efficiencies, whereas the remaining elements represent the cross efficiency values. A DC with high efficiency values along its column is a good overall performer; a DC with low efficiencies along its column is a poor performer. Warehouse Performance of each DC in the sample is measured by the average value of each column of the CEM. See Appendix G for the so-called aggressive CEE model (Doyle and Green, 1994; Liang *et al.*, 2008) we use in this research. To check robustness of performance, we also implemented the ranked super-efficiency scores (Lovell and Rouse, 2003; Zhu, 2001). The difference between the ranked super-efficiency score and the Warehouse Performance score turned out to be minimal (Pearson correlation coefficient is 0.90).

The average (CEE) Warehouse Performance score for the sample is 0.39 with a standard deviation of 0.14. The minimum score is 0.16 and the maximum score is 0.85. The histogram of Warehouse Performance is shown in Figure 4.4. A Kolmogorov-Smirnov test indicates that the null hypothesis that the distribution Warehouse Performance is normal with mean 0.39 and standard deviation 0.14 cannot be rejected ($p < 0.157$).

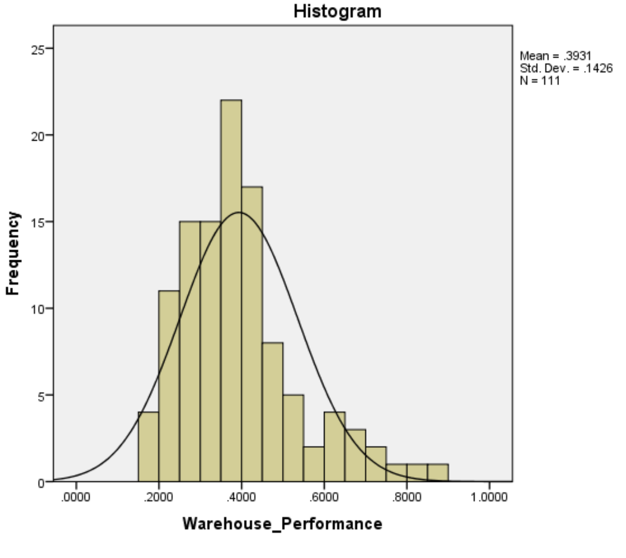

Figure 4.4 Histogram Warehouse Performance (n = 111)

4.5 Analysis and findings

The DCs in our analysis operate in a variety of industry sectors, are run by the company itself (insourced) or by an LSP (outsourced), and differ with respect to operations types (finished goods production, spare parts, wholesale, retail). We use ANOVA tests to explore the role of these different control variables and find that the industry sector 'agricultural/food products' has significantly higher Warehouse Performance scores than other sectors ($F(7,103) = 3.005$, $p < 0.007$; see Appendix H). Upon a more close inspection, the 'agricultural/food products' DCs ($n = 8$) appear to have significant lower automation degrees than the other sectors, and Task Complexity is significantly lower for this group, which might explain the relatively high performance. We found no significant differences in Warehouse Performance between insourced and outsourced DCs ($F(1,109) = 1.042$, $p < 0.310$; see Appendix H) or between different operation types ($F(3,107) = 1.332$; $p < 0.268$; see Appendix H).

The objective of our study is to assess the relationship between warehouse management fit and Warehouse Performance. Warehouse management fit refers to the alignment of Warehouse Management structure with its warehouse characteristics. Table 4.4 shows the correlations of the Warehouse Management structure variables, warehouse characteristics variables, interaction terms, and Warehouse Performance.

	TC	DU	PE	DRC	CS	TCxPE	TCxDRC	TCxCS	DUxPE	WP
Task Complexity (TC)	1									
Demand Unpredictability (DU)	-0.18	1								
Planning Extensiveness (PE)	0.33***	-0.27**	1							
Decision Rules Complexity (DRC)	0.49***	-0,19*	0.32***	1						
Control Sophistication (CS)	0.23*	0.01	0.11	0.36***	1					
Interaction TCxPE	0.09	0.03	-0.26**	-0.04	0.03	1				
Interaction TCxDRC	0.05	0.00	-0.04	0.15	0.11	0.29**	1			
Interaction TCxCS	0.02	-0.02	0.03	0.10	0.10	0.04	0.27**	1		
Interaction DUxPE	0.03	-0.02	-0.01	0.07	0.05	-0.12	0.02	0.05	1	
Warehouse Performance (WP)	- 0.39***	-0.02	-0.15	-0.27**	-0.22*	-0.10	0.16	0.00	-0.14	1
N	111	110	111	111	110	111	111	110	110	111
Min	-2.26	-1.63	-2.32	-1.88	-1.67	-2.9	-2.7	-2.7	-3.9	0.16
Max	2.0	1.8	1.1	2.32	1.6	2.7	3.4	3.4	2.5	0.85
Mean	0	0	0	0	0	0	0	0	0	0.39
SD	1	1	1	1	1	1	1	1	1	0.14

Note: Significant at: *p < 0.05; **p < 0.01; ***p < 0.001

Table 4.4 Mins, maxs, means, SDs, and Pearson correlation coefficients of Warehouse Management structure variables, warehouse characteristics variables, interaction terms, and Warehouse Performance

To test our four hypotheses, we use the linear regression model. Warehouse Performance is first regressed on the control variables stepwise (industry sector, ownership, operations type). Next, the warehouse characteristics (Task Complexity and Demand Unpredictability), Warehouse Management structure (Planning Extensiveness, Decision Rules Complexity and Control Sophistication), and interaction terms (TCxPE, TCxDRC, TCxCS and DUxPE) are entered into the regression model. Table 4.5 shows the results. All reported *p*-values are two-tailed. Standardized explanatory (mean = 0 and standard deviation = 1) variables are employed in the regression model to ensure that differences in scale among the variables do not affect the results, and to increase interpretability of the regression terms.

	Warehouse Performance							
	Step 1				Step 2			
	B	**β**	***t***	***p***	**B**	**β**	***t***	***p***
Constant	0.377	-	28.68	0.00**	0.370	-	25.69	0.00**
Control variables								
Sector Agricultural/ Food products	0.215	0.39	4.43	0.00**	0.132	0.24	2.45	0.02**
Warehouse characteristics								
Task Complexity (TC)					-0.034	-0.24	-2.29	0.02**
Demand Unpredictability (DU)					-0.014	-0.10	-1.12	0.27
Warehouse Management variables								
Planning Extensiveness (PE)					-0.020	-0.14	-1.42	0.16
Decision Rules Complexity (DRC)					-0.012	-0.09	-0.82	0.42
Control Sophistication (CS)					-0.011	-0.08	-0.88	0.38
Interactions								
TCxPE					-0.020	-0.14	-1.40	0.16
TCxDRC					0.029	0.18	1.89	0.06*
TCxCS					-0.006	-0.04	-0.46	0.65
DUxPE					-0.020	-0.15	-1.82	0.07*
R^2	0.16				0.32			
F-value	19.657				4.682			
Sig F Change	0.00				0.01			
R^2 change	0.16				0.17			
n=	109				109			

Note: Significant at: *p < 0.10, **p < 0.05

Table 4.5 Regression results for Warehouse Performance

With respect to the control variables, the regression results in Table 4.5 show only significant effects for the industry sector ‘agriculture/food products’. In step 2, an omnibus F-test shows that the added variables (i.e., main effects and interactions) representing our four hypotheses contribute significantly to the variance explained over and above the first step (F = 4.68, $p < 0.01$; R^2-change = 0.17). In step 2, a statistically significant interaction term would indicate that the two variables exhibit a fit, and that this fit influences the independent variable, Warehouse Performance. This applies to interaction term TCxDRC (β = 0.18; p = 0.06) and interaction term DUxPE (β = -0.15; p = 0.07) but not for interaction terms TCxPE (β = -0.14; p = 0.16) and TCxCS (β = -0.04; p = 0.65). The interaction term DUxPE is negative when there is fit between Demand Unpredictability and Planning Extensiveness: a higher Demand Unpredictability requires a lower Planning Extensiveness. Therefore, in Table 4.5, the interaction term DUxPE has the expected sign by influencing Warehouse Performance negatively. Furthermore, Table 4.5 shows a significant negative effect of Task Complexity on Warehouse Performance (β = -0.24; p = 0.02).

The direction of the effect of fit cannot be interpreted solely from the β-coefficient of the interaction term because the main effects (single variable terms) and interaction term must be interpreted collectively (Venkatraman, 1989; Hoffman *et al.*, 1992; Stock and Tatikonda, 2008). We therefore need to delve a bit deeper to find out the nature of the moderation. First, we discuss the nature of interaction effect TCxDRC, testing hypothesis 1. We select TC low and TC high values to be the mean minus one standard deviation, and the mean plus one standard deviation, respectively. Because the variables are standardized, the low and high TC values are -1 and +1, respectively. Figure 4.5 shows that Warehouse Performance is higher when there is a greater fit between TC and DRC. This can be seen by examining the endpoints of the two regression lines shown in Figure 4.5.

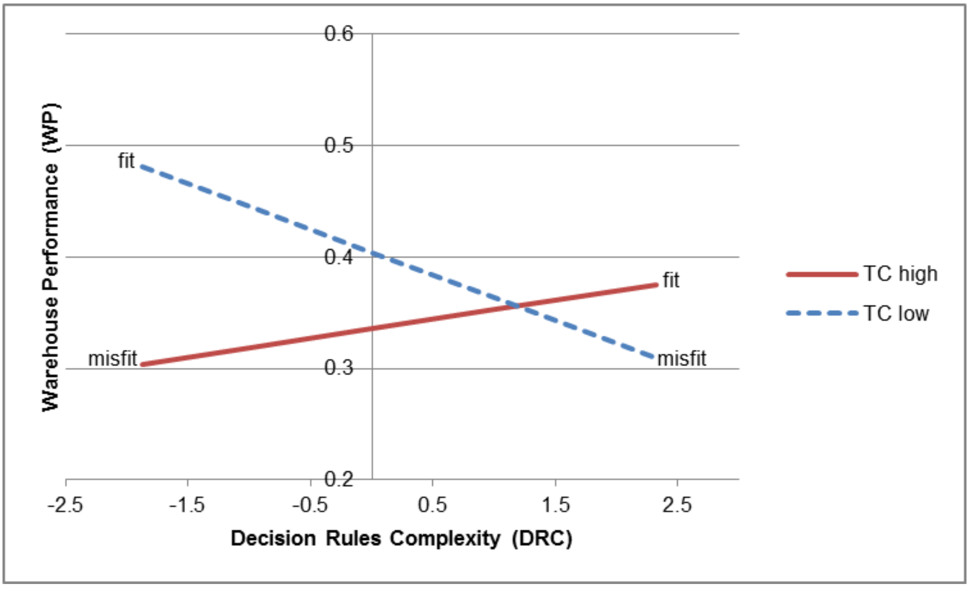

Figure 4.5 Interaction effect TCxDRC on Warehouse Performance

For a high level of Decision Rules Complexity (DRC = +2.32), there is a higher level of Warehouse Performance when Task Complexity is high (TC = +1) than for low Task Complexity (TC = -1). For a low level of Decision Rules Complexity (DRC = -1.88), there is a higher level of Warehouse Performance for the TC low line (TC = -1) than for the TC high line (TC = +1). To test whether the relationship between Decision Rules Complexity and Warehouse Performance significantly changes at different levels of Task Complexity, we compare these slopes in a simple slopes analysis (Aiken and West, 1991). Results show that when Task Complexity is low, there is a significant negative relationship between Decision Rules Complexity and Warehouse Performance ($\beta = -0.04$; $p = 0.08$) (striped line in Figure 4.5), and when Task Complexity is high (solid line in Figure 4.5), there is a positive but non-significant relationship between Decision Rules Complexity and Warehouse Performance ($\beta = +0.02$; $p = 0.40$). The reported p-values are two-tailed. In conclusion, when Task Complexity is low implementing more decision rules and more complex ones significantly influences Warehouse Performance negatively. Implementing more, and more complex decision rules when Task Complexity increases has a positive effect on Warehouse Performance, but this effect is only directionally significant. In conclusion, the results of the current study show that *H1* is supported when Task Complexity is low: with decreasing Task Complexity, a lower Decision Rules Complexity is required to achieve a higher Warehouse Performance. *H1* is only directionally supported when Task Complexity is high: with increasing Task Complexity, a higher Decision Rules Complexity tends to increase Warehouse Performance.

Second, we discuss the nature of the interaction effect DUxPE, testing hypothesis 2. We select DU low and DU high values to be the mean minus one standard deviation, and the mean plus one standard deviation, respectively. Again, the variables are standardized so that the low and high DU values are -1 and +1, respectively. Figure 4.6 shows that as Planning Extensiveness increases, the Warehouse Performance score is higher when there is a better fit between Demand Unpredictability and Planning Extensiveness. This can be seen by examining the endpoints of the two regression lines shown in Figure 4.6.

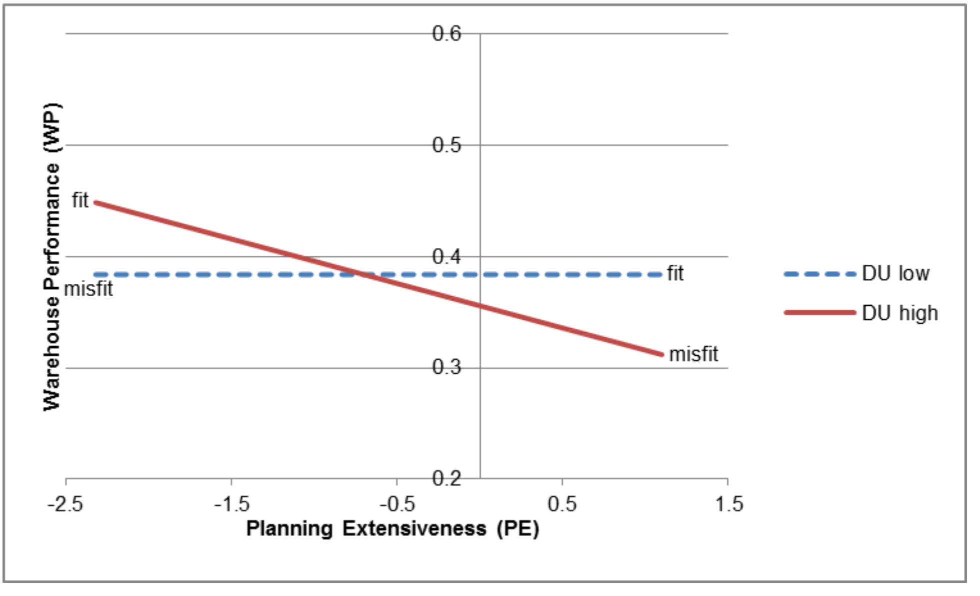

Figure 4.6 Interaction effect DUxPE on Warehouse Performance

For a high level of Planning Extensiveness (PE = 1.1), Warehouse Performance is higher for DU low (DU = -1) than for DU high (DU = +1). For a low level of Planning Extensiveness (PE = -2.32), Warehouse Performance is higher for DU high (DU = 1) than for DU low (DU = -1). Applying a simple slopes analysis reveals that when Demand Unpredictability is low, there is no relationship between Planning Extensiveness and Warehouse Performance (β = -0.00; p = 0.99) (striped line in Figure 4.6), and when Demand Unpredictability is high (solid line in Figure 4.6), there is a significant negative relationship between Planning Extensiveness and Warehouse Performance (β = -0.04; p = 0.03). In conclusion, for a high level of Demand Uncertainty more extensive planning influences Warehouse Performance significantly negative. The data does not support the relationship between Planning Extensiveness and Warehouse Performance when Demand Unpredictability is low. Thus, the results show that *H4* is only supported for high Demand Unpredictability: to achieve a high performance, a higher Demand Unpredictability requires a less extensive planning.

4.6 Towards a model for structuring high performance Warehouse Management

In this paper, we hypothesized and tested the relationship between warehouse management fit and performance, where warehouse management fit is achieved by aligning Warehouse Management structure with the characteristics of the DC. Figure 4.7 shows the relationships (directionally) between Warehouse Management structure and warehouse characteristics, that taken together constitute warehouse management fit for DCs.

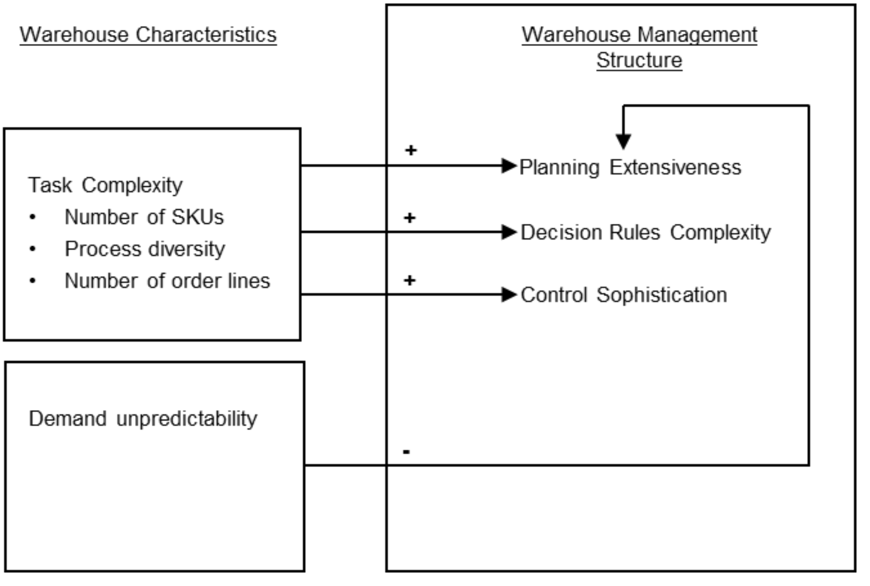

Figure 4.7 Warehouse management fit: Effects of Task Complexity and Demand Unpredictability on Warehouse Management structure of DCs

In section 4.5, we tested whether these relationships positively influence performance. Figure 4.8 shows the conceptual framework of this research where the effect of Warehouse Management structure on Warehouse Performance was hypothesized to be contingent on warehouse characteristics.

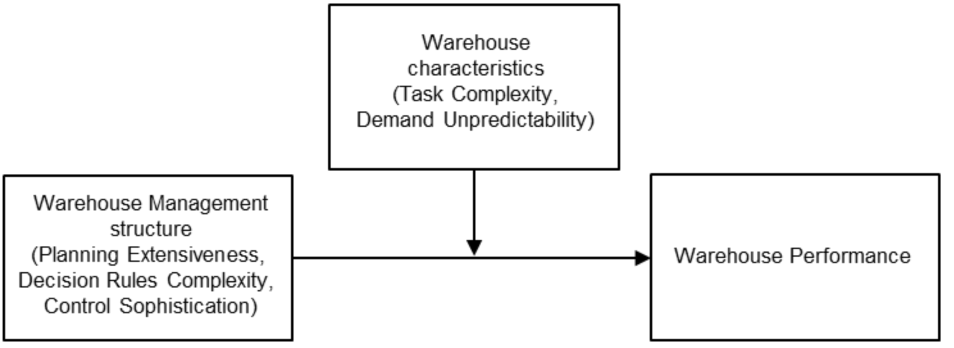

Figure 4.8 Conceptual framework of the performance implications of warehouse management fit

We first discuss the findings of the effect of planning structure on performance. The performance-planning relationship was hypothesized to be contingent on Task Complexity as well as on Demand Unpredictability, but with conflicting implications. The results in section 4.5 show that when demand is more difficult to predict, performance increases if planning efforts are limited. In other words, investing in tactical plans decreases performance when demand is more unpredictable. Most likely this is because human resources are captured in drawing up and maintaining plans which have to be modified continuously, thereby reducing efficiency. On the other hand, when demand is predictable, no effect was found of planning on performance. Also, the research results show no moderation effect of Task Complexity on the performance-planning relationship. It stands to reason that the moderation effect of Task Complexity on the performance-planning relationship is affected by Demand Unpredictability and vice versa. Extensive planning was expected to be a waste of time and resources when demand is more predictable and the warehouse task is more simple, but was expected to increase performance when the task becomes more complex. However, a three-way interaction analysis did not support this proposition. This may be due to the relatively small sample size of 111 DCs, which reduces the power of the test.

Second, we discuss the effect of decision rules structure on performance. The research results show that managing a simple warehouse task by applying a limited number of simple decision rules increases performance. Thus, in this case, investing in software offering many different and complex decision rules seems to be a waste of money. On the other hand, the results show that managing a more complex warehouse task by applying more, and more complex decision rules affect performance positively, but the effect is only directionally significant.

Third, we found no moderating effect of Task Complexity on the relationship between the control element of Warehouse Management structure and Warehouse Performance. All in all, the results show that a simple Warehouse Management structure (i.e., limited planning efforts, and limited number of simple decision rules) increases performance when the warehouse task is simple and demand is difficult to predict (see first row in Figure 4.9). A simple Warehouse Management structure is also expected to increase performance when the task is simple and demand is predictable (see third row in Figure 4.9), but this is not fully supported by this research. Furthermore, a Warehouse Management structure that typically focuses on optimization (i.e., limited planning efforts, and more, and more complex decision rules) tends to increase performance when the warehouse task is complex and demand is difficult to predict (see second row in Figure 4.9). Finally, a complex Warehouse Management structure (i.e., extensive planning, and more, and more complex decision rules) is expected (but not fully supported by the research) to increase performance when the task is complex and demand is predictable (see last row in Figure 4.9).

Contingencies (warehouse characteristics)	Value	Warehouse Management structure	Warehouse Performance
Task Complexity Demand Unpredictabillity	low high	**Simple** (i.e., limited planning efforts + limited number of simple decision rules)	High
Task Complexity Demand Unpredictabillity	high high	**Optimization focused** (i.e., limited planning efforts + more, and more complex decision rules)	High *(tendency)*
Task Complexity Demand Unpredictabillity	low low	**Simple** (i.e., limited planning efforts + limited number of simple decision rules)	High *(expected)* *Not fully supported by this research*
Task Complexity Demand Unpredictabillity	high low	**Complex** (i.e., extensive planning + more, and more complex decision rules)	High *(expected)* *Not fully supported by this research*

Figure 4.9 Theoretical model for structuring high performance Warehouse Management

4.7 Conclusions and future research

In this paper, we took a first step towards understanding the impact of Warehouse Management structure on warehouse performance. The study show that it is important to implement the appropriate level of planning extensiveness and decision rules complexity to achieve higher warehouse performance, beyond effects of industry sector, ownership, or operations type. Our results are of importance for managers, as they show that demand unpredictability and task complexity can effectively be managed by choosing the appropriate level of planning and level of decision rules complexity. Our contribution to warehousing practice is that we demonstrate that fit between Warehouse Management structure and warehouse context has a positive impact on performance. This is a novel finding for Warehouse Management. Managers can use such knowledge in selecting appropriate planning and control systems for their warehouse, fitting the context. Warehouse planning systems that are too extensive in dynamic contexts, or scheduling and optimization that are too complex in simple contexts imply a misfit and lead to underperformance. Additionally, Warehouse Management structure dictates the form and operation of the information system supporting it. Therefore, our findings can also help managers in selecting an appropriate warehouse management information system.

The research in this paper (Chapter 4) has some limitations. The high level of aggregation implies a limited operational applicability of the findings for a specific warehouse. Warehouse Management structure is operationalized by three main constructs, thereby perhaps underscoring its complexity. Consequently, future research could further develop measures of Warehouse Management structure and/or more specific and detailed operationalizations of each dimension. For example, we expected that more, and more complex decision rules would be able to manage a large number of products, processes, and daily order lines (i.e., a complex task) and consequently increase performance. One possible explanation for the lack of finding a strong effect for this is that we did not study whether the decision rules are appropriate for the different specific tasks they have to optimize or schedule. In future research, complex DCs could be studied in more detail with respect to applied decision rules. Furthermore, we found no support for the hypothesis that managing internal task complexity by sophisticated control increases performance. This may be due to the current operationalization of Control Sophistication that solely focuses on swift (online or real time) data processing to allow human decision-making. We thus speculate that taking into account just one dimension (swift data processing), even though it is an obvious and important one, may not fully capture the control system of Warehouse Management. For example, another important aspect of the control system is human behavior, especially with respect to interpreting information and taking action on it. Future research on the (behavioral) control element of Warehouse Management structure, incorporating hard and soft controls, and its impact on warehouse performance is therefore called for.

While complexity and uncertainty appear to be useful as contingent factors for simple Warehouse Management structures, the results suggest other contingency factors are involved, especially for more complex Warehouse Management structures. Thus, another useful direction for future research is to examine other contingent factors. Factors such as supply chain development stage, chosen competitive strategy (cost focused vs responsiveness), and resource base (labor or automation) could also determine Warehouse Management structure.

Another limitation of the research is that performance is measured using a score constructed from eight input-output variables. In practice, other variables and aspects may play a role in determining warehouse performance, e.g., financial criteria (e.g., ROA, ROI), customer satisfaction scores, innovativeness, service, and safety and environmental aspects.

A final remark concerning researching drivers of warehouse performance. The coefficient of determination ($R^2 = 0.32$) in our research indicates that a partial model is investigated. Other factors such as leadership style, employee motivation, or lay-out of the DC may also hold predictive power for warehouse performance and these are omitted in our conceptual framework.

5

Conclusions and future research

5.1 Conclusions

In this dissertation, we developed a model for structuring high performance Warehouse Management. We adopted a contingency perspective, meaning that the structure of Warehouse Management is considered to be context dependent in order to attain high performance. Therefore, we first identified key characteristics that drive Warehouse Management structure (research question 1). Based on a multiple case study of 20 warehouses in the Benelux (Chapter 2) and a literature study (Chapter 3), we determined two key warehouse characteristics for structuring Warehouse Management: Task Complexity and Market Dynamics. Then, by analyzing the data of the 20 cases and by reviewing the literature, we distinguished three key determinants of Task Complexity; namely, the number of daily order lines, the number of SKUs, and the variety of warehouse processes. The literature study led to characterizing the external environment of a warehouse by the construct Market Dynamics, consisting of two key determinants, namely demand unpredictability and frequency of assortment changes.

The second research question aimed to define the dimensions of Warehouse Management structure. The general operations management literature and production management literature in combination with interviews with warehousing experts were used to identify these dimensions (Chapter 3). On this basis, Warehouse Management structure was defined as *the blueprint specifying the way in which Warehouse Management processes are organized. These processes consist of planning, controlling, and optimizing. In the optimizing process, inbound and outbound decision rules are used.* Warehouse Management structure was measured by three constructs: Planning Extensiveness, Decision Rules Complexity, and Control Sophistication.

The third research question aimed to characterize the warehouse management information system with respect to warehouse planning and control. This question was answered by conducting the multiple case study (Chapter 2) and literature study (Chapter 3), and resulted in defining the construct Specificity of the information system functionalities as its core characteristic.

The combination of the multiple case study, the literature study, and a survey contributed to answering the fourth research question on the effects of warehouse characteristics on Warehouse Management structure, and on the specificity of the related warehouse information system (Chapter 3). Hypotheses were developed on the effects of both Task Complexity and Market Dynamics on each of the three dimensions of

Warehouse Management structure and on the specificity of the related warehouse information system. These hypotheses were tested in a sample survey of 215 warehouses in the Netherlands and Flanders (Belgium). Overall, the results show that Warehouse Management structure is affected by the warehouse type (i.e., production warehouse or distribution center), by Task Complexity, and to a lesser extent by Market Dynamics.

An interesting difference was found between production warehouses and distribution centers. The 'frequency of assortment changes' (a key determinant of Market Dynamics) did not show significant effects for distribution centers. Since, assortment changes are more predictable downstream the supply chain, they therefore cause fewer disturbances at distribution centers. It was concluded therefore that production warehouses and distribution centers structure their planning function to different characteristics of the external environment. That is, production warehouses structure their planning function to Market Dynamics (i.e., demand unpredictable and frequency of assortment changes), whereas distribution centers structure their planning function to Demand Unpredictability. More precisely:

- Production warehouses prepare fewer tactical plans as the market is more dynamic (relationship A in Figure 5.1).
- Distribution centers prepare fewer tactical plans as demand is more unpredictable (relationship B in Figure 5.1).

Both warehouse types also structure their planning function differently in response to Task Complexity:

- Production warehouses show no significant reaction to the complexity of the task.
- Distribution centers prepare more tactical plans as the task becomes more complex (relationship C in Figure 5.1).

The other results of this study which apply to both warehouse types are:

- More, and more complex decision rules are used to schedule and optimize warehouse activities as the task a warehouse has to perform becomes more complex (relationship D in Figure 5.1).
- The control system is more sophisticated if the task a warehouse has to perform becomes more complex (relationship E in Figure 5.1).
- The warehouse management information system is more specific when the task a warehouse has to perform becomes more complex (relationship F in Figure 5.1).

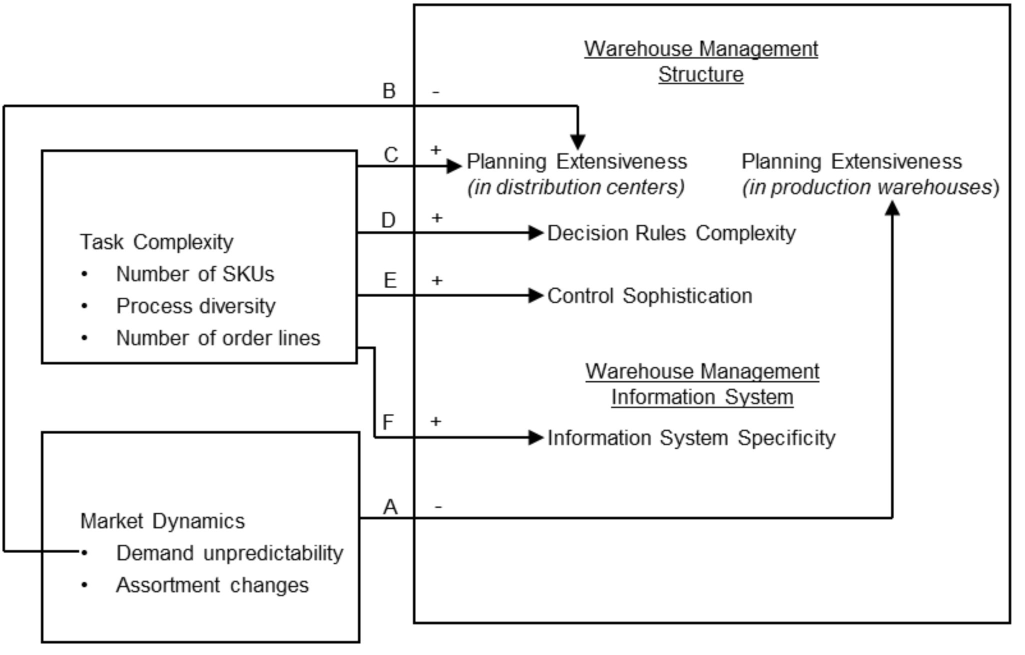

Figure 5.1 Effects of Task Complexity and Market Dynamics on Warehouse Management structure: Main findings Chapter 3

In sum, Figure 5.1 shows the empirically found relationships between warehouse characteristics and Warehouse Management structure, and between warehouse characteristics and the related warehouse management information system (Chapter 3).

In Chapter 4, the relationships found between Warehouse Management structure and warehouse characteristics (see Figure 5.1) were tested on whether they influence warehouse performance positively (research question 6). As production warehouses and DCs responded to different external environmental characteristics (see Figure 5.1), the study of Chapter 4 focused on DCs only; DCs constituted the majority of warehouses in the sample. Therefore, in this study, Demand Unpredictability was defined as the construct for the external environment of a warehouse. Furthermore, we introduced the concept warehouse management fit and defined it as the appropriateness of the level of planning extensiveness, decision rules complexity and control sophistication to the level of task complexity and demand unpredictability as found in Chapter 3. In Chapter 4, a survey was conducted to examine the effect of warehouse management fit on Warehouse Performance. We hypothesized that the fit between structure and characteristics predicts performance and tested the hypotheses in a survey of 111 DCs in the Netherlands and Flanders (Belgium). To operationalize warehouse management fit, we used Venkatraman's 'Fit as

Moderation' model. This model explicitly examines Warehouse Performance differences between warehouses, testing for an interaction effect between pairs of structural and characteristics (i.e., contingency) factors on performance. A linear model was assumed such that warehouse characteristics determine the sign and magnitude of the linear effect of the structural variables (Planning Extensiveness, Decision Rules Complexity, and Control Sophistication) on Warehouse Performance. In other words, the effect of Warehouse Management structure on Warehouse Performance was hypothesized to be contingent on warehouse characteristics (Task Complexity and Demand Unpredictability). A positive interaction term implies that an increase (decrease) in a warehouse characteristic variable makes the slope of the structural variable in predicting Warehouse Performance more positive (negative). To test the hypotheses of Chapter 4, we also measured Warehouse Performance. The fifth research question was aimed at defining and operationalizing Warehouse Performance. This question was answered by conducting a literature review to search for a single overall performance score that could easily compare the performance effects of different Warehouse Management structures in different situations. Warehouse Performance was operationalized by the ratio of produced outputs to all relevant input factors (resources). The input factors selected in this research were: number of FTEs, warehouse size, degree of automation, and number of SKUs. The output factors were: number of order lines, number of special warehouse processes, quality of the produced outputs, and flexibility. The performance ratios of the warehouses (DCs) in the survey were measured by DEA and CEE methods. The results of the study of Chapter 4 are shown in Figure 5.2.

Evaluating the main research question of this dissertation – i.e., *how can Warehouse Management be structured to attain high warehouse performance?* - the results of the research of Chapter 4 show that a simple Warehouse Management structure (i.e., limited planning efforts, and limited number of simple decision rules) increases performance when the warehouse task is simple and demand is difficult to predict (see first row in Figure 5.2). A simple Warehouse Management structure is also expected to increase performance when the task is simple and demand is predictable (see third row in Figure 5.2), but this is not fully supported by the research. Furthermore, a Warehouse Management structure that typically focuses on optimization (i.e., limited planning efforts, and more, and more complex decision rules) tends to increase performance when the warehouse task is complex and demand is difficult to predict (see second row in Figure 5.2). Finally, a complex Warehouse Management structure (i.e., extensive planning, and more, and more complex decision rules) is expected (but not fully supported by the research) to increase performance when the task is complex and demand is predictable (see last row in Figure 5.2).

Contingencies (warehouse characteristics)	Value	Warehouse Management structure	Warehouse Performance
Task Complexity Demand Unpredictabillity	low high	**Simple** (i.e., limited planning efforts + limited number of simple decision rules)	High
Task Complexity Demand Unpredictabillity	high high	**Optimization focused** (i.e., limited planning efforts + more, and more complex decision rules)	High *(tendency)*
Task Complexity Demand Unpredictabillity	low low	**Simple** (i.e., limited planning efforts + limited number of simple decision rules)	High *(expected)* *Not fully supported by this research*
Task Complexity Demand Unpredictabillity	high low	**Complex** (i.e., extensive planning + more, and more complex decision rules)	High *(expected)* *Not fully supported by this research*

Figure 5.2 Warehouse Management structure affecting Warehouse Performance is contingent on warehouse characteristics: Main findings Chapter 4

To conclude, the research of this dissertation is a first step to understand how Warehouse Management, considered as a coherent whole of decisions, should be structured to attain high warehouse performance. The results of this study show that it is important to align the level of planning extensiveness and decision rules complexity with the level of demand unpredictability and task complexity, respectively, to achieve high warehouse performance.

5.2 Contributions to theory

This dissertation provides several contributions to the body of knowledge in the field of warehouse operations planning and control. First, this research has developed a model for structuring Warehouse Management (see Figure 5.2). It has identified and operationalized key warehouse characteristics and the main elements of Warehouse Management structure, and has empirically determined the relationships between key characteristics and elements of Warehouse Management structure. This is new to the area of warehouse planning and control. So far, research has mainly focused on developing quantitative methods to model isolated decision-making situations in order to achieve some well-defined objectives. A model to guide structuring warehouse planning and control, where warehouse planning and control is regarded as a coherent whole of decisions rather than a combination of isolated warehouse operations planning and control models, was still lacking. Second, this research has empirically assessed the impact of the degree of fit among warehouse characteristics and Warehouse Management structure. Although the literature has recognized the importance of measuring and comparing warehouse performance (De Koster and Balk, 2008; Hackman *et al.*, 2001; Hamdan, 2005; Johnson and McGinnis, 2011; Kiefer and Novack, 1999; Tompkins *et al.*, 2003; Zimmerman *et al.*, 2001), little work is available on the drivers of warehouse performance. As such, this research contributes to knowledge on the drivers of warehouse performance. Finally, this dissertation contributes to the field of warehouse operations planning and control by taking a novel research perspective. Instead of developing models for isolated decision-making situations, this research considers warehouse planning and control as a coherent whole of decisions. The model in this research offers a starting point to develop a comprehensive framework for warehouse planning and control that aims at integrating various models and theories addressing well-defined isolated problems in warehouses. The model also constitutes a useful starting point for the development of a framework for functional design models of warehouse information systems.

5.3 Managerial implications

This dissertation generated knowledge about the fit of Warehouse Management structure to different contexts. Context plays an important role by restricting managerial choices. This research can help warehouse managers in developing their own optimal model for planning, controlling, and optimizing warehouse processes, and can help them in selecting an appropriate WMS.

More specifically, management should limit planning efforts and avoid investing in software offering extended planning functionalities when demand is more difficult to predict. Planning efforts should also be limited when demand is predictable and the task is simple, but should be more extensive when the task is more complex. When a warehouse only has to perform simple tasks, in other words, it has a limited number of SKUs, processes and order lines, only a limited number of simple decision rules are required to increase performance, and it is thus counterproductive to invest in software offering many different and complex decision rules and optimization models. On the other hand, when the tasks are more complex, performance tends to increase when more, and more complex decision rules are implemented, and thus investing in complex software may be more feasible.

These findings can assist the management of an underperforming warehouse in search of improvements by assessing the level of fit among the existing Warehouse Management structure and the warehouse characteristics. All in all, the results of the research can help warehouse managers to effectively and efficiently manage warehouse processes by adjusting the level of planning and the complexity of the decision rules to the complexity of the internal warehouse task and the predictability of external demand. The results also offer warehouse managers more and better insights in the requirements of the supporting warehouse management information system.

5.4 Limitations and future research

In the course of this dissertation, choices were made about the research design that also largely determine the limitations of the study. In general, limitations shed light on future research directions. A fundamental decision made in this dissertation was to conduct empirical research. This decision was mainly motivated by the scarcity of (empirical) literature on Warehouse Management. A subsequent decision was to search for general applicable theories instead of detailed, specific models. This decision was rooted in the problems warehouses have in selecting standard WMSs, and in the fragmented research into warehouse planning and control. Both decisions led to choosing a survey research strategy using a questionnaire. By conducting survey research and by using statistical techniques, we were able to obtain general insights on Warehouse Management structure. A sample size of 215 warehouses was collected, which was large enough to draw meaningful conclusions.

One of the drawbacks of survey methods is that the depth of the research (i.e., insights into and motivation of management decisions) is somewhat limited and that it does not test the causality of the relationships found. Consequently, a limitation of the research in this dissertation is the high level of aggregation and thereby the limited operational applicability of the findings for a specific warehouse. Warehouse Management structure was operationalized by three main constructs, thereby perhaps underscoring its complexity. Consequently, future research could develop further measures of Warehouse Management structure and/or more specific and detailed operationalizations of each dimension. The ultimate purpose of further developing the model is to integrate fragmented theories and models from the warehouse planning and control literature and to serve as a functional design model for selecting standard software functionalities. Therefore, in the search for further measures of Warehouse Management structure, functional aspects of planning such as centralized vs decentralized planning, and optimization of, for example, cost, time or customer service, can be considered.

Furthermore, special attention is needed for the control element of Warehouse Management. The current operationalization of control was focused on swift (online or real-time) data processing to allow human decision-making. However, another important aspect of the control system is human behavior, especially with respect to interpreting information and taking actions on it. Future research on the (behavioral) control element of Warehouse Management structure, incorporating hard and soft controls, and its impact on warehouse performance is therefore called for.

The research results showed that performance is indifferent to tactical planning when demand is more predictable, irrespective of task complexity (see Figure 5.2). However, contingencies task complexity and demand unpredictability are expected to interact. That is, when demand is more predictable and the task is more complex, extensive planning is needed to increase performance, and when demand is more predictable and the task is more simple, planning efforts should be limited. It stands to reason that a sample size of 111 DCs, as used in the research, is rather small to find support for such three-way interactions due to the power of the statistical test. Therefore, future research using a large sample could investigate the interaction effect of complexity and uncertainty on the performance-planning relationship.

While complexity and uncertainty appear to be useful as contingent factors for simple Warehouse Management structures, the results suggest other contingency factors may be involved, especially for more complex Warehouse Management structures. Thus, another useful direction for future research is to examine other contingent factors. It is suggested that factors such as: supply chain development stage, competitive strategy (cost focussed vs responsiveness), and resource base (labor or automation) might influence Warehouse Management structure, especially in complex warehouses.

In this dissertation, theory was built and tested in empirical research. Such an approach assumes that variety exists and that some of the warehouses in the samples have structured Warehouse Management successfully such that structure-context relationships can be tested effectively. Therefore, it would be interesting to test the hypotheses in a different sample, preferably in another area of Europe.

The measurement of warehouse performance using DEA deserves special attention. Although, Johnson (2006) concludes that DEA offers a valuable solution as a method of performance measurement to compare alternative designs (i.e., in this research: structures) and operation decisions, he also concludes that there are still many problems related to performance measurement using DEA, and that future research is needed. Johnson and McGinnis (2011) give a number of directions for additional research using DEA for warehouse benchmarking. That is, additional insights into the factors that impact warehouse technical efficiency are called for, and the use of technical efficiency needs to be augmented in some way with financial data. Also, the maturity of the warehouse should somehow be reflected in the model.

In this research, fit was interpreted as an interaction effect of context and structure. Drazin and Van de Ven (1985) state that mixed results have been obtained from modeling interactions from field survey data. These authors and Sousa van Voss (2008) are proponents of the system approach. They argue in order to understand context-structure relationships, the many contingencies, structure alternatives, and performance criteria must be addressed simultaneously. However, such an approach requires a much deeper understanding of warehouse planning, control and decision rules, and was therefore not chosen for this research. Given the more advanced insights into Warehouse Management structure and its contingencies provided by this dissertation, such an approach would be more feasible in future research. For example, such an approach might be useful in tackling the conflicting contingencies found for Task Complexity and Demand Unpredictability in relation to Planning Extensiveness.

Finally, future research would be helpful for validating the developed model (see Figure 5.2). For example, fit between structure and characteristics could be tested by action research. Action research is an approach to research which aims at both taking action and creating knowledge about that action as the action unfolds; the outcomes are both an action and a research outcome (Coghlan and Brannick, 2014). This means that performance effects could be studied in warehouses-in-progress as structure elements are adapted to the warehouse characteristics. Consequently, the model could be validated and further developed. Also, the developed model could be validated by case studies. For example, high and low performing warehouses could be compared with respect to their degree of fit among structure and characteristics. Another example could be case studies on warehouses with different characteristics and different structures. Another interesting direction of research in validating the developed model is longitudinal research. Performance changes of warehouses over time could be studied and explained by the degree of their warehouse management fit. Such a study can shed more light on the cause and effect relationships between warehouse management fit and performance, but also between characteristics and structure.

To conclude, this dissertation identified and explored a new topic of relevance in warehousing. It took a first step towards an integrated generic theory for structuring high performance Warehouse Management that can support the design and evaluation of Warehouse Management, and also the selection and evaluation of state-of–the-art (standard) warehouse management information systems. There is still a long road to be explored, but that is what makes doing research so exiting. I therefore close with Christopher Columbus' words: "Following the light of the sun, we left the Old World."

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Appendix A: Overview of functionality of WMSs

Overview of functionality of WMSs

Jacobs *et al.* (1997) classify the warehousing functions of a state-of-the-art WMS in three clusters:

(1) Inter-warehouse management functions
(2) Warehouse management functions
(3) Warehouse execution control functions

Baan, a leading enterprise resource planning software developer and vendor, has adopted this classification; see Baan (1998).

Inter-warehouse management functions

The inter-warehouse management functions include:

- *Enterprise definition*. This functionality defines the bill of distribution and the clustering of warehouses.
- *Inventory analysis*. This functionality provides information about the inventory of a product or a group of products in the different warehouses, including value, assortment, and ABC analysis.
- *Replenishment management*. This functionality supports the strategy to replenish the different warehouses – it may take place from a central warehouse, from production centers, or from suppliers. It also controls the inventory assortment spread on basis of expected demand.
- *Tracing*. The tracing functionality allows management to follow the flow of specific goods and orders.

Warehouse management functions

The warehouse management functions include:

- *Warehouse organization definition*. This functionality concerns physical storage. It specifies the different zones and storage areas, including dimensions, storage rules, picking strategies, and storage conditions.
- *Inventory control (on location)*. Based on aggregated data from execution reports in relation to inventory levels, it is possible to identify low demands, excess stock, and inactive, blocked and obsolete products.
- *Resources and activities planning*. To perform tasks as efficiently and effectively as possible, available resources are matched with receiving, shipping, transferring, loading, unloading, cycle counting, and assembling activities.
- *Management information*. Three types of management reporting can be distinguished in warehouses. First, daily progress monitoring: e.g., bottlenecks and orders that are not on schedule, etc.. Second, performance overviews of

different sorts: e.g., number of order lines processed during a certain period, number of trucks departed on time, number of receipts handled, etc. Third, reports needed for long term efficiency: e.g., overviews of misplaced articles, rack occupation, articles that need condensation, articles with problems, etc.

Warehouse execution control functions

To enable the flow of products through the warehouse, employees need to know what to do, when to do it, and how to make sure the work is done properly. This is a cycle of (operational) planning, execution and control, which includes:

- *Yard management*. This function generates information to plan and control the use of the receiving and shipping docks.
- *Receiving*. This function generates information to plan, execute and control all operational activities performed from the moment products are announced as shipment to the warehouse receiving dock or verification with the original purchase order. The receiving operations include goods to be received from suppliers, from production or other warehouses (replenishment) and goods returned by the customer. Also unexpected goods must be detected and required information gathered for purchase validation.
- *Inspection quality of goods*. This function can be initiated from item and/or supplier specification and can be performed during receiving, shipping or during a (periodical) inventory check. The initiation and managing of testing activities is part of this function. After inspection the approval process defines what should be done with the inspected goods (e.g. accept, reject, scrap, re-work).
- *Stock movement*. This function generates information to execute and control all the movements of goods within the warehouse. It concerns the processes of putting away, picking and internal transfers (including crossdocking). These activities are based on warehouse orders which can be grouped in picking and put-away runs.
- *Location control*. This function determines and registers the storage location of the stored goods based on the chosen storage strategies.
- *Inventory control*. This function generates information to monitor stock levels, flows of products, and the status of orders.
- *Warehouse service activities*. This function generates information to plan, execute and control service activities, like assembly and other value-added services, requested by the customer. This function might be applicable during inbound, storage, and outbound.
- *Packaging and packing*. This function generates information to repackage goods to handling units with the same unit of measure or to group items (packing).

- *Shipping*. This function generates information to control the organization of loads. Shipping documents like bill of loading, custom-clearance are prepared.
- *Transport and distribution*. This function optimizes transport and distribution processes, including truck loading and vehicle routing.
- *Internal replenishment*. The information system controls the pick stock. Under a certain level, a replenishment order will be generated to replenish the pick stock from the bulk.
- *Cycle counting*. This function supports the checking of the physical inventory. The actual stock level is registered, analyzed, and validated.
- *Customs management*. This function supports all customs and tax-related activities that have a direct relation with physical operations. For example, administration of single administrative documents (SADs), customs status of products on location, country of origin codes, etc.

Appendix B: Summary of measures of warehouse characteristics

Variable	Description	Accompanying question/instruction	Response categories	Computation
TC	*Task Complexity*			Sum (TCa, TCb, TCc)[a]
TCa	Log number of SKUs	What is the average number of SKU?	(open)	Log (number of SKUs)
TCb	Process diversity			Sum (TCb1,TCb2)
TCb1	Number of special processes	Tick process if applicable.	- quality control - return handling - recoding - cross-docking - product repacking - cycle counting - internal product transportations - value added logistics - other special processes	Count number of processes ticked. 1: count is 5 or less 2: count is more than 5
TCb2	Average number of modes	What is the average number of modes in which processes can be carried out?	- 3 or less - more than 3	1: average number of modes per process is 3 or less 2: average number of modes per process is more than 3
TCc	Log number of order lines	What is the average number of order lines per day?	(open)	Log (number of order lines)
DU	*Demand unpredictability*			Sum (DU1, DU2, DU3)
DU1	Demand unpredictability long term	How predictable is the total number of order lines for long term (half a year - 1 year)?	- predictable - predictable to a limited extent - difficult to predict	1: demand is predictable 2: demand is predictable to a limited extent 3: demand is difficult to predict
DU2	Demand unpredictability short term	How predictable is the total number per product/product group for short term? (1 week - 1 month)	- predictable - predictable to a limited extent - difficult to predict	1: demand is predictable 2: demand is predictable to a limited extent 3: demand is difficult to predict
DU3	Demand unpredictability very short term (1 day)	How predictable is the total number of order lines per day for the very short term (1 day - 1 week)?	- predictable - predictable to a limited extent - difficult to predict	1: demand is predictable 2: demand is predictable to a limited extent 3: demand is difficult to predict

[a] All variables are standardized before summing

Appendix C: Summary of measures of Warehouse Management

Variable	Description	Accompanying question/instruction	Response categories	Computation
PE	*Planning Extensiveness*	Tick plans if applicable	- stock planning - storage location planning - capacity planning - transport planning	Count number of plans ticked.
DRC	*Decision Rules Complexity*			Sum (Dca, DCb)[a]
DRCa	Number of activities explicitly using decision rules	Tick activities using decision rules.	- Allocate dock doors to inbound transport units (e.g., trucks) - Allocate capacity (personnel and equipment) to inbound transport units - Allocate inbound products to storage locations or cross-docking - Allocate inbound products and storage locations to inbound routes (optimal routes) - Allocate inbound routes to available capacities - Cluster orders to be shipped to transport units - Cluster customer orders to batches - Settle the executing start point per batch - Allocate pick order lines to storage locations - Allocate pick order lines and storage locations to pick routes (optimal routes) - Allocate pick routes to available capacities - Allocate dock doors to outbound transport units	Count number of activities ticked.
DRCb	Perceived complexity of decision rules			Sum (DCb1, DCb2)

Variable	Description	Accompanying question/instruction	Response categories	Computation
DRCb1	Perceived complexity of inbound decision rules	How complex are inbound decision rules?	- simple - not simple, not complex - complex	1: decision rules are simple 2: decision rules are not simple and not complex 3: decision rules are complex
DRCb2	Perceived complexity of outbound decision rules	How complex are outbound decision rules?	- simple - not simple, not complex - complex	1: decision rules are simple 2: decision rules are not simple and not complex 3: decision rules are complex
CS	*Control Sophistication*			Sum (CS1, CS2, CS3, CS4, CS5)
CS1	Operational data registration	Is operational data generally registered real time and online?	- no - yes	1: registration is not real time and online 2: registration is real time and online
CS2	Operational information availability	Is information for operational control generally available real time and online?	- no - yes	1: information is not real time and not available online 2: information is real time and available online
CS3	Reaction to unforeseen situations	What is the reaction to unforeseen situations?	- takes some time - immediate	1: reaction takes some time 2: reaction is immediate
CS4	Operational information from suppliers	Is operational information from suppliers (e.g., stock levels) available online?	- no - yes	1: supplier information is not available online 2: supplier information is available online
CS5	Operational information from customers	Is operational information from customers (e.g., point-of-sale information) received online?	- no - yes	1: customer information is not received online 2: customer information is received online

[a] All variables are standardized before summing

Appendix D: Measure of information system specificity

Variable	Description	Accompanying question/instruction	Response categories	Computation
IS	*Information system specificity*	Tick information system type used to manage warehouse if applicable	No automated information system Standard ERP Standard ERP with substantial customization Standard WMS Standard WMS with substantial customization Tailor-made system	0: no automated information system 1: standard ERP 2: standard ERP with substantial customization 3: standard WMS 4: standard WMS with substantial customization 5: tailor-made system (increasing level of specificity)

Appendix E: Summary of DEA input measures

Variable	Description	Accompanying question/instruction	Response categories	Computation
Labor	*Number of direct FTEs*	What is the average number of FTEs working in the distribution center?	(open) NB. The yearly number of working hours per full-time employee does not differ much in the Netherlands and Flanders due to national agreements with labor unions.	Number of direct FTEs
Size	*Size of the distribution center in m^2*	What is the size of the distribution center?	less than 1000 m^2 1000 - 3000 m^2 3000 - 5000 m^2 5000 - 10000 m^2 10000 - 20000 m^2 20000 - 50000 m^2 more than 50000 m^2	1: size is less than 1000 m^2 2: size is between 1000 - 3000 m^2 3: size is between 3000 - 5000 m^2 4: size is between 5000 - 10000 m^2 5: size is between 10000 - 20000 m^2 6: size is between 20000 - 50000 m^2 7: size is more than 50000 m^2
Automation	*Level of automation*			Combination of 'Automated Systems' and 'Information System Specificity': 1: no automated systems are used 2: basic automation (ERP-system) 3: warehouse management system (WMS) 4: WMS, barcoding and wireless communication are used 5: WMS, barcoding, wireless communication and light technology systems (conveyor, pick-to-light, put-to-light) are used 6: WMS, barcoding, wireless communication and automated systems like automated-guided vehicles, miniloads, automatic storage and retrieval systems, sorters, or robots are used

Variable	Description	Accompanying question/instruction	Response categories	Computation
- Automation: 'Automated systems'	Different types of automated systems used in the distribution center.	Which automated systems are used in the distribution center (e.g., cranes, sorters, palletizers, AGV, radio frequency)?	(open)	
- Automation: 'Information System Specificity'	Information system used in the distribution center.	Tick information system type if applicable.	no automated information system standard ERP standard ERP with substantial customization standard WMS standard WMS with substantial customization tailor-made system	0: no automated information system 1: standard ERP 2: standard ERP with substantial customization 3: standard WMS 4: standard WMS with substantial customization 5: tailor-made system
SKUs	*Number of SKUs*	What is the average number of stored SKUs?	(open)	Number of SKUs

Appendix F: Summary of DEA output measures

Variable	Description	Accompanying question/instruction	Response categories	Computation
Production - order lines	*Number of order lines*	What is the average number of order lines per day?	(open)	Number of order lines
Production - special processes	*Number of special processes*	Tick process if applicable	quality control return handling recoding cross-docking product repacking cycle counting internal product transportations value added logistics other special processes (open)	Count number of processes ticked.
Quality	*The percentage of error-free order lines*	What is the percentage of error-free order lines shipped? (errors include wrong number of products, wrong products, late or early delivery, wrong packaging, etc.)	(percentage)	Percentage of error-free order lines. "No idea of this percentage"/"We do not measure" was given a low 90% score
Flexibility	*The perceptive ability to respond to changes in the market environment compared to competitors*			Sum ('Production Volume', 'Changes', 'Response')
- Flexibility: 'Production Volume'	The ability to respond to changes in production volume	The ease to respond to changes in production volume compared to competitors	worse than competitors equal to competitors better than competitors	1: worse than competitors 2: equal to competitors 3: better than competitors
- Flexibility: 'Changes'	The ability to respond to late changes in orders	The ease to respond to late changes in orders compared to competitors	worse than competitors equal to competitors better than competitors	1: worse than competitors 2: equal to competitors 3: better than competitors

Variable	Description	Accompanying question/instruction	Response categories	Computation
- Flexibility: 'Response'	The ability to respond quickly to orders	The ease to deliver orders faster compared to competitors	worse than competitors equal to competitors better than competitors	1: worse than competitors 2: equal to competitors 3: better than competitors

Appendix G: **DEA and Cross Efficiency**

The original DEA model (Charnes *et al.*, 1978) known as the CCR model, considers *n* *DMUs* each with *m* inputs and *s* outputs to be evaluated. The jth input and the kth output of DMU_o are denoted by x_{jo} where j = 1,…,m and y_{ko} where k = 1,…,s, respectively. The ratio of the weighted combination of outputs to the weighted combination of inputs is used to measure the relative efficiency of a particular DMU under study (DMU_o). In the input-oriented CCR model as formulated in (1), the objective is to maximize the efficiency score of an DMU_o (o = 1,…,n) under evaluation. u_j and v_k represent the jth input and the kth output weights for DMU_o.

$$Max \sum_{k=1}^{s} v_k\, y_{ko}$$

$$s.t. \sum_{j=1}^{m} u_j\, x_{jo} = 1$$

$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \le 0 \qquad i = 1, \dots, n$$

$$v_k, u_j \ge 0 \qquad k = 1, \dots, s,\ j = 1, \dots, m \qquad (1)$$

The LP given above is solved for each DMU and the efficiency score (θ) of each DMU is obtained from each linear program. A DMU is considered to be efficient if the optimal value for the LP problem is equal to one, otherwise it is inefficient.

The cross-efficiencies of *DMUs* can be found using the optimal input and output weights that other *DMUs* chose in model (1). However, the optimal weights obtained from the CCR model may not be unique (Baker and Talluri, 1997) which deteriorates the effectiveness of the CE method in identifying good and poor performers. In order to overcome this limitation, Doyle and Green (1994) propose the following aggressive formulation:

$$\text{Min} \sum_{k=1}^{s} (v_k \sum_{i \neq o} y_{ki})$$

$$s.t. \sum_{j=1}^{m} (u_j \sum_{i \neq o} x_{ji}) = 1$$

$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leq 0 \quad \forall\, i \neq o$$

$$\sum_{k=1}^{s} v_k y_{ko} - \theta_o \sum_{j=1}^{m} u_j x_{jo} = 0$$

$$v_k, u_j \geq 0 \quad \forall\, k \text{ and } j \tag{2}$$

where DMU_o is the DMU under study, $\sum_{k=1}^{s} (v_k \sum_{i \neq o} y_{ki})$ is the weighted output of a composite DMU, $\sum_{j=1}^{m} (u_j \sum_{i \neq o} x_{ji})$ is the weighted input of the composite DMU and θ_o is the optimal efficiency of DMU_o derived from the CCR model. The formulation given in (2) is based on maximizing the efficiency of the target DMU while minimizing the efficiency of the composite DMU constructed from the other *n*-1 DMUs. The cross efficiency of DMU_i, using the weights that DMU_o chose in the aggressive model is then:

$$E_{oi} = \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \quad o, i = 1, 2, \ldots, n; \quad E_i = \frac{1}{n} \sum_{o=1}^{n} E_{oi} \,,$$

where v_k and u_j denote the optimal values obtained from model (2) and E_i is referred to as the cross efficiency score for DMU_i.

Appendix H: Anova tests ownership, sector, operations type

	No. of DCs	*Warehouse Performance* (mean)
All	111	0.39
Ownership		F(1,109)=1.042; *p*<0.310
DCs insourced	70	0.40
DCs outsourced	41	0.38
Sector		F(7,103)=3.005; *p*<0.007)
Automotive	7	0.38
Heathcare and Pharmaceutical	5	0.37
Food retail	5	0.42
Agricultural/Food products	8	0.59
ICT	5	0.41
Industrial products	22	0.35
Other products	39	0.38
Public warehouses	20	0.39
Operations type		F(3,107)=1.332; *p*<0.268
Finished goods production DC	58	0.41
Spare parts DC	7	0.36
Wholesale DC	22	0.35
Retail DC	24	0.41

Appendix I: Interview WMS expert, 8 April 2015

1. Can you reflect on the statement that the WMS market has matured in the last decade?

Answer: For incumbent WMS vendors, this is true with respect to functionality. However, these vendors are not particularly sensitive to incorporate new technologies in their WMSs. Today, new innovative oriented market entrants (e.g., parties integrating cloud technology into their solution, or parties focusing on using mobile platforms to host WMS and related supply chain functionalities) are challenging the established WMS vendors. However, the WMS functionalities of these innovative platforms or applications are still limited compared to the established WMS-applications.

2. Has the number of warehouses using a WMS increased over the last decade?

Answer: Yes, but the increase of new WMS implementations over the last decade is especially due to wholesalers and logistic service providers. The number of large warehouses using a WMS has not changed much over the last decade.

3. Has the quality of after-sales service improved over the last decade?

Answer: After-sales service is still poor. Warehouse managers still experience long waiting times to their requests. In general, WMS vendors are relative small businesses and they have problems to react quickly to customer requests. However, thanks to IT improvements, users are nowadays able to design and produce their own reports and can make other small adjustments themselves. Also, in-the-cloud technology makes it easier for WMS vendors to offer their customers the latest improvements.

4. Is the implementation of a tailor-made WMS still longer, more problematic, and more costly than that of a standard WMS.

Answer: Yes, this has not changed. Implementing a tailor-made WMS still takes more time than a standard WMS. This is particularly due to the extended testing phase when implementing tailor-made software.

5. Can you explain when a warehouse should use a standard and when it should use a tailor-made WMS?

Answer: Recently, a discussion concerning when to use a tailor-made or standard WMS has been published on the website of Logistiek.nl (in Dutch). This discussion followed a study executed by Logistiek.nl (2015) on the use of tailor-made and standard WMSs in the Netherlands. In my opinion, the choice between standard and tailor-made is driven by the business strategy. When logistics is considered a main differentiator, a tailor-made WMS is implemented (e.g., Amazon, Docdata, Ocado). An important reason for this is that these companies aim to grow and innovate through IT and do not want to depend on a WMS vendor. WMS vendors are often small companies. Also, these small software companies have to deal with uncertainty about their future, either exposed to be taken over or confronted with new unexpected competition. Companies with a low-cost strategy choose to implement a standard WMS, even for complex warehouses (e.g., DHL).

6. Can you reflect on the statement that in general the use of both standard and tailor-made WMSs are successful (in 2002, 10% of the warehouses indicate that their WM was a failure).

Answer: Difficult to reflect on this statement. In my opinion, stating that 90% of the warehouses are satisfied with their WMS seems quite high.

7. Can you reflect on the statement that implementing a standard WMS in close cooperation with designing a warehouse is more successful?

Answer: In my opinion, to start with no legacies is always preferable.

Summary

This dissertation studies the management processes that plan, control, and optimize warehouse operations. The inventory in warehouses decouples supply from demand. As such, economies of scale can be achieved in transport, production, and purchasing. Developments such as global competition, production off-shoring, and e-commerce have put warehouses in pole position in the supply chain to satisfy customer expectations. Warehouses face increasing demands with respect to costs, productivity, and customer service. Consequently, planning, controlling, and optimizing warehouse operations, defined as Warehouse Management in this dissertation, has become a distinguishing factor for supply chain performance. At the same time, warehouse operations have become more complex due to developments such as value added services (e.g., simple assembly tasks), e-fulfillment (i.e., processing large numbers of small orders), and up-scaling warehouses.

With the increasing pressure on warehouses to improve overall supply chain performance, the development and implementation of standard computerized warehouse information processing systems, called Warehouse Management Systems (WMS), have grown considerably. Selecting a standard WMS for a specific warehouse is a challenging task. A WMS must accurately support the management functions that plan, control, and optimize the material flows and the use of resources in a warehouse in order to deliver goods in accordance with customer demands while minimizing operational costs. In other words, a WMS supports Warehouse Management. In general, the form and operation of a business information system should be dictated by the management system it supports. This means that the form and operation of a WMS should be determined by the way Warehouse Management is structured (i.e., designed) or that both should be developed simultaneously.

It is important to gain insights into the principles of structuring Warehouse Management for two reasons. First, such insights may help to improve *existing* Warehouse Management structures, and second, they may help to select a standard WMS. However, research into how warehouse operations should be planned, controlled, and optimized is currently fragmented. This dissertation therefore treats Warehouse Management as a coherent whole and takes a business perspective in contrast to the dominant perspective in the literature of developing quantitative optimization models on isolated decision-making situations in warehouses.

In this dissertation, a model for structuring high performance Warehouse Management is developed. This model offers a starting point to develop a comprehensive framework for Warehouse Management that aims at integrating various models and theories addressing well-defined isolated problems in warehouses. The model also constitutes a useful starting point for the development of a framework for functional design models of warehouse management information systems.

In developing the model, this dissertation adopts a contingency approach, meaning that the structure of Warehouse Management is considered to be context dependent in order to attain high performance. Two key warehouse context characteristics are identified: Task Complexity and Market Dynamics. In addition, three dimensions of Warehouse Management structure are distinguished: Planning Extensiveness, Decision Rules Complexity, and Control Sophistication. The related warehouse management information system (WMS) is characterized by the specificity (i.e., the degree to which it is tailored) of the functionalities of the information system. Chapter 3 focuses on the effects of the two warehouse context characteristics on the dimensions of Warehouse Management structure and on the specificity of the related information system are studied. Chapter 4 addresses the match (i.e., fit) between context and structure as an important driver of Warehouse Performance. Warehouse Performance is operationalized by the ratio of produced outputs to relevant inputs (resources). The input factors include: number of FTEs, warehouse size, degree of automation, and number of SKUs. The output factors include: number of order lines, number of special warehouse processes, quality of the produced outputs, and flexibility. In Chapter 4, the performance ratios are measured by Data Envelopment Analysis (DEA) and Cross Efficiency Evaluation (CEE) methods.

The results show that the specificity of a WMS strongly depends on the internal complexity of the warehouse (i.e., Task Complexity), where Task Complexity is determined by the number of SKUs, the number of special warehouse processes, and the number of order lines processed per day. Furthermore, findings show that production and distribution warehouses respond to different external context characteristics. Production warehouses structure their planning function to Market Dynamics (i.e., demand unpredictability *and* frequency of assortment changes), whereas distribution warehouses structure their planning function only to demand unpredictability. The underlying reason may be that assortment changes are more predictable downstream the supply chain and therefore cause fewer disturbances at distribution warehouses.

The final part of this dissertation (Chapter 4) focuses on distribution warehouses. The results show that it is important to adapt the level of planning extensiveness and decision rules complexity to the predictability of demand and the complexity of the warehouse task in order to achieve high warehouse performance. That is, to increase warehouse performance, warehouse managers should limit planning efforts and avoid investing in software offering extended planning functionalities when demand is difficult to predict. They should also use a limited number of simple decision rules when the warehouse task is simple, i.e., when it has a limited number of SKUs, processes, and order lines. In this situation, investing in software offering many different and complex decision rules and optimization models tends to be counterproductive. On the other hand, when the tasks are more complex, performance tends to increase when more, and more complex decision rules are implemented, and thus investing in complex software may be feasible. These findings can assist the management of an underperforming warehouse in search of improvements by assessing the level of fit among the existing Warehouse Management structure and its characteristics. This dissertation has identified and explored a new topic of relevance in warehousing, but there is still a long road of discovery ahead.

Nederlandse Samenvatting

(Summary in Dutch)

Dit proefschrift bestudeert de aansturing van de processen en activiteiten in een warehouse: de managementfuncties die de warehouse processen en activiteiten plannen, optimaliseren en bijsturen. In dit proefschrift worden deze functies samengevat onder de term Warehouse Management.

De voorraden in een warehouse zorgen ervoor dat de aanvoer van producten wordt losgekoppeld van de vraag naar de producten, zodat schaalvoordelen kunnen worden behaald in de productie, inkoop en transport van de producten. Door het toenemend belang van warehouses in de supply chain worden hoge eisen gesteld aan de kostenbeheersing, de productiviteit en het serviceniveau aan de klant. Deze eisen moeten worden gerealiseerd door de planning, bijsturing en optimalisatie van de warehouse processen, Warehouse Management.

Met de toenemende druk op warehouses om de prestaties te verbeteren, heeft de ontwikkeling en implementatie van standaard informatiesystemen die de aansturing van de warehouse-processen ondersteunen, Warehouse Management Systemen (WMS) genoemd, een grote vlucht genomen. Het selecteren van een standaard WMS voor een specifiek warehouse is echter niet eenvoudig. Wel is duidelijk dat de vereiste WMS-functionaliteiten worden bepaald door de gekozen inrichting van de warehouse-aansturing (Warehouse Management). Uiteindelijk moet het WMS de informatie leveren die nodig is om de warehouse-processen zodanig te plannen, optimaliseren en bij te sturen dat het afgesproken serviceniveau wordt behaald tegen minimale kosten.

Om twee redenen is het belangrijk om inzicht te hebben in de uitgangspunten voor het inrichten van Warehouse Management. Ten eerste kunnen deze inzichten helpen om een bestaande inrichting van Warehouse Management te verbeteren en ten tweede om de selectie van een standaard WMS te onderbouwen. Het huidige onderzoek naar het plannen, optimaliseren en bijsturen van warehouse-processen richt zich voornamelijk op het ontwikkelen van kwantitatieve beslissingsmodellen voor afgebakende specifieke sub-processen in een warehouse. In dit proefschrift is gekozen voor een bedrijfskundige benadering, waarbij Warehouse Management wordt beschouwd als een samenhangend geheel van beslissingsprocessen. Uitgaande van deze benadering is in dit proefschrift een generiek model ontwikkeld voor het structureren van Warehouse Management.

Uitgangspunt in dit proefschrift is dat er geen *one-size-fits-all* optimale Warehouse Management structuur is, maar dat deze afhankelijk is van de context: de karakteristieken van omgeving (zowel intern als extern). In het onderzoek zijn twee essentiële warehousekarakteristieken geïdentificeerd: *Task Complexity* (de interne complexiteit van het warehouse) en *Market Dynamics* (de veranderlijkheid van de omgeving waarin het warehouse functioneert). Daarnaast zijn drie dimensies gedefinieerd van de Warehouse Management structuur: *Planning Extensiveness*, *Decision Rules Complexity* en *Control Sophistication*. Het WMS is gekarakteriseerd door de specifiteit van zijn functionaliteiten: in hoeverre zijn de functionaliteiten geschikt om een specifieke situatie te ondersteunen (varieert van een standaard tot een eigen op-maat-gemaakt informatiesysteem). In Hoofdstuk 3 zijn de effecten van de warehouse karakteristieken op de dimensies van de Warehouse Management structuur onderzocht. In Hoofdstuk 4 is nagegaan in hoeverre een juiste afstemming (fit) tussen karakteristieken en structuur invloed heeft op de warehouseprestatie. Daartoe is de warehouseprestatie in het onderzoek geoperationaliseerd door de verhouding te berekenen tussen de output (resultaten) en de input (middelen) van het warehouse. Daarbij is gebruik gemaakt van de methode Data Envelopment Analysis (DEA).

De bevindingen van het onderzoek tonen aan dat de specificiteit van een WMS sterk wordt bepaald door de interne complexiteit van het warehouse. Verder blijkt dat er verschil is tussen productie en distributie warehouses voor de planningsfunctie. De planningsfunctie in productiewarehouses wordt beïnvloed door *Market Dynamics*, die bestaat uit de vraagvoorspelbaarheid en de frequentie van assortimentswijzigingen. De planningsfunctie in distributiewarehouses wordt alleen bepaald door de vraagvoorspelbaarheid. Een mogelijke verklaring hiervoor is dat assortimentswijzigingen voor minder dynamiek zorgen stroomafwaarts in een supply chain. In hoofdstuk 4 wordt alleen ingegaan op distributiewarehouses. Uit de onderzoeksresultaten van dit hoofdstuk blijkt dat een hoge warehouseprestatie afhankelijk is van de mate van afstemming (fit) van de planningsinspanningen (*Planning Extensiveness*) en de complexiteit van de gebruikte optimalisatiemodellen (*Decision Rules Complexity*) op de vraagvoorspelbaarheid en de interne complexiteit van het warehouse.

Het in dit onderzoek ontwikkelde model kan als uitgangspunt dienen voor het ontwikkelen van een raamwerk waarin de verschillende reeds ontwikkelde optimalisatiemodellen voor specifieke warehouse sub-processen in samenhang met elkaar kunnen worden gebracht. Zodoende kan het model ook een startpunt bieden voor de ontwikkeling van een raamwerk voor standaard WMS functionaliteiten.

About the author

Nynke Faber was born in Arnhem, the Netherlands on 14 November 1959. She attended secondary school in Paramaribo (Surinam), and in Utrecht and Dongen in the Netherlands. She graduated in Industrial Engineering at Eindhoven University of Technology in June 1987. Her Master's thesis was on production planning and control. From 1987 to 1995, she worked as a technical and functional designer, and as a project manager to develop and implement business information systems at Royal Dutch Shell in the Netherlands. In 1995, she switched to teaching and started working as an Assistant Professor of Management Information Systems at the Netherlands Defense Academy in Breda and has been an Associate Professor of Logistics and Supply Chain Management at this academy since 2005. In 1999, she became an external PhD candidate at the Rotterdam School of Management, Erasmus University Rotterdam and has conducted research on structuring warehouse planning and control processes. She has presented her research at international conferences in Belgium and in Switzerland. Two of her articles have been published in academic journals and several have appeared in professional journals. Nynke is married and has two daughters and a son.

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STRUCTURING WAREHOUSE MANAGEMENT

EXPLORING THE FIT BETWEEN WAREHOUSE CHARACTERISTICS AND WAREHOUSE PLANNING AND CONTROL STRUCTURE, AND ITS EFFECT ON WAREHOUSE PERFORMANCE

This dissertation studies the management processes that plan, control, and optimize warehouse operations. The inventory in warehouses decouples supply from demand. As such, economies of scale can be achieved in production, purchasing, and transport. As warehouses become more and more vital for the success of many companies, they are facing increasing demands with respect to costs, productivity, and customer service. At the same time, warehouse operations have become more complex due to developments such as value added services, e-fulfillment, and up-scaling warehouses. Consequently, planning, controlling, and optimizing warehouse operations, defined as warehouse management in this dissertation, have become a distinguishing factor for supply chain performance. This dissertation explores warehouse management by studying the effects of the characteristics of a warehouse (i.e., context) on the structure (i.e., design) of warehouse management. In addition, the match (i.e., fit) between characteristics and structure is researched as an important driver of warehouse performance. By conducting empirical research using a multiple case study and a survey study, an overall theoretical model on structuring high performance warehouse management has been developed.

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