



# Organizing warehouse management

N. Faber

*Netherlands Defence Academy, Breda, The Netherlands, and*

M.B.M. de Koster and A. Smidts

*Rotterdam School of Management,  
Erasmus University, Rotterdam, The Netherlands*

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## Abstract

**Purpose** – The purpose of this paper is to investigate how warehouse management, understood as a cluster of planning and control decisions and procedures, is organized and driven by task complexity (TC) and market dynamics (MD).

**Design/methodology/approach** – A multi-variable conceptual model is developed based on the literature and tested among 215 warehouses using a survey.

**Findings** – The results suggest that TC and MD are the main drivers of warehouse management, measured by planning extensiveness (PE), decision rules complexity, and control sophistication. Differences between production and distribution warehouses are found with respect to the relationship between assortment changes and PE. Furthermore, TC appears to be a main driver of the specificity of the warehouse management (information) system (WMS).

**Research limitations/implications** – This paper is based on 215 warehouses in The Netherlands and Flanders (Belgium); future research may test the model on a different sample. More research should be conducted to further validate the measures of the core dimensions of warehouse management.

**Practical implications** – Different levels of TC and MD characterize warehouses. Such a characterization is a first step in determining generic warehouse functionalities and helping managers to decide on the best software for their warehouse operations.

**Originality/value** – The paper defines the core dimensions of warehouse management, makes them measurable, tests them and assesses how these drivers impact specificity of WMS. The paper shows that PE in production warehouses is driven by different variables than in distribution centers.

**Keywords** Logistics, Survey, Conceptual framework, Empirical, Information management, Operations planning

**Paper type** Research paper

## 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



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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 organized 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 (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 seems to be lacking. Rouwenhorst *et al.* (2000) and Gu *et al.* (2007, 2010) conclude in their reviews of warehouse management literature that analysis-oriented research on isolated subproblems is dominant in the current warehouse management literature. This study takes the first step in exploring the drivers of warehouse management.

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

Our first contribution is to define and make measurable the core characteristics of warehouse management. To the best of our knowledge, there is currently hardly any literature that clearly captures warehouse management as a coherent whole. Because this study is just a first step in exploring the dimensions of warehouse management, we consider warehouse management 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. Following the literature on production systems (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 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 (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 2 and 3, we develop our constructs and formulate our hypotheses. In Section 4, we describe our research methodology, including the sample selection and data collection approaches and the measures of the constructs. Section 5 describes the results of the data analysis and hypotheses testing. Section 6 concludes the paper.

## 2. General framework for warehouse management

### 2.1 Warehouse management

Analogous to production management (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, for many warehouses the tactical planning horizon 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

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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 (Alter, 1999; 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, 1999). 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 as a combination of planning extensiveness, decision rules complexity, and control sophistication.

### *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 will differ per warehouse. We define the construct information system specificity by distinguishing six different types of information systems with an ascending degree of specificity.

### *2.3 Drivers of warehouse management*

The basic premise of our study is that the best approach to 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 organization 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, the environment refers to the immediate operating environment that is beyond the control of management in the short run. Therefore, we decided to concentrate on narrowly defined parts of the environment rather than overall industry parameters. Analogous to Van Assen (2005), in this study,

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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 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; and
- the number of order lines processed by the warehouse per day.

Task complexity affects warehouse management 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 and, for this reason, are not considered in this study. We conceptualize environmental dynamism with regard to warehouse management as the dynamism in the customer market. We define the construct market dynamics by:

- the unpredictability of market demand; and
- 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 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. Our full research model is shown in Figure 1. Task complexity and market dynamics are expected to strongly affect how warehouse management is organized. The organization of warehouse management takes shape in three dimensions (planning extensiveness, decision rules complexity, control sophistication), and is reflected in warehouse management's information system specificity.

It should be noted that warehouse management is not solely determined by these two main drivers. In reality, many other elements must be in place for warehouse management 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. 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

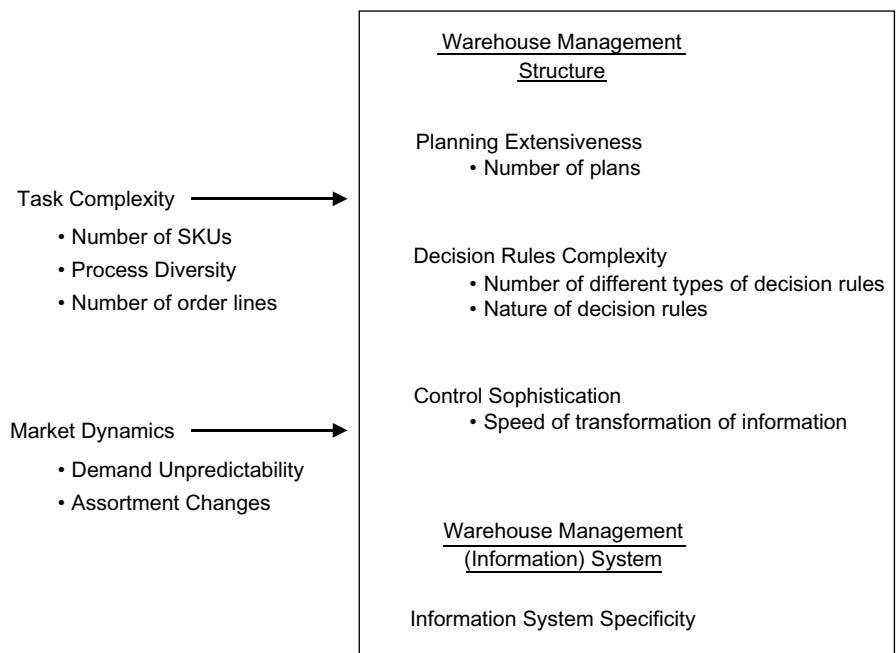


Figure 1.  
Research model

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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, a standard software solution will be difficult to find 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 (DU) 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 *H6* of this study are shown in Figure 2. All hypotheses are directional, which means the relationships are positive or negative. We carried out a survey to test our hypotheses.

#### 4. Method

##### 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 pre-tested 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

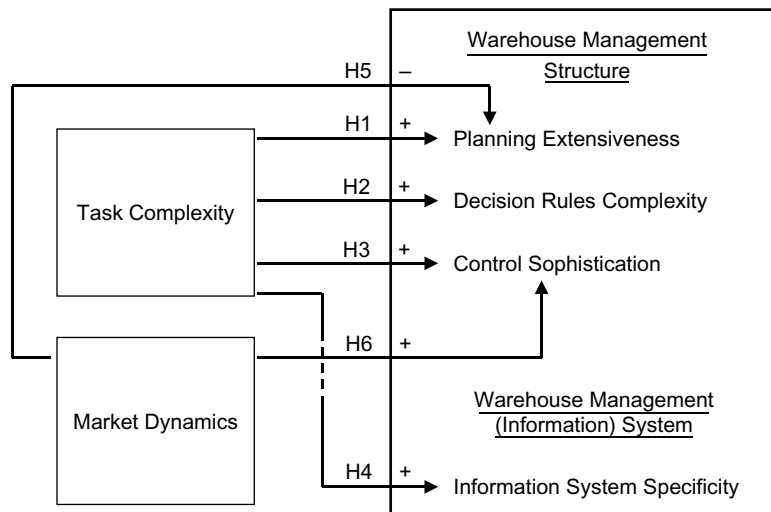


Figure 2.  
Hypotheses

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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](http://www.NDL.nl), [www.FENEX.nl](http://www.FENEX.nl), IMCC and VLM) and Flanders (Belgium) ([www.VIL.be](http://www.VIL.be), [www.warehouseandlogisitcs.com](http://www.warehouseandlogisitcs.com) and [www.bruca.rgo.be](http://www.bruca.rgo.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). 101 warehouses were willing to participate. The most often-heard argument for non-response 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 non-response 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 I shows that we were quite successful in contacting the preferred informant: 85 percent of the

| 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  |
|                       |      |                                |       | Foodretail                                | 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    |
|                       |      |                                |       |   |       | SD                            | 106   |

**Table I.**  
Sample description

**Note:**  $n = 215$

respondents are senior warehouse managers and 15 percent are logistics staff members. Table I also shows other demographic data such as warehouse types, general industry classification, and number of warehouse employees.

Table I 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.

#### 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

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a formative versus a reflective specification depends on the causal priority between the measurable items and the latent variable (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 Appendix.

Task complexity 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:

- (1) *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).
- (2) *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 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).
- (3) *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 for precise levels).

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

## 5. Results

To assess the relationship between warehouse characteristics and warehouse management, we performed a series of regression analyses. The correlations between the variables specified in Table II are the input for the regressions. The results are shown in Table III. The regressions were conducted both at the construct level (see results on upper part of Table III) and at the subdimension level (results on lower part of Table III). At the subdimension level, we conducted stepwise regression among the five independent variables and we present results only for variables for which  $p < 0.10$  (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.

*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 III confirm a significant and positive effect of task complexity (standardized regression coefficient  $\beta = 0.29$ ,  $p < 0.001$ )

|                                     | TC        | Tca     | TCb      | TCc      | MD     | DU        | AC       | PE      | DC     | CS     | IS   |
|-------------------------------------|-----------|---------|----------|----------|--------|-----------|----------|---------|--------|--------|------|
| Task complexity (TC)                | 1.00      |         |          |          |        |           |          |         |        |        |      |
| Log no. of SKUs (TCa)               | 0.81 *    | 1.00    |          |          |        |           |          |         |        |        |      |
| Process diversity (TCb)             | 0.66 *    | 0.33 *  | 1.00     |          |        |           |          |         |        |        |      |
| Log no. of order lines (TCc)        | 0.72 *    | 0.45 *  | 0.12     | 1.00     |        |           |          |         |        |        |      |
| Market dynamics (MD)                | 0.08      | 0.09 ** | 0.14 *** | -0.04 *  | 1.00   |           |          |         |        |        |      |
| Demand unpredictability (DU)        | -0.17 *** | -0.05   | 0.03     | -0.34 *  | 0.70 * | 1.00      |          |         |        |        |      |
| Assortment changes (AC)             | 0.29 *    | 0.18 ** | 0.16 *** | 0.28 *   | 0.70 * | -0.03     | 1.00     |         |        |        |      |
| Planning extensiveness (PE)         | 0.28 *    | 0.07    | 0.18 *** | 0.38 *   | -0.10  | -0.27 *   | 0.12     | 1.00    |        |        |      |
| Decision rules complexity (DC)      | 0.44 *    | 0.28 *  | 0.28 *   | 0.39 *   | -0.01  | -0.14 *** | 0.12     | 0.35 *  | 1.00   |        |      |
| Control sophistication (CS)         | 0.21 **   | 0.18 ** | 0.14 *** | 0.14 *** | 0.07   | 0.00      | 0.09     | 0.11    | 0.27 * | 1.00   |      |
| Information system specificity (IS) | 0.33 *    | 0.18 ** | 0.22 *   | 0.35 *   | 0.08   | -0.03     | 0.14 *** | 0.18 ** | 0.23 * | 0.23 * | 1.00 |
| <i>n</i>                            | 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 |
| SD                                  | 1         | 0.74    | 0.8      | 0.92     | 1      | 1.74      | 0.54     | 1.22    | 1      | 1.48   | 1.8  |

Note: Significant at: \* $p < 0.001$ , \*\* $p < 0.01$ , \*\*\* $p < 0.05$

Table II.  
Correlations



|                              | Planning extensiveness (PE) |          |          | Decision rules complexity (DC) |          |          | Control sophistication (CS) |          |          | Information system specificity (IS) |          |          |
|------------------------------|-----------------------------|----------|----------|--------------------------------|----------|----------|-----------------------------|----------|----------|-------------------------------------|----------|----------|
|                              | $\beta$                     | <i>t</i> | <i>p</i> | <i>B</i>                       | <i>t</i> | <i>p</i> | $\beta$                     | <i>t</i> | <i>p</i> | $\beta$                             | <i>t</i> | <i>p</i> |
| 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                                |          |          |
| <i>n</i>                     | 210                         |          |          | 210                            |          |          | 207                         |          |          | 208                                 |          |          |
| Subdimension analysis        |                             |          |          |                                |          |          |                             |          |          |                                     |          |          |
| 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                                |          |          |
| <i>n</i>                     | 210                         |          |          | 210                            |          |          | 207                         |          |          | 208                                 |          |          |

**Table III.**  
Regressions

and a negative effect of market dynamics ( $\beta = -0.14, p < 0.038$ ). Table III shows that task complexity and market dynamics explain approximately 10 percent of the variance in planning extensiveness. However, the regression analysis in the lower part of Table III shows that 21 percent of the variance in planning extensiveness is explained by the subdimensions. Especially “number of order lines” has a strong positive effect on planning extensiveness.

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 II), 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 II). 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 (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 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 (Table IV) 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 IV because the effects of the other variables, especially “number of order lines” are more dominant. The results of correlation analyses (Table V)

|                              | Production warehouses<br>Planning extensiveness (PE) |       |       | Distribution centers<br>Planning extensiveness (PE) |       |       |
|------------------------------|--|-------|-------|---|-------|-------|
|                              | $\beta$  | $t$   | $p$   | $\beta$   | $t$   | $p$   |
| 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        |  |       |       |   |       |       |
| 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 IV.**  
Regression production  
warehouses vs  
distribution centers

|                         | Production warehouses<br>Planning extensiveness (PE) |       |     | Distribution centers<br>Planning extensiveness (PE) |       |     |
|-------------------------|--|-------|-----|---|-------|-----|
|                         | $R$  | $p$   | $n$ | $r$   | $p$   | $n$ |
| Assortment changes (AC) | -0.38  | 0.083 | 22  | 0.18  | 0.015 | 192 |

**Table V.**  
Correlation “assortment  
changes” and planning  
extensiveness

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.

Table IV shows, in addition, that market dynamics drives planning extensiveness ( $\beta = -0.60$ ,  $p < 0.005$ ) in production warehouses, and that task complexity drives planning extensiveness ( $\beta = 0.32$ ,  $p < 0.001$ ) in distribution centers. Distribution centers appear to process significantly more order lines (mean = 11,715, SD = 27,585) 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 III shows that 19 percent of the variance in decision rules complexity is explained by task complexity. The results in Table III 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 III confirm *H3* ( $\beta = 0.20$ ,  $p < 0.003$ ) and rejects *H6* ( $\beta = 0.04$ ,  $p < 0.587$ ). A more complex warehouse task requires more sophisticated control, while a more dynamic market does not affect control. Only 4 percent 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 III 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 III, 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 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 percent 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. This could also explain the significantly higher-than-average decision rules complexity in public warehouses ( $p < 0.013$ ). In addition, decision rules complexity

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 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* (Figure 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.

### 6. Conclusions and future research

In this paper, we proposed and defined warehouse management by three constructs: planning extensiveness, decision rules complexity, and control sophistication.

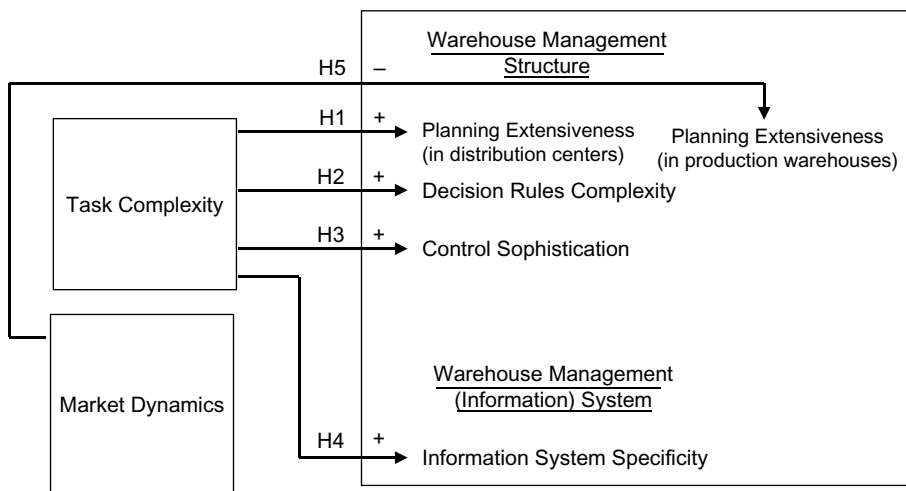


Figure 3.  
Results

We developed a model linking the two main drivers of warehouse management, 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 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 *H5* 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 *H6* is not supported by the data. Apparently, only task complexity plays a dominant role.

We expected to find the choice of the WMS (measured by information system specificity) to be driven by task complexity. Indeed, the data confirm our *H4* that the more complex the warehouse task is, the more specific is the functionality of the information system. Other factors than TC obviously play a role in the WMS choice. For example, logistics service providers do not base their WMS choice on a single warehouse but on the various warehouses they operate. The organization of warehouse management 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 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 cross-dock 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

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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.

Our proposed operationalization provides means to systematically study other aspects of warehousing. Most notably, how warehouse management 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 organized impacts warehouse performance. Such a study would complement current studies on warehouse performance (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 layout) 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 WMS and the choice of WMS 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 organize warehouse management and assist them with their choice of WMS; in particular, whether a standard system will do, or whether a system with specific functionalities will be more appropriate.

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#### About the authors

N. Faber is an Associate Professor of Logistics at The Netherlands Defense Academy, and a Doctoral Researcher at the Rotterdam School of Management, Erasmus University. Her research interests are warehousing, defense logistics and supply chain management. N. Faber is the corresponding author and can be contacted at: [n.faber@nlda.nl](mailto:n.faber@nlda.nl)

M.B.M. de Koster is Professor of Logistics and Operations Management at the Rotterdam School of Management, Erasmus University. His research interests are warehousing, material handling, retail operations, and behavioral operations. He is (co-) author/editor of eight books and over 130 papers in books and journals including *Journal of Operations Management*, *Transportation Science*, *Production and Operations Management*, and *International Journal of Operations and Production Management*. He is a member of the ELA R&D committee, of the BVL Scientific Advisory Board, Chairman of the Material Handling Forum, and in the editorial review boards of seven journals.

A. Smidts is Professor of Marketing Research at the Rotterdam School of Management, Erasmus University and Director of the Erasmus Center for Neuroeconomics. He was Scientific Director of the Erasmus Research Institute of Management (ERIM) and Dean of Research of the Rotterdam School of Management from 2004 to 2011. His research interests include behavioral decision making and persuasive communication. He is currently working in the area of decision neuroscience and neuromarketing. His research has been published in journals such as *Management Science*, *Academy of Management Journal*, *Marketing Science*, *International Journal of Research in Marketing*, *Journal of Consumer Research*, *Journal of Consumer Psychology*, *Social Cognitive & Affective Neuroscience*, *Psychological Science*, *Journal of Neuroscience* and *Neuron*.

| Variable | Description                 | Accompanying question/<br>instruction  | Response categories  | Computation   |
|----------|-----------------------------|--|--|---|
| TC       | Task complexity             |  |  | Sum (TCa, TCb, TCc) <sup>a</sup>  |
| 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 | Check off process if applicable  | Quality control<br>Return handling   | Count number of processes checked off<br>If count is five or less TCb1 = 1; if count is more than five TCb1 = 2 |
|          |                             |  | Recoding<br>Gross-docking<br>Product repacking<br>Cycle counting<br>Internal product transportations<br>Value added logistics<br>Other special processes |   |
| TCb2     | Average number of modes     | What is the average number of modes in which processes can be carried out?               | Three or less<br>More than 3   | If average number of modes per process is three or less TCb2 = 1; if more than three TCb2 = 2                   |
| TCc      | Log number of order lines   | What is the average number of order lines per day?                                       | (open)   | Log (number of order lines)   |
| MD       | Market dynamics             |  |  | Sum (DU, AC) <sup>a</sup>   |
| DU       | Demand unpredictability     |  |  | Sum (DU1, DU2, DU3)   |
| DU1      | DU long-term                | How predictable is the total number of order lines for long-term (half a year-one year)? | Predictable<br>Predictable to a limited extent<br>Difficult to predict   | If demand is predictable DU1 = 1; if predictable to a limited extent DU1 = 2; if difficult to predict DU1 = 3   |
| DU2      | DU short-term               | How predictable is the total number per product/product group for short-term?            | Predictable<br>Predictable to a limited extent<br>Difficult to predict   | If demand is predictable DU2 = 1; if predictable to a limited extent DU2 = 2; if difficult to predict DU2 = 3   |

(continued)

Table AI.  
Summary of measures

| Variable  | Description   | Accompanying question/<br>instruction  | Response categories  | Computation  |
|-----------|---|--|--|--|
| DU3       | DU very short-term (one day)  | How predictable is the total number of order lines per day for very short-term (one day-one week)? | Predictable<br>Predictable to a limited extent<br>Difficult to predict   | If demand is predictable<br>DU3 = 1; if predictable to a limited extent DU3 = 2; if difficult to predict DU3 = 3 |
| AC        | Assortment changes  | Is the assortment liable to changes?   | Hardly<br>To a limited extent<br>To a great extent   | If assortment hardly changes<br>AC = 1; if AC to a limited extent<br>AC = 2; if AC to a great extent<br>AC = 3   |
| PE        | Planning extensiveness  | Check off plans  | Stock planning<br>Storage location planning<br>Capacity planning<br>Transport planning   | Count number of plans checked off  |
| DC<br>DCa | Decision rules complexity<br>Number of activities explicitly using decision rules | Check off activities using decision rules  | Allocate dock doors to inbound transport units (e.g. trucks);<br>Allocate capacity (personnel and equipment) to inbound transport units;<br>Allocate inbound products to storage locations or cross-docking;<br>Allocate inbound products and storage locations to inbound routes (optimal routes);<br>Allocate inbound routes to available capacities;<br>Cluster orders to be shipped to transport units;<br>Cluster customer orders to batches; | Sum (DCa, DCb) <sup>a</sup><br>Count number of activities checked off  |

*(continued)*

| Variable  | Description   | Accompanying question/<br>instruction                          | Response categories  | Computation   |
|-----------|---|--|--|---|
| DCb       | Perceived complexity of decision rules                  |  | Settle the executing start point per batch;<br>Allocate pick order lines to storage locations;<br>Allocate pick order lines and storage locations to pick routes (optimal routes);<br>Allocate pick routes to available capacities;<br>Allocate dock doors to outbound transport units | Sum (DCb1, DCb2)  |
| DCb1      | Perceived complexity of inbound decision rules          | How complex are the inbound decision rules?                    | Simple<br>Not simple, not complex<br>Complex   | If decision rules are simple<br>DCb1 = 1; if decision rules are not simple and not complex<br>DCb1 = 2; if decision rules are complex<br>DCb1 = 3 |
| DCb2      | Perceived complexity of outbound decision rules         | How complex are the outbound decision rules?                   | Simple<br>Not simple, not complex<br>Complex   | If decision rules are simple<br>DCb2 = 1; if decision rules are not simple and not complex<br>DCb2 = 2; if decision rules are complex<br>DCb2 = 3 |
| CS<br>CS1 | Control sophistication<br>Operational data registration | Is operational data generally registered real time and online? | No<br>Yes  | Sum (CS1, CS2, CS3, CS4, CS5)<br>If registration is not real time and online CS1 = 1; if registration is real time and online CS1 = 2             |

(continued)

Table AI.



| Variable | Description                            | Accompanying question/<br>instruction   | Response categories   | Computation   |
|----------|--|---|---|---|
| CS2      | Operational information availability   | Is information for operational control generally available real time and online?            | No<br>Yes   | If information is not real time and not available online<br>CS2 = 1; if information is real time and available online<br>CS2 = 2  |
| CS3      | Reaction to unforeseen situations      | What is the reaction to unforeseen situations?  | Takes some time<br>Immediate  | If reaction takes some time<br>CS3 = 1; if reaction is immediate<br>CS3 = 2   |
| CS4      | Operational information from suppliers | Is operational information from suppliers (e.g. stock levels) available online?             | No<br>Yes   | If supplier information is not available online<br>CS4 = 1; if supplier information is available online<br>CS4 = 2  |
| CS5      | Operational information from customers | Is operational information from customers (e.g. point-of-sale information) received online? | No<br>Yes   | If customer information is not received online<br>CS5 = 1; if customer information is received online<br>CS5 = 2  |
| IS       | Information system specificity         | Check off information system type used to manage warehouse                                  | No automated information system<br>Standard ERP<br>Standard ERP with substantial customization<br>Standard WMS<br>Standard WMS with substantial customization<br>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) |

**Note:** <sup>a</sup>All variables are standardized before summing

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