Managing Warehouse Utilization:
An Analysis of Key Warehouse Resources

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Supply Chain Management

by

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December 2014
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ABSTRACT

The warehousing industry is extremely important to businesses and the economy as a whole, and while there is a great deal of literature exploring individual operations within warehouses, such as warehouse layout and design, order picking, etc., there is very little literature exploring warehouse operations from a systems approach.

This study uses the Theory of Constraints (TOC) to develop a focused resource management approach to increasing warehouse capacity and throughput, and thus overall warehouse performance, in an environment of limited warehouse resources. While TOC was originally developed for reducing operational bottlenecks in manufacturing, it has allowed companies in other industries, such as banking, health care, and the military, to save millions of dollars (Watson et al., 2007; Polito et al., 2006; Bramorski et al., 1997; Gardiner et al., 1994; Demmy and Petrini, 1992). However, the use of TOC has been limited to case studies and individual situations, which typically are not generalizable. Since the basic steps of TOC are iterative in nature and were not designed for survey research, modifications to the original theory are necessary in order to provide insight into industry-wide problems.

This study further develops TOC's logistics paradigm and modifies it for use with survey data, which was collected from a sample of warehouse managers. Additionally, it provides a process for identifying potentially constrained key warehouse resources, which served as a foundation of this study. The findings of the study confirm that TOC's methods of focused resource capacity management and goods flow scheduling coordination with supply chain partners can be an important approach for warehouse managers to use in overcoming resource capacity constraints to increase warehouse performance.

ACKNOWLEDGEMENTS

This work would not have come to fruition if it had not been for the many individuals whose efforts I would like to recognize here.

I would like to thank the members of my dissertation committee: Dr. John Ozment, Dr. Matt Waller, and Dr. Terry Esper. Dr. Ozment, my committee chairperson, has spent countless hours guiding me in this journey from beginning to end in a way that only he can master: hearing me out, letting me play on my own at times and then gently pushing me in the right direction, offering his ideas, experience and guidance, and caring about my motivation by providing numerous examples and stories from his experience and an occasional lunch – thank you for that! I could not have wished for a better adviser and friend.

Dr. Matt Waller's support has been the cornerstone of this research effort. Thank you for suggesting this research area as a dissertation topic, finding sources of financial support for it and believing in me.

I am very grateful to Dr. Terry Esper, whose quick grasp of the matter and to-the-point advice has made this study better.

A number of individuals not on my dissertation committee have contributed to making this thesis a reality. I would like to thank Dr. Christian Hofer for trying to keep me on track. Dr. Adriana Rossiter-Hofer's passion for theories was my inspiration in developing the theory for this study. Dr. Dub Ashton's attitude to stand strong despite incredible odds gave me the strength to brave any challenges along the way. Invariably, in many small ways, I have always felt the encouragement from all the faculty and doctoral students in the department, the staff of the college and the supportive Dean Dr. Eli Jones.

There is a group of people who went beyond support; they made a true sacrifice. This is my family. My wife Irina and my daughter Olga abruptly changed the regular course of their lives and their lifestyles, left their relatives and friends behind and came here to join me. I am forever indebted to them for their love and faith in me. Writing a dissertation took long hours, the time that I would have loved to spend with them and my daughter Masha. I am grateful to you all for your understanding and ability to make every short moment we were together count as the happiest time an eternity cannot compare with.

By defending the dissertation I am following in the footsteps of my father Boris and I am proud to be his son. If my mother Talina had lived to this moment, I know she would have been very happy.

DEDICATIONS

To the loving memory of my Mother

and

To my Father

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CHAPTER I

INTRODUCTION

Importance of the study

The importance of this study stems from the importance of warehousing. Warehouses are an integral part of the modern supply chain of a firm as well as a major industry by itself. Thus, warehousing can be looked at from the macroeconomic perspective of the national economy and the microeconomic perspective of a firm. The North American Industry Classification System (NAICS) groups establishments whose primary activity is warehousing and storage of goods into the Warehousing and Storage subsector, NAICS code 4931. In 2013, there were approximately 16,000 establishments in this category, employing approximately 710,000 employees (Bureau of Labor Statistics, 2014). Many more warehouses are auxiliary parts of companies that fall under different NAICS codes based on their primary activities.

Private warehousing or purchased warehousing services are a part of logistics cost in many industries. In 2012, the total cost of business logistics in the United States was $1.33 trillion, 8.5% of the GDP. The total cost of warehousing was $130 billion, about 10% of the total logistics costs (CSCMP's Annual State of Logistics Report, 2013). Two decades before, this amount was close to $60 billion (Delaney, 1992). Obviously, warehouses are an important and growing part of the US economy.

In addition to the government statistics, the importance of warehousing is also borne out by recent academic research within the supply chain management domain. In an empirical study using social network analysis of archival panel data for two decades, Iyengar et al. (2012) demonstrated that, "over time, logistics and warehousing have not only become more powerful, but have gone from being peripheral activities to being increasingly central and important in the larger economy" (p. 373).

Private (i.e., company-owned) warehouses were an overwhelming part of the business model throughout the end of the 20th century (Maltz, 1994). They accounted for over 85% of all domestic warehousing services in the early 1990s (LaLonde and Maltz, 1992; Maltz, 1994). Traditionally, private warehouses were viewed as logistics cost centers (Murphy and Poist, 1992). Firms emphasized the facility and equipment side of warehousing with little regard for human resources and information technology (Murphy and Poist, 1992; Faber et al., 2002). Private warehouse investment decisions were based on a combination of analysis (such as formal capital budgeting) and intuition or just on intuition (McGinnis et al., 1990). Outsourcing of warehousing was not popular because third-party warehouses were perceived to be lacking on the service side (Maltz, 1994).

However, since the 1990s, warehousing has gone through fundamental changes driven by rising costs of money and labor, rapid development of technology and information technology in particular, fierce global competition and rising customer expectations (Dadzie and Johnston, 1991; Raney and Walter, 1992; Faber et al, 2002). Warehouses have experienced a dramatic increase in productivity and throughput rate, level of automation, reliance on information technology systems, expanded menus of services, improved service quality, and reduction of lead times and order processing costs (Dadzie and Johnston, 1991; Stank et al., 1994; Faber et al, 2002). However, the most important changes were at the strategic level.

After the influential work of Porter (1985) on competitive advantage of firms and business strategies and its adaptation to warehousing by McGinnis et al. (1987) and McGinnis and Kohn (1988), warehousing started to be viewed as a part of a broader business strategy, both in business and in research (Murphy and Poist, 1992). It has been recognized that warehouses are not merely cost centers but they are part of the value creation chain and can contribute to the cost leadership strategy through advantages in operating costs and the differentiation strategy through improved service quality (McGinnis and Kohn, 1988; Murphy and Poist, 1992; Stank et al., 1994).

In summary, warehousing has been getting higher prominence in the US economy, in business strategies of firms seeking competitive advantage, and in academic research. Recent academic literature has emphasized the need for further research focusing on management of warehouse processes as an integrated system (Rouwenhorst et al., 2000; Gu et al., 2007) and on, "identifying the antecedents and consequences of managerial performance in obtaining financial, market, and logistics goals" (Stank et al., 2011). Thus, the importance of this study is established by its addressing a matter of high economic significance to the society and business community and by answering the specific calls for academic research.

Focus of the study

The primary role of warehouses is to serve as buffers in the flow of inventory along the supply chain (Baker, 2007; Gu et al., 2007). During the 21st century, total US business inventories have been growing consistently and reached $2.269 trillion in 2012 (CSCMP, 2013). The growth of inventories demands an increase in the warehouse capacities. However, capacity increases can only occur in much higher increments than inventory changes and result in a substantial cost. In 2012, the total logistics costs in the US and the total inventory carrying costs grew by 3.4% and 4%, respectively, while the cost of warehousing, a part of inventory carrying costs, increased by 7.6% (CSCMP, 2013).

Just as volume of product flow through the supply chain has grown over the years, so has its velocity, driven by the development of e-commerce, globalization, quick response, value-added activities and ever increasing consumer expectations (Ackerman, 1999; Frazell, 2002). The cycle times from order to delivery for consumer products have become particularly short. Retailers involved in e-commerce, such as Walmart and Amazon, are paving the way for the same-day delivery market (CSCMP, 2014). This puts the resources of warehouses to the test: they need to cope with the growing speed of the goods flow as well as the overall increasing level of inventory.

Thus, modern warehouses face a double-sided challenge of accommodating the ever-increasing demands on capacity and throughput, especially during periods of peak demand. Failure to meet these challenges will mean imposing constraints on the ability of the warehouse to store the required volume of goods, or handle the required goods flow, or both. In the long term, a single warehouse firm can address the growth of operations through planned warehouse expansion, such as moving to larger premises or renting adjacent or remote warehousing space to complement the existing facility. Larger multi-warehouse firms may have an additional option of redistributing finished goods flows based on changing the product mix or geographical areas served by individual warehouses. Warehouses of raw materials for manufacturing firms may lack this option.

Moving to a larger facility or constructing a new warehouse is a major decision likely to be made by senior management since it involves substantial capital resources and coordination across the departments of the organization beyond warehousing. It is also one that takes considerable planning and time. It is rare that this long-term process can be precisely synchronized with the dynamic changes in modern high-paced warehouse operations. In other words, the warehouse may reach limits in its storage capacity or throughput well before the long-term solution arrives. In situations like this, managers often are plagued with problems such as overflowing product in storage, long lines of trucks waiting for loading and unloading, complaints from customers and/or managers in other departments within their own organizations, or countless other challenges arising at times of limited or inadequate capacity of warehouse resources.

Naturally, this can lead to service failures and/or increasing costs as managers struggle to find on-the-fly solutions. It is the decision processes of managers in situations where warehouse resources are inadequate during periods of peak demand or are being strained due to the increasing overall volume of goods moving through the warehouse that is the focus of this study. More specifically, this study explores warehouse utilization problems and solutions under constrained capacity or throughput.

Research questions and model

Current academic literature on warehousing looks at warehouses as systems comprised of processes, resources and organization (e.g. Rouwenhorst et al., 2000). The basic processes are receiving, storage, order picking, and shipping (Gu et al., 2007). Warehouse resources are most frequently understood to include personnel, material handling equipment, a computer system, and a storage system (Hackman et al., 2001; Rouwenhorst et al., 2000). Storage and order picking have received the most coverage, while research on other processes is clearly lacking (Gu et al., 2007).

The inability of a warehouse manager to fully cope with increased storage and throughput requirements is an indication of inadequate levels of one or more of its resources. However, there is little agreement on what constitutes a warehouse resource. For example, some view bar code scanners and carton boxes as resources (Rouwenhorst et al., 2000). The inclusion or exclusion of resources from the warehouse resource lists seems to be arbitrary. An argument can easily be made to consider as warehouse resources a pen and paper as well as the lighting and ventilation systems. There does not appear to be a comprehensive definition of warehouse resources based on attributes of the resources, which allows them to be grouped into a useful typology.

Academic literature has another division. Researchers tend to delineate problems of warehouse design from warehouse operations (Gu et al., 2007; Gu et al., 2010). As a result, some warehouse features that have a major impact on operations, such as doors and dock space, have not been considered in the research domain of warehouse operations except for a specific case of cross-docking operations (Gu et al., 2007).

Therefore, before an empirical study of the influence of warehouse resources on its performance and factors that moderate that influence can be undertaken, a conceptual understanding of what constitutes a warehouse resource must be developed. This study undertakes a comprehensive review of warehouse resources with a goal to come up with classification principles and a *key warehouse resource* typology that is useful in practical operations and provides a more cogent basis for theoretical research. This was accomplished through a comprehensive literature review and industry survey with a subsequent analysis. Thus, the first research question of the study is:

RQ1. *What are the key warehouse resources?*

Despite a considerable body of literature on warehousing design and operations, there are very few academic papers that addressed the problem of warehouse expansion. Most studies have assumed that warehouse space is given and matches the required capacity, and these studies typically focused on cost minimization by considering the warehouse storage layout, material handling, or both. This literature is reviewed in Chapter II. The few studies that addressed warehouse expansion (such as Cormier and Gunn, 1996, 1999) focused on optimization of a capacity expansion schedule, assuming a given inventory policy and constant or arbitrary demand growth.

It is evident that simulation techniques used in operations research are not very useful tools for finding practical solutions for constrained resources capacity problems. A management theory that specifically deals with constraint resources may offer a better insight. According to the Theory of Constraints (TOC) originally proposed for manufacturing (Goldratt and Cox, 1986), every system has at least one resource constraint. Formally identifying it and implementing measures to alleviate it has been shown to lead to higher performance (Gardiner et al., 1994). The principles of TOC have been transferred to and tested in other fields, including supply chain management (Gupta, 1997; Perez, 1997, Rahman, 2002). However, there does not appear to be any research broadly applying these principles in a warehouse setting. To address this gap, it is of interest to determine through which mechanisms the application of the TOC logic could lead to increased performance in warehousing. Therefore, the second research question of the proposed study is:

RQ2. *How does the use of TOC logic to manage warehouse resources in order to alleviate constraints in warehouse operations lead to better warehouse performance?*

The model in Figure 1 represents the general framework for this research.

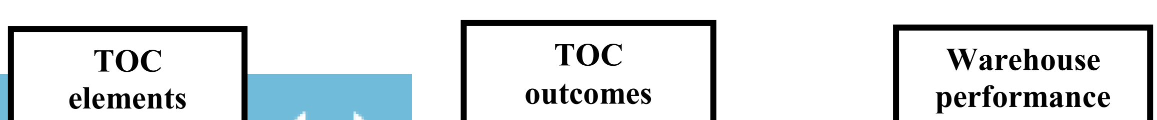

Figure 1: Research framework.

A discussion and a more detailed model are presented in Chapter III.

Contributions to theory and practice

This study is expected to make contributions to theory and practice in several ways. First, various warehouse resources have been analyzed and those that are critical for its mission have been identified. Resources were selected based on important attributes, such as the potential to become a long-term constraint on warehousing operations, critical for the constant flow of goods, etc. This analytical exercise resulted in a group of six key warehouse resources two of which were not previously identified as such in warehousing research. Development of this typology will be a contribution to the academic literature on warehousing as well as providing managers with a new perspective of their warehouse operations.

Second, TOC is modified for use with survey data for analysis of problems in the warehousing industry. The development of measurable constructs within TOC, which are suitable for survey-based research, should increase the attractiveness of this theory for use in future empirical studies that seek results that are generalizable on an industry-wide basis. Opening the door to explore the logistics paradigm of TOC in detail, beyond the traditional general boundaries, is an important contribution to TOC-focused empirical research.

Third, previous research in warehousing has used an empty box approach, assuming that operations can be modeled from scratch. The current research is based on the business needs of existing warehouses through which volumes have grown such that the initial capacity is no longer sufficient, especially during periods of peak demand. This is a common situation in industry but it has been overlooked by academic research due to negligible collaboration with industry (Gu et al., 2007). To overcome this shortfall, warehouse managers are provided with an evaluation of methods for dealing with constraints in existing warehouses, which is supported by solid theory.

Lastly, the identification of key warehouse resources and TOC elements for the warehouse will give managers a better understanding of their options in resource management and will help managers to focus their efforts on improving existing operations, even if they choose to act outside of the TOC paradigms.

Contributions of this study are discussed in more detail in Chapter VI.

Plan of the dissertation

Chapter I introduced the problem of warehouses reaching the full originally planned capacity of their resources while trying to adjust to the growing volume of operations as the focus of this study. It has also stressed the importance of this study for industry as well as outlined the theoretical contributions it aspires to make.

Chapter II provides a review of relevant academic literature on the subjects of warehousing and the theory of constraints and summarizes the conclusions that can be drawn from previous studies to be used in this research.

Chapter III develops a detailed framework for the study. It applies TOC to the warehousing context, discusses the notion of a key warehouse resource, and develops a model and a set of hypotheses to be tested in the empirical part of the study.

Chapter IV discusses the methodology of the study. The operationalization of the constructs, data collection and the method of analysis are be explained.

Chapter V provides the findings of the empirical research and conclusions that can be drawn from them.

Chapter VI concludes this work with a detailed discussion of contributions of this study, its limitations and suggestions for future research.

CHAPTER II

LITERATURE REVIEW

Introduction

In this section, the literature relevant to this research is reviewed. There is an abundance of academic literature on warehousing, however, most papers deal with narrow well-defined problems (Rouwenhorst et al., 2000), so general classifications of warehouse resources and processes can only be found in practitioners' handbooks, such as Frazell (2002) and Tompkins (2003), or in academic papers whose main purpose is literature review, such as Gu et al. (2007), Gu et al. (2010), Cormier and Gunn (1992), and Rouwenhorst et al. (2000).

Most literature reviews on warehousing separate design and operations into two different frameworks. Warehouse resources largely fall under design, while warehouse processes are covered in the warehouse operations research. There is also a large body of literature on the theory of constraints, which will be modified for use in analyzing the management of warehouse resources. Thus, for the purposes of this study, it is expedient to split the literature review into two sections: warehouse design and operations, and the theory of constraints.

Warehouse design and operations

It has been noted that research on warehouse design is very disjointed, dealing with specific problems, and that integrative methods of warehouse design have not been proposed (Rouwenhorst et al., 2000; Goetschalckx et al., 2008). Gu et al. (2010) proposed a framework of warehouse design that consists of five components: overall structure, sizing and dimensioning, department layout, equipment selection, and operation strategy selection. However, there is a considerable overlap in many papers dealing with these topics, and very few of them seem to fall strictly within one of the five categories (e.g., Rosenblatt and Roll, 1984), which is understandable, given how interconnected these categories are. For the purposes of this literature review, the only research that was included dealt with the storage area (whether sizing or layout), other areas (departments) of the warehouse, and/or equipment selection.

The layout of a storage area in conjunction with a particular storage system emerges as a key focus area of warehouse design research. One direction of research was determining the optimum size of the storage area with a view to minimize the total storage and handling cost. One of the early works in this research stream was undertaken by Francis (1967). He developed mathematical models that minimized the total annual costs of an item's movement between an outside point (a loading/unloading dock) and any point within a rectangular shaped storage area containing one or multiple items. His models took into account costs associated with warehouse perimeter construction and maintenance costs for a fixed warehouse dimensions (surface area and height). However, the models were based on some restrictive assumptions which do not reflect modern real-world warehouse operations. He assumed a single point of goods loading and unloading (dock) and equal probability of an item movement between the dock and any point in the warehouse.

Francis (1967) did not consider the inner structure of the storage area beyond its size and rectangular shape. A key characteristic of storage is its capacity (Rouwenhorst et al., 2000). In addition to its size and shape it depends on its internal layout and storage systems used. Three types of storage systems are widely considered in the literature: floor storage (block stacking), racks, and automated storage and retrieval systems (AS/AR). Storage of goods on the floor is the simplest way of storing. It has its advantages (flexibility) and disadvantages (honey-combing and poor utilization of the volume of the storage area). The AS/AR systems, as the name suggests, is a combination of the two processes, storage and retrieval, performed with a certain degree of automation. When automation is achieved through automatic storage and retrieval systems, the rigid design of processes and capacity of automated warehouses does not allow much room for maneuvering in terms of finding untapped reserves of warehouse resources, so we formally control for this condition in this study.

Further research relaxed some of the simplifying assumptions of Francis (1967). Following previous research, Berry (1968) equated the optimum efficiency of the warehousing operation to the one that minimizes the total costs, which are made up of two categories: costs associated with the storage area or volume occupied, and material handling costs. He investigated in detail two layouts: a rectangular block with aisles parallel to the two walls and a perpendicular connecting aisle along another wall; and a rectangular block with a single diagonal aisle. He actually considered and rejected as inferior a number of other layouts: those with cross aisles, multiple radial aisles and others. In addition to block storage on the floor, he considered storage on racks of various height as well as different storage allocation policies (random and dedicated) and fast and slow moving SKU's. He proposed a number of recommendations to be taken into account in warehouse design.

One of his main conclusions important for this study is that he explicitly stated the trade-off between the space utilization and material handling costs in a warehouse: "The warehouse layout which gives maximum utilization of space is different from one which minimizes handling distance" (p.115). It should be noted that travel distance, as well as time, in the warehouse are routinely used as a proxy for material handling costs (e.g., Rosenblatt and Roll, 1984: Goetschalckx and Ratliff, 1988; Ashayeri & de Booy, 2008; Ellis et al., 2008). In a conventional warehouse, material handling costs are incurred through the use of personnel and lift trucks. It is common knowledge that distance traveled is a product of time and speed of travel. In, a warehouse setting, the typical travel speed of a person or a lift truck are perceived as known since they are limited by the physical ability of a person, technical specifications of the machine, and, often, safety rules. This makes the shortest travel time and distance interchangeable objectives for cost minimization.

Bassan et al. (1980) incorporated the same material handling and warehouse perimeter costs as Francis (1967) but considered two scenarios of aisles in a rectangular shaped storage area: aisles going lengthwise (parallel to the long side of the storage area) and aisles going across (parallel to the short side of the storage area). The authors developed an optimization model for these parameters and proposed some guidelines to execute a warehouse layout for these scenarios.

The stream of research concerned with the layout of the storage area has been very potent. The most typical attributes of layout considered are: lane depth and orientation in block-stacking pallet storage (e.g., Moder and Thornton, 1965; Berry, 1968; Marsh, 1979; Goetschalckx and Ratliff, 1991), and number of aisles and their configuration (e.g., Berry, 1968; Larson et al., 1997; Bassan et al., 1980; Pandit and Palekar, 1993). Most recently, unconventional aisle configurations (flying V, fishbone, leaf, butterfly and chevron) were explored by Gue and Meller (2006), and Öztürkoğlu et al. (2012). The details of particular layouts considered by these and other papers in this stream are not important for our research and are therefore not discussed here. However, we note as relevant for our research the explicit conclusion that the reduction of retrieval travel time comes at a cost of a loss of storage space utilization (Öztürkoğlu et al., 2012). Or in more general terms, there is a tradeoff between storage capacity and material handling cost, a conclusion already stated by Berry (1968) and in many research papers that followed.

Another problem of storage area design arises because of separating the area into picking and reserve areas, also referred to as forward and reserve. One of the earliest studies of this type was performed by Bozer (1985). He split the pallet rack horizontally into a lower picking area and an upper reserve area. The forward picking area, whether it is lower or closer to the center of the aisle, saves handling time, but requires periodic replenishment from the reserves. The objective of his and many other studies that followed (e.g., Hackman and Rosenblatt, 1990; van den Berg et al., 1998) was to minimize material handling cost (especially picking time), and thus increase the throughput capacity of the storage area.

Starting from White and Francis (1971), researchers have recognized that there is a cost of not having enough storage capacity. Consequently, they have incorporated this cost into their optimization models. Rosenblatt and Roll (1984), who made an attempt at integrating several warehouse design problems (size, layout and storage policy), also included a cost of load rejection due to lack of storage space in their model. For a warehouse with pallet racks, they considered a combination of two types of storage policies: zoning and degree of randomness. The zoning of the storage area dictates that the whole incoming load of pallets must be stored within the same zone. The degree of randomness of storage implies that under the grouped storage policy all of the pallets of the incoming load must be stored together, while under the random storage policy, it is not a requirement. The authors make an important conclusion that there are trade-offs involved in the storage space utilization (and associated costs) and storage policies. The best space utilization is achieved with no zoning and complete randomness of storage; the worst (and higher level of load rejection due to capacity shortage) is likely to occur in a storage area split into small zones combined with the grouped storage policy.

Their work described above is representative of the stream of research by these authors exploring factors that affect storage capacity (e.g., Roll and Rosenblatt, 1983). In their later work (Rosenblatt and Roll, 1988), they introduced the concept of service level in the determination of capacity. The service level is defined as, "the proportion of days (or any other unit of time) for which the given warehouse capacity is sufficient for accommodating the required replenishment shipments" (p. 1847). They found that for a predetermined service level the required warehouse capacity is affected by the number of SKUs stored, the demand characteristics (picking), and the replenishment policy.

Previously reviewed work typically considers one storage area. In reality, available space may be allocated to several competing activity areas (e.g., pallet racks, block stacking, receiving buffer and shipping staging area). Pliskin and Dori (1982) compared seven suggested area assignments for a tools warehouse, a part of a metal-cutting operation, by considering trade-offs among four space categories. They proposed a method of multi-attribute value functions which assigned a score and permits the ranking of options according to the decision maker's preferences. Of relevance to our research here is an explicit consideration of trade-offs among several space categories.

Tradeoffs between allocating a limited resource (floor space) to two different storage systems (a random access system and a rack system) were studied by Azadivar (1989). Under the random storage system, the throughput is higher because every storage slot is immediately accessible from the floor level but the storage capacity is lower (only one tier). The rack system has the opposite characteristics: its throughput is lower but the storage capacity is higher (several tiers). The objective of the study was to find the best tradeoff between the two systems that balances the storage capacity and operational efficiency.

While Azadivar's study was performed in the context of an automated storage and retrieval system operating in the rack storage and a nonautomated material handling system operating in the random access storage area, its principal tenet applies to completely conventional warehouses as well. For example, the problem he solved for an automated storage system warehouse is similar to deciding between the share of racks with narrow aisles, which provide better storage capacity but slower pallet putaway and retrieval, and the share of racks with regular (wide) aisles, where capacity is decreased due to more floor space taken by the aisles but the operational efficiency is higher, in a conventional warehouse.

Park and Webster (1989) pursued an even more integrated approach to comparing three-dimensional pallet storage systems. They proposed a model that, "simultaneously considered the following factors: control procedures, handling equipment movement in an aisle, storage rules, alternative handling equipment, input and output patterns for goods flow, storage rack structure, component costs and the economics of each storage system" (p. 985) with appropriate optimization targets.

Several studies reviewed above (e.g., Francis, 1967; Bassan et al., 1980) as well as others have included assumptions about the location of doors relative to the storage area in their travel time optimization models. However, there is practically no academic literature on warehouse doors that considers their capacity and potential to constrain the goods flow or their potential to relieve other constrained resources. The scarce cross-docking literature considers the optimum door layout for truck assignments (Gue, 1999) or travel and waiting time minimization due to congestion (Bartholdi and Gue, 2000). However, these works are not applicable to the door capacity problem considered in our study. The number of doors can be a serious constraint or, in some instances, can be used to relieve other constrained resources.

Selection of material handling equipment such as lift trucks is part of any warehouse design. It is often considered together with the selection of the storage system. Baker and Canessa (2007) reviewed the literature on individual steps in warehouse design from 1973 through 2006. Of the 14 studies reviewed only 5 list designing or selecting material handling equipment as separate steps. Šraml et al. (2008) used discrete simulation to analyze the efficiency of four principal warehouse transportation vehicles: a counterbalance lift truck, a reach truck, a narrow-aisle lift truck, and a stacker crane. There is paucity of academic studies on lift truck selection but advice to practitioners can be found in popular warehousing handbooks.

In Baker and Canessa's (2007) review of research on warehousing design steps, only two papers identify calculation of staffing needs as a step. Most studies consider personnel implicitly when optimizing material handling costs. As Rowenhorst et al. (2000) observed, "minimizing operational costs in particular often boils down to minimizing the required work force" (p. 522).

Ashayeri and de Booy (2008) looked at warehouse personnel from a different perspective. They addressed the issue of workload balancing in order to reduce response time, an increasingly important objective in modern warehousing operations. They proposed a three-phased framework, the middle phase of which is workforce planning. They presented three different models of workforce planning (capacity assignment, mean value analysis, and CAN-Q approach) and evaluated them using simulation.

Outside of operations research, a considerable body of literature on warehouse human resources management has been published in supply chain management journals. Most studies recognize the critical importance of availability and effective management of human resources to warehouse operations (e.g., Autry and Daugherty, 2003). There are also indications of problems with employee job satisfaction and turnover in warehouses, with turnover exceeding 100% in the worst cases (Murphy and Poist, 1992). However, smaller warehouses were found to do a better job of attracting and retaining human resources (Min, 2007). Only two ways to match the workload with the availability of personnel appear to be considered in the academic literature. Some studies emphasized efficient labor scheduling and workload forecasting that, "minimizes labor costs while maintaining service commitments" (Sheehan, 1989; Sanders and Ritzman, 2004), whereas most other work considered ways to simply attract more employees and do a better job of retaining them, such as through higher job satisfaction (e.g., Murphy and Poist, 1993; Autry and Daugherty, 2003).

There does not appear to be literature that considered the possibility of operational tradeoffs between warehouse labor and other resources. The closest to this was the study by Sanders and Ritzman (2004) that considered the flexibility of warehouse personnel in itself (e.g., through cross-training) to be used as a tool to offset workload forecast errors. However, labor is frequently the most flexible resource in the warehouse.

Academic supply chain literature also has focused on information technology in the warehouse and tracked its evolution from humble beginnings as electronic data interchange (EDI) between warehouses and customers (see for example, Raney and Walter, 1992) to the modern "smart" warehouse management systems (WMS). WMS are information technology systems used to "plan, optimize, and execute operations" (Autry et al., 2005, p. 167), the definition we will use in this study.

Researchers have studied WMS from a variety of perspectives. The antecedents of WMS have been examined, revealing that the introduction of information technology in the warehouse was largely driven either by customers or by top management who saw it as a tool to gain a competitive advantage (e.g., Raney and Walter, 1992; Rogers et al., 1996; Autry et al., 2005). Best practices were reviewed in detail in case studies (e.g., Min, 2009) and "buy standard" vs. "get one tailor-made" decisions were analyzed (e.g., Faber et al., 2002). More importantly, most researchers who studied the link between the degree of WMS implementation (degree of sophistication, level of investment, dedicated personnel, etc.) and organizational performance appear to agree that there is a significant positive relationship between the two (e.g., Rogers et al., 1996; Faber et al., 2002; Autry et al., 2005).

Another important finding is that a functionally inadequate WMS may be a constraint in warehouse operations by forcing management to compromise, "…between the way a warehouse wants to work and the way the system allows the warehouse to work" (Faber et al., 2002, p. 381).

Most warehouse design literature is concerned with planning new warehouse facilities. There is very limited research on optimization of existing operations, and attributes of existing facilities are usually considered to be static. This literature is largely limited to the relocation of storage items (SKUs). For example, it may become necessary to relocate SKUs if changes in demand cause former fast-moving items to become slow-movers, leading to longer picking times. Two representative papers are briefly described below.

Christofides and Colloff (1973) solved the problem of movement cost minimization for such transfer under assumptions of moving all items one at a time, using only one vehicle, and that the time when an item is not located in a proper warehouse location is at its minimum.

Sadiq et al. (1995) studied the problem of periodically reassigning stock items to create a dynamic stock mix that correlates with dynamically changing demand. They used cluster analysis to develop a heuristic Dynamic Stock Location Assignment Algorithm which appeared to be superior to the well-known cube-per-order index (Heskett, 1963; Kallina and Lynn, 1976; Janea and Laihb, 2005) in dynamic environments.

A more radical approach to designing warehouses that are able to accommodate change was presented by Ackerman (1999). He lists several trends that affect the function and operations of warehouses: faster cycle times, high inventory turns, growth of cross-docking operations, and increased use of information technology. These changes will impose new requirements on warehouse design and operations: more dock doors, different door locations (close to each other on one side of the building rather than on the opposite sides) and flexible door allocation (no doors dedicated to a customer or particular operation); brighter lights to accommodate night shifts; higher quality floors for high velocity operations; more office space and storage flexibility. Information technology allows to constantly analyze the quickly changing 80/20 rule of item velocity based slotting. To implement changes flexible storage systems are necessary. They should replace the efficient but inflexible automated storage systems. Hence, the emphasis should be on flexibility and not on efficiency or storage capacity.

Ackerman (1999) illustrates the right tradeoff (balance) between efficiency and flexibility with an example of warehouse dock doors. Since dock doors are expensive, it is common to design and build a warehouse with a limited number of doors sufficient to cover the present time operation. However, flexibility dictates a higher number of doors. One practical way to balance the costs and flexibility is to install just the required number of doors but prepare the foundation and the walls for future door additions by depressing the building footer. This emphasis on flexibility over cost minimization and efficiency is a dissonance from the traditional warehouse operations research literature.

In summary, there are several important conclusions from the reviewed body of literature on warehousing that are relevant for this research:

1. Storage capacity is important. It has been a primary focus of academic research on warehouse design. Storage capacity is influenced by many factors of warehouse design (storage area size, layout, storage system, separation into zones, storage policy and others).
2. Academic literature recognizes a negative effect on performance when there is a shortage of capacity. The capacity shortage results in a rejection of incoming loads. The sufficient capacity can be expressed as a service level. Thus, it is expressly recognized that capacity may be a major constraint in a warehouse.
3. There are trade-offs involved in optimizing storage capacity and minimizing costs associated with other warehouse resources. Academic literature expressly recognizes that it is impossible to maximize storage capacity and minimize material handling costs at the same time. These costs are linearly proportional to the amount (quantity) of resources used (such as labor hours of warehouse personnel and machine hours of lift trucks; the needed work hours in turn largely determine the quantity of the required personnel and machines in the warehouse).
4. The studies aimed at optimization of material handling costs implicitly consider personnel and lift trucks. Behavioral human characteristics were not taken into account in warehouse operations research. Supply chain literature raised a few issues relating to human resources which are relevant to this study. In particular, the literature notes the high importance of this resource, the need for its effective management, and ways to increase its capacity. The literature also suggested warehouse size as a potential control

variable, since warehouses were found to differ on employee satisfaction and turnover based on size. Flexibility was identified as a property of this resource with a cost savings potential.

5. Other components of warehouse layout (doors, shipping and receiving areas) received very little coverage in the academic literature.
6. Selection of warehousing equipment, specifically, lift trucks, did not receive much attention from scholars either. However, there is a considerable body of research on optimization of their use (costs, time, distance) within the framework of existing operations by manipulating storage policies (which affects storage capacity) or picking policies holding existing storage policies and picking area layout constant.
7. Information technology plays a prominent role in a modern warehouse in the form of a WMS. Limited functionality of the WMS may lead to lower warehouse efficiency (act as a constraint), whereas higher level of WMS implementation is positively associated with warehouse performance.
8. Academic studies of warehousing design and operations are either concerned with initial selection of warehouse parameters (such as storage area) or assume that they are already given. There is little work on adjusting existing operations to accommodate changes in demand, product types, etc.
9. Flexibility in warehouse design and operations is regarded by some as a contemporary alternative to a traditional focus on efficiency in the academic operations research literature.

These conclusions support the need to focus on basic warehouse resources: storage space; personnel; equipment; doors; dock space; and information systems. They also suggest the need to consider these resources as potential constraints in the flow of inventory through the warehouse, which can lead to inefficient and ineffective warehouse operations. Finally, they suggest that managers should understand that there are trade-offs among these resources, and that one resource can be used to relieve a constraint created by another, effectively increasing the capacity of the warehouse without adding physical expansion.

However, some gaps in this literature are evident. They refer to both the domain of the research and the methods used. Supply chain literature addresses warehousing problems at a very general level. It tends to use a firm as the smallest unit of an analysis and is usually not concerned with the operations of a warehouse as an organizational unit of a firm. On the other hand, operations research looks at warehousing problems very narrowly. The complexity involved in the mathematical modeling and simulation, the traditional tools of operations research, require imposition of very restrictive assumptions, which severely limits the practical uses of the research results.

We hope that this study, which takes the tools of supply chain management research and brings them down from the "30,000 feet level" of the whole organization to the "bird's eye view" of operations in a warehouse as one organizational unit of the firm, will pave the path to eventually closing this literature gap.

Theory of constraints

One management theory that addresses bottlenecks in operations is the Theory of Constraints (TOC). TOC was proposed by Eliyahu Goldratt in the 1980-s and popularized in a number of books (Goldratt and Cox, 1986; Goldratt and Fox, 1986; Goldratt, 1994). TOC is widely accepted in business and is extensively used in academic research.

The purpose of TOC is to make a firm more competitive by running its operations in a more efficient way (Polito et al., 2006). TOC originally appeared as a scheduling algorithm for manufacturing and was marketed as a software package. However, there was a need to explain to the users how it works, so the book *The Goal* (Goldratt and Cox, 1986) was published.

According to it, the firm's business is viewed as a combination of throughput (rate of generating money through sales), inventory (everything purchased in order to be sold), and operational expense (money spent on turning inventory into throughput). The underlying premise is that the system will have at least one constraint, since infinite throughput is not possible. The constraint slows down the whole system's throughput and prevents the firm from achieving higher financial performance. To rectify the situation it is first necessary to understand what needs to be changed and the process for the change. Five focusing steps are proposed for the purpose:

1. identify the constraint;
2. decide how to maximize the throughput through it;
3. subordinate the whole organization and processes to this decision;
4. implement measures that will relax this constraint;
5. repeat from the beginning (Goldratt and Cox, 1986).

The five focusing steps are an alternative method of continuous improvement. It is different from other methods, such as total quality management in that it focuses on a single or very limited number of constraints rather than attempting to improve quality everywhere (Gardiner et al., 1994).

Based on the five focusing steps a specific production scheduling technique called drum-buffer-rope (DBR) was proposed. The allusion is to a scout troop march illustrative example in

The Goal. The drum represents the constraint that sets the rate of output of the whole system. It is critical to keep this resource operating at maximum capacity. For this reason, there is a buffer of material for processing in front of the constrained resource and a space buffer for processed inventory right behind it. This ensures that the constrained resource will keep operating during temporary disruptions up or down the stream. The rope represents the fixed lead time of releasing raw materials into the processing chain based on the rate of operation of the constrained resource. This ensures that the resource is never starved for materials, but also that no more materials are released than actually needed for the operation of that resource, even if other resources may temporarily be idle. Under TOC, buffer management is the only production control technique that is needed (Gardiner et al., 1994).

The specific methods discussed above are said to comprise the logistics paradigm of TOC (Rahman, 1998). As physical constraints are overcome one by one, eventually the next constraint will be found outside the production floor. The constraint may be nonphysical and completely external, e.g., insufficient market demand to support the increased level of production of the firm, or internal but elsewhere within the organization, e.g., managerial constraints in the form of restrictive policies (Simatupang et al., 2004). In response, a thinking process (TP) was developed to address any problems in general. Using a specific set of tools (current reality tree, evaporating cloud, future reality tree, prerequisite tree and transition tree), managers should be able to find answers to the three main questions of initiating change:

- what to change;
- what to change to;
- how to cause the change.

The problem solving paradigm of TP complements the logistics paradigm and is believed to be the most lasting contribution of the TOC philosophy because it can be applied in a very general way (Rahman, 2002).

TOC was compared to and in many cases was found superior to kanban, JIT, MRP, linear programming and total quality management (Rahman, 1998; Gardiner et al., 1994; Luebbe and Finch, 1992; Sale and Inman, 2003). In addition to manufacturing, the primary industry for which it was originally designed, TOC was successfully applied in the airline industry, health care, banking, military logistics and many others, where companies like Proctor and Gamble, Ford, GM and others saved millions of dollars by implementing the logistics or problem solving paradigms of TOC or both (Watson et al., 2007; Polito et al., 2006; Bramorski et al., 1997; Gardiner et al., 1994; Demmy and Petrini, 1992).

Boyd and Gupta (2004) attempted to integrate TOC, along with JIT, economic order quantity and a number of other theories, into a more general Constraint Management Theory. They suggested for future empirical studies (but did not test empirically themselves) several hypotheses based on TOC as part of Constraint Management Theory, including one whose parts are in line with our treatment of TOC:

> There is a significant positive relationship between the degree of throughput orientation and organizational performance.
>
> Process improvements … at a constraint will have significantly greater positive impact on performance than similar improvements at a non-constraint (p. 365).

Instead of being currently recognized as consisting of the two main parts (the logistics and problem solving paradigm), TOC was initially seen as a rather eclectic collection of smaller components. Spencer (1993, p. 37) listed seven of them: "…the five focusing steps, V-A-T analysis, effect-cause-effect analysis, drum-buffer-rope scheduling, buffer management, the performance measurement system, and the thought process." His illustrative paper appears to be the only attempt to apply a part of TOC to warehousing. His work is based on an argument that a warehouse is merely a type of a production facility, which allows us to apply automatically the V-A-T logical structure analysis for manufacturing to warehousing (where the letters V-A-T refer to three potential shapes of a logical structure of goods flow in a warehouse) (Spencer, 1993). Even though his paper concedes that, "warehouse operations may be less rigidly defined" than in manufacturing (p. 37), the reader is left with an impression that the rigid production structure is forced upon warehouse operations, particularly when the case of value-added assembly activities is chosen as an illustration. The paper provides advice on identifying a particular operation that constrains the whole output and assumes that creating a buffer of materials and proper scheduling (i.e., using buffer management and DBR scheduling techniques of TOC) will solve the problem, but it does not address the problems of severe resource shortages or resource sharing between independent operations. The author concludes that, "[d]ifferent warehouses have different processes and require different management" (p. 46). In contrast, our study examines *common* approaches under TOC to management of warehouse *resources* rather than processes and does not treat warehousing as a variety of manufacturing.

Kim et al. (2008) reports that TOC received much attention in academic literature in the functional areas of supply chain management and human resources management. However, there are very few empirical studies of TOC and there is no evidence of research involving the TOC logistics paradigm in the context of traditional warehousing operations. Major survey-based empirical work on TOC is absent from operations research (Gupta and Boyd, 2008).

CHAPTER III

THEORY DEVELOPMENT

Adapting TOC to the warehousing context

Need for modifications

In this study we seek better understanding of warehouse resources and their management using the theory of constraints (TOC). TOC was originally suggested for the manufacturing environment. In *The Goal* (Goldratt and Cox, 1986), the five-step focusing process was introduced in a hypothetical but realistic manufacturing setting (Reid, 2007). The product flow went through a fixed sequence of machines, one of which had a low capacity and constrained the whole system's throughput. Solutions offered by TOC were intended to be generalized to many manufacturing enterprises.

The use of TOC to analyze warehousing resources on an industry-wide basis requires some modifications to the basic theory. These modifications are necessary for several reasons. First, warehousing is substantially different from manufacturing in many important respects. Second, our study covers a period of three years that is not necessarily synchronous with a TOC cycle at any particular warehouse. Third, the originally developed logistics paradigm of TOC is not conducive to survey research, yet the survey method is a very important technique for studying a variety of warehouses in such a diverse industry. In this chapter, we consider these reasons for TOC modification and explain the ways we do it in detail.

Applicability to warehousing in principle

To decide whether TOC can automatically be extended to warehousing without adaptation, we need to consider several arguments. On the one hand, in the previous chapter, we have listed examples of other industries (airlines, banking, etc.) where TOC was successfully applied. We have also reviewed what appears to be the sole academic paper attempting to apply one TOC element to warehousing. This can be interpreted as an indication that TOC is not limited to manufacturing and can in fact be used in different contexts, including warehousing.

On the other hand, there are arguments that appear to offer support to the opposing view. First, the prevailing view is that warehousing is not manufacturing. Sanders and Ritzman (2004) describe warehouses as, "service organizations whose 'product' is not the creation of tangible goods, but the ability to efficiently mix and move goods at short notice" (p. 251). To determine if TOC solutions for manufacturing can be automatically extended to warehousing, we need to consider how similar these industries are for the TOC relevant characteristics. Specifically, we need to establish if warehousing has the type of manufacturing throughput process described above: a fixed set of machines and a continuous rigid sequence of inventory flow through the system.

Warehouses do not have stationary machines like in manufacturing with the exception of automated storage / automated retrieval systems (AS/AR), machines for value-added processing (e.g., promotional sets packaging) and some auxiliary machines (e.g., to shrink-wrap a pallet). In this research, we only consider traditional warehouse operations and disregard the manufacturing functions of the warehouses. Any auxiliary equipment by definition is outside the primary warehousing operations we are focusing on. Thus, the traditional warehouse operations are not built around a set of stationary machines that processes raw materials into inventory of finished goods and are more flexible.

The seeming similarity of presence of inventory and its flow in a manufacturing plant and a warehouse is also deceptive. Inventory buffering options (a major part of TOC in manufacturing) such as inventory safety stock for made-to-stock items are not available in warehousing (Sanders and Ritzman, 2004). Warehouse buffers may be of a different nature (e.g., time buffers created by a queue of picking orders to process or trucks to unload) and may be resource specific.

The product flow is different, too. The primary function of a traditional warehouse is storage (Gu et al., 2007; Frazell, 2002). In the storage area, the flow of goods is broken. Vogt and Pienaar (2007) clearly state that, "[t]he storage of the stock in the warehouse completely segregates the inbound and outbound processes" (p. 87). The inventory placed in storage may remain there for a long time and even become obsolete (Rouwenhorst et al., 2000). While this will have a negative impact on the financial performance of a private warehouse, in case of a public warehouse, the warehousing company will still receive revenue by providing this storage service to its customers. This is in sharp contrast with manufacturing where an accumulation of unsold finished inventory is definitely a negative factor (Goldratt and Cox, 1986).

In any case, the interruption of the goods flow in a warehouse makes treating the TOC goal of increasing throughput in the same manner as for a manufacturing plant impossible: the throughput of a warehouse is broken into the inflow and outflow, with storage separating the two. The processes generating the incoming and outgoing flows may compete for the same warehouse resources. Some literature (e.g., Elton and Roe, 1998; Steyn, 2002) suggests that TOC may not be fully applicable to concurrent competing projects as they will compete for the same resources, a situation that seems to fit the disjoint but concurrent warehouse flows.

The arguments above offer grounds to doubt TOC's automatic applicability to warehousing without modification. Given the contradictory evidence from literature and logical analysis, empirical research is definitely warranted. Due to the differences between the two contexts, some special tools need to be found to translate TOC for manufacturing into warehousing for testing in empirical research. Manufacturing is the original but not the sole TOC domain. In academic research, TOC has been used outside manufacturing, most often in a service industry. However, most papers were case studies or general illustrative applications (e.g., Bramorski et al., 1997; Olson, 1998; Roybal et al., 1999; Zadry and Yosuf, 2006; Polito et al., 2006, Reid, 2007). Research that produced hypotheses and scales to test TOC empirically (e.g., Boyd and Gupta, 2004; Moss, 2007; Inman et al., 2009) has not focused on the logistics paradigm of TOC we are interested in and is still too general to be applied to warehousing as is. Thus, we are unable to base TOC modification on prior research and must undertake the complete task of adapting TOC to warehousing. This includes changes to some of its constructs and relationships among them.

Processes vs. resources

As the initial step of TOC adaptation, we turn to the core of TOC. Reid (2007) suggested that TOC's single unique characteristic as a managerial philosophy is an emphasis on identification of a single or a few factors, such as a resource or process, that actually limit the performance of the whole system.

Let us consider the possibility of process constraints in the warehouse first. According to Gu et al. (2007), a typical warehouse operation can be viewed as a flow of goods first entering the warehouse then consecutively going through the processes of receiving, storage, order picking and shipping and then physically leaving the warehouse, as shown in Figure 2. Additional steps of inspection, sorting, packing and others are possible (Keller and Keller, 2014).

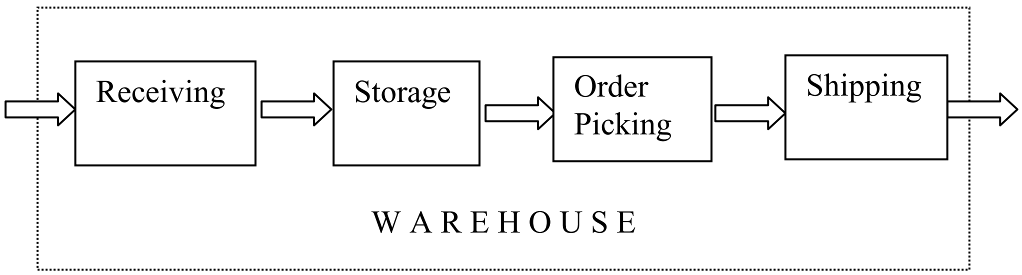

Figure 2: Flow of goods in a warehouse (adopted from Gu et al., 2007).

It is very obvious that many of these processes can be performed using the same space, personnel and material handling equipment. In other words, they share certain resources. In case the actual productivity (throughput) of a process is not meeting the demand, management can shift the resources to the lagging process quickly. However, if the total quantity of a particular resource is not sufficient to cover all the required processes, then the total system throughput will decrease. The relative ease of allocation and reallocation of warehouse resources to the operational processes indicates that it is not warehouse processes but the capacity of the resources that may be a true constraint in a warehouse. Thus, for the purposes of TOC application, we will need to focus on warehouse resources, not warehouse processes.

Clearly, every warehouse uses a big variety of inputs that may be treated as resources. Lack of capacity of some of them may present only a trivial problem, whereas a shortage of some other resources may be difficult to overcome. We turn to the warehousing literature again to identify the most critical resources that have a potential to become a constraint in a typical warehouse.

The following sections of this chapter discuss the concept of a key warehouse resource and name specific attributes of a warehousing operation that qualify as key warehouse resources. A more detailed model of hypothesized relationship between constructs is offered and hypotheses are developed.

Key warehouse resources

Definition and tests

An important point of this research is a definition of a critical, or key, warehouse resource. We offer the following definition: *It is a component of a warehouse design or operation that is critical to the mission of the warehouse, is not easily acquirable or modifiable, and has a finite or limited capacity at least in the short term*.

To clarify specific parts of the definition, the mission of the warehouse is commonly understood as a combination of storage and throughput of products at a desired level of quality and minimum resource cost (Gu et al., 2007; Frazell, 2002). It follows then that for a warehouse resource to have a critical bottleneck potential it must affect the flow of goods or related information directly and have an impact on quality and cost. We will refer to this statement as the goods flow impact test.

In the definition of the key warehouse resource, “easily acquirable or modifiable” refers to the fact that a change in the resource, such as an acquisition of additional quantity of this resource or a modification of its characteristics, is not possible to accomplish within the routine processes of the day-to-day operations. It requires substantial waiting time, or will incur a substantial cost, or is subject to a hierarchical management review process, or is simply not available (or no longer available) or any combination of the above. It is also not easily substitutable within the routine processes of the day-to-day operations. For short, we will call this the time-effort-cost test.

Finite capacity refers to the attribute of the key warehouse resource that cannot be increased infinitely within the existing warehouse organization and process design. In other words, a key warehouse resource has the potential to become a long-term bottleneck in the warehouse operations if the demand for it has outgrown its capacity and management has not been proactive to implement a plan to alleviate the problem, such as increasing the capacity of the resource. A key warehouse resource may reach its maximum capacity, and then it will become a permanent constraint until the existing warehouse design or process is changed.

It should be noted that this research concerns an increase of demand for the resource capacity due to growth of the regular operations, not a one-time peak in demand and not a situation when a resource is out of order or broken and just needs to be restored to its normal capacity to stop being a bottleneck in the warehouse operations.

Relation to RBV and RMT

The Resource Based View (RBV), a popular management theory proposed by Barney (1991), also deals with firm's resources, so it is important to compare our treatment of the concept of key warehouse resources to that of RBV.

RBV's main original tenet is that a firm can gain a sustained competitive advantage over other firms if it possesses resources that are valuable, rare, imperfectly imitable and nonsubstitutable. On the surface, these resource attributes may seem close to the definition of the key warehouse resources. However, there are substantial differences.

RBV considers resources of one firm as they relate to competitors, whereas this research focuses on one firm and its internal warehouse operation. This makes inimitability, one of the four resource attributes of RBV, not applicable since it implies taking into account other firms. The other attributes do not apply either. This research looks at resources that are *typically* used in non-automated warehouses, so they cannot be rare. We will specifically show that trade-offs are possible to partially substitute for a shortage of a key warehouse resource, so the non-substitutability cannot be an attribute of a key warehouse resource.

Finally, under RBV, a resource is valuable only if it underlies a firm's strategy to improve its efficiency and effectiveness. While key warehouse resources, or their specific attributes, may become part of a particular strategy and thus generate extra value for competitive positioning of the firm, Barney et al. (2001) stresses that the value of a resource is determined by a specific market context. In other words, a valuable resource may stop being valuable if the market conditions change. This is where the difference lies. Key warehouse resources, regardless of the market context of the whole firm, are a critical necessity of a regular daily operation of the warehouse as its organizational unit. Thus, the four resource attributes of the original RBV are not generally applicable to the concept of key warehouse resources used in this research.

Over the years, several extensions of RBV have emerged. It has transitioned from identifying resources of the firm to focusing on their use (Fawcett and Waller, 2011). In this vein, one recent approach to resources that is on par with contemporary theoretical extensions of RBV is resource management theory (RMT) (Esper and Crook, 2014). RMT contends that possession of valuable, rare, inimitable and non-substitutable resources is important but not sufficient for obtaining a competitive advantage over other firms (Sirmon et al., 2007). It is critically important how resources are created, deployed, combined, managed and exchanged by the management of the firm (Lippman and Rumelt, 2003). TOC, on which we base this study, can be viewed under the general umbrella of RMT as a specific strategy of value creation from resource manipulation.

Typology

Before we can discuss resource manipulation in a warehouse, it is necessary to clearly identify which key resources are normally found in a warehouse. The academic literature on warehousing provides several lists of various warehouse resources. The most succinct list is comprised of four resources: labor, space, equipment, and warehouse management system (Hackman et al., 2001). The most comprehensive list is found in Rouwenhorst et al. (2000):

1. Storage unit, e.g., pallets, carton boxes and plastic boxes;
2. Storage system, e.g., shelves;
3. Pick equipment, e.g., a reach truck;
4. Orderpick auxiliaries, e.g., bar code scanners;
5. Computer system, e.g., warehouse management system;
6. Material handling equipment for sorting, packing and loading into transportation vehicles, e.g., sorter systems, palletizers and truck loaders;
7. Personnel.

Applying the time-effort-cost test of a key warehouse resource to the latter typology, we can eliminate items 1 and 4 since their representative examples (pallets, boxes and bar code scanners) can be acquired relatively easily and inexpensively. Items 3 and 6 represent material handling equipment used for the picking operation and the steps following it. Separating it into two different categories seems illogical for two reasons: (1) the same piece of equipment, such as a counterbalance forklift can be used for both picking a pallet and loading it into a truck, even on the same move; and (2) this division ignores operations preceding picking, such as goods unloading and putaway, which, coincidentally, can also be performed by that same forklift. So it makes sense to aggregate material handling equipment into one category. Finally, this research emphasizes traditional warehousing operations that are less likely to use sorter systems and palletizing machines found in high-velocity warehouses that rely on substantial automation. Thus, we can replace the broader term of material handling equipment simply with lift trucks, a general term for warehouse machines such as forklifts, reach trucks, order pickers, etc.

The arguments above reduce the list of warehouse resources to just four items: storage system, lift trucks, personnel and warehouse management system. Each of them meets the goods flow impact test in that the capacity of the resource directly affects the capacity and throughput of the warehouse. In case of the warehouse management system, it is the information flow. However, the flow of goods and information is synchronized at least periodically and a warehouse management system lagging in speed or deficient in functionality negatively impacts the flow of goods in the end.

The four identified resources also meet the time-effort-cost test. Adding more storage racks, buying more lift trucks, hiring and training more warehouse workers or upgrading the existing warehouse management system are projects that take months and substantial investment or spending and are likely to be presented by warehouse managers to their superiors for approval before any implementation is initiated. Moreover, all the four resources can be viewed as potentially finite, the first three due to spatial limits (as well as possible others), and the warehouse management system may not be modified to include new functionalities or increase processing speed due to the internal limitations of the software.

However, the list of key warehouse resources identified above appears to be incomplete. Some resources have been overlooked by researchers and need to be added to this list. They can be discovered by identifying potential bottlenecks in the typical goods flow in a warehouse, which has been described previously and shown in Figure 2. This illustration implies that the putaway operation (moving goods from the receiving area to storage locations) is viewed as part of another step: receiving (Gu et al., 2007) or storage (Rowenhorst et al., 2000). However, it can also be viewed as a separate operation between receiving and storage, a common approach of warehouse managers and warehouse management system designers as well as some authors who wrote for practitioners (Frazell, 2002; Keller and Keller, 2014). We will adopt it as our view of the warehouse goods flow (Figure 3).

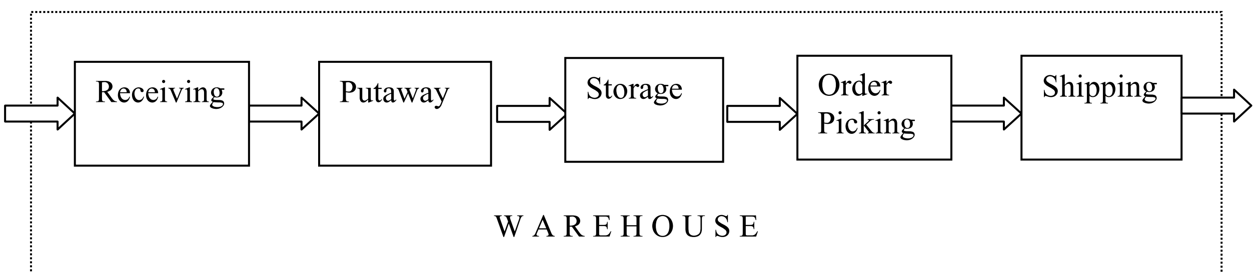

Figure 3: Flow of goods in a warehouse, including the putaway operation.

It is clear from this diagram that the four previously identified key warehouse resources have a direct impact on the goods flow in putaway and picking and on capacity in goods storage by becoming a constraint, should the demand for a particular resource exceed the resource capacity. Receiving and shipping deserve a more detailed analysis.

Examples of receiving activities, are unloading, checking for discrepancies and repacking (Gu et al., 2007; Rowenhorst et al., 2000). Shipping may involve goods preparation for transportation (palletizing, shrink-wrapping), quality control, and loading into a transport conveyance such as a truck or a railcar (Rowenhorst et al., 2007). Trucks carried 68.4% of tonnage nationwide in 2012, five times more than rail (13.5%) (S&P Capital IQ, 2013) and are a much more common mode of transportation serving warehouses. Ramps to unload railcars at warehouses are designed differently from truck docks. For these two reasons, warehouse shipping and receiving operations directly to or from railcars are not considered by this research.

In their comprehensive review of research on warehouse operations, Gu et al. (2007) classify assigning trucks to docks (doors) and scheduling of loading and unloading trucks as part of the receiving and shipping operation. They also note that research on receiving and shipping is scarce (4 papers out of 124 they reviewed). Most work that deals with receiving and shipping concerns cross-docking operations, particularly the truck-to-dock assignment problem, e.g., Tsui and Chang (1990, 1992). Cross-docking is not a traditional warehouse operation. Cross-docking is viewed as a strategy to reduce the time inventory spends in the supply chain (Galbreth et al., 2008). In cross-docking, the function of the warehouse changes from inventory storage point to inventory coordination point (Simchi-Levi et al., 2003). Consequently, some supply chain and inventory management analysis research uses cross-docking setting as a direct alternative to the traditional warehouse operation (Waller et al, 2006; Vogt, 2010). We control for the share of cross-docking in operations by using a control variable.

Now that we have defined receiving and shipping for the purposes of this research, we can consider the role of the four key warehouse resources. Labor, lift trucks and warehouse management system are essential for receiving and shipping. However, storage system does not apply: receiving and shipping occurs outside it. This means that we are missing an important spatial component. It is clear that warehouse space is needed for receiving and shipping, given the breakdown into specific operations described above, and the shortage of that space may severely constrain the goods flow. This space is finite and cannot be easily added to within the context of routine operations, i.e., keeping the existing warehouse organization and process design fixed. We will use the term *dock space* to designate this key warehouse resource.

According to Gu et al. (2007), receiving and shipping are the two warehouse interfaces for incoming and outgoing material flow. However, a careful look at Figure 1 will reveal that the goods have to pass through the warehouse wall twice: first, to get into the receiving area and second, when leaving warehouse from the shipping area. They go through a warehouse door. The number of doors and sometimes their specific characteristics (size, availability and length of dock-leveler, etc.) can put a physical constraint on the goods flow in and out of the warehouse if the demand for the doors or specific type of doors is higher than their availability.

There is practically no academic literature on warehouse doors that considers the supply and demand relationship within the traditional warehouse operations. The scarce cross-docking literature considers the optimum door layout for truck assignments (Gue, 1999) or travel and waiting time minimization due to congestion (Bartholdi and Gue, 2000). These works are not applicable to the insufficient door capacity problem in an existing traditional warehouse operation. However, there is plenty of evidence from industry that companies prefer more doors than fewer doors in warehouse layouts, ration and monitor door use when doors become a constraint, and even break walls to make more doors in the existing warehouse.

Warehouse dock doors meet all the tests of the key warehouse resource. Even with wall breaking, the number of doors is finite; adding this resource is very difficult and costly, and it definitely has the potential to become a constraint and slow down the goods flow.

In a way, doors as a resource are similar to labor or lift trucks: they have capacity measured in numbers (number of people in the shift, number of working (available, not broken) lift trucks and number of working doors) and productivity (units of output per unit of time per person or per lift truck and number of trucks served per unit of time per door). Just like warehouse workers' skills and lift trucks, doors may be more specialized or more universal. This provides insight into the similarity of constraints that doors can impose on warehouse operations.

What about lighting, temperature control or fire safety systems (such as sprinklers)? Do they fall under our definition of key warehouse resources? No, they do not. They are a precondition to a normal warehouse operation. They can become a constraint if there is a change in the content of the operation, but not the volume. For example, switching to storing and handling a different product in the warehouse may require a change in lighting, ventilation, fire safety systems, etc. However, as part of the normal operation, these systems do not affect the goods flow and are not considered key warehouse resources for the purposes of this research. To emphasize, this research does not consider situations when something is broken and simply needs fixing.

Thus, analyzing previous research and the flow of goods through the warehouse we have identified a total of six key warehouse resources. They are:

1. dock doors;
2. dock space (area);
3. storage system;
4. labor;
5. lift trucks;
6. warehouse management system.

Any one of them can become a serious bottleneck, or constraint, in warehouse operations.

Development of conceptual model

Introduction

In this study, we are exploring how the theory of constraints (TOC) works in warehousing. Specifically, we want to test if implementing the logistics paradigm of TOC will relax resource capacity constraints and lead to higher performance in the warehouse in the same way as predicted by this theory for manufacturing environments. The generic framework of these relationships for manufacturing is borrowed from the work of Inman et al. (2009), who tested them empirically and found them statistically significant. The framework is shown in Figure 4.

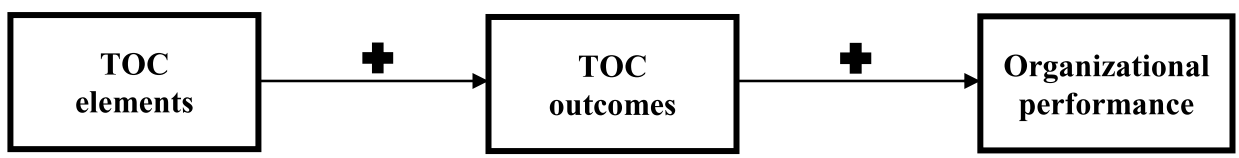

Figure 4: TOC impact model (adopted from Inman et al., 2009).

For warehousing, this model is shown in Figure 5 and is further developed in the next sections.

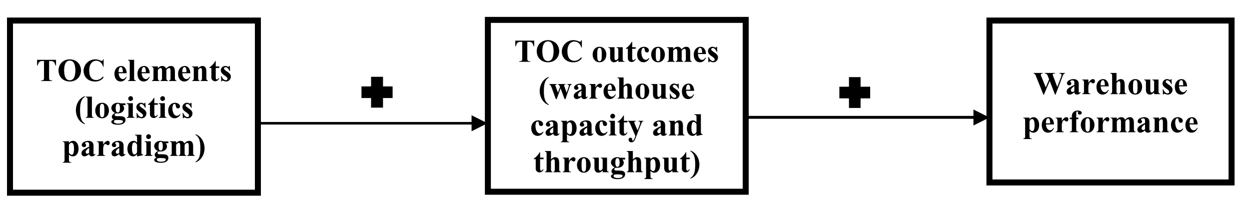

Figure 5: General model adapted for warehousing.

The notion of a constraint and model development

A key notion of TOC is a constraint. A constraint is defined as, "anything that limits a system from achieving higher performance versus its goal" (Goldratt, 1988, p. 453). The foundation tenet of TOC is that every system has at least one constraint that has a negative impact on its performance. According to TOC, since constraints determine the performance of the whole system, a way to improve performance is to relax ("elevate" in TOC's original terminology) the system's constraints (Rahman, 1998). A constraint on the flow of goods can be eliminated ("broken" in TOC's terminology) if either its capacity is increased or the flow of goods is decreased. Relaxing the constraint will increase the system's throughput but will result in a constraint elsewhere. A management philosophy of continuous identification of new constraints and actions to relax them will lead to a higher performance of the organization (Goldratt and Cox, 1986).

TOC addresses both principal ways to break a constraint. The five focusing steps (described in the TOC literature review in Chapter II) are a way to increase the capacity of the constrained resource, while the drum-buffer-rope scheduling technique and buffer management are managerial tools to control the material flow in manufacturing (Rahman, 1998). When viewed together, they have become known as the logistics paradigm of TOC (Rahman, 1998). Application of the logistics paradigm of TOC should relax the constraint and improve the system's performance. We are testing this in the warehousing context.

Applying the TOC logic described above to the warehouse as a system, we can state that every warehouse has at least one constraint. In other words, the capacity of at least one of the warehouse resources within the existing operational processes has reached a limit and is insufficient to accommodate the required goods flow. If the constraint happens to be at one of its key resources, then by definition it is very hard to relax (it takes time, money, administrative effort; or it may already be at its finite capacity level). We want to see, however, if an application of the two blocks of elements of TOC's logistics paradigm (the five focusing steps and scheduling and buffering) in the warehouse will overcome this obstacle. Thus, the generic model in Figure 5 can be further contextualized for this study of warehousing as follows in Figure 6:

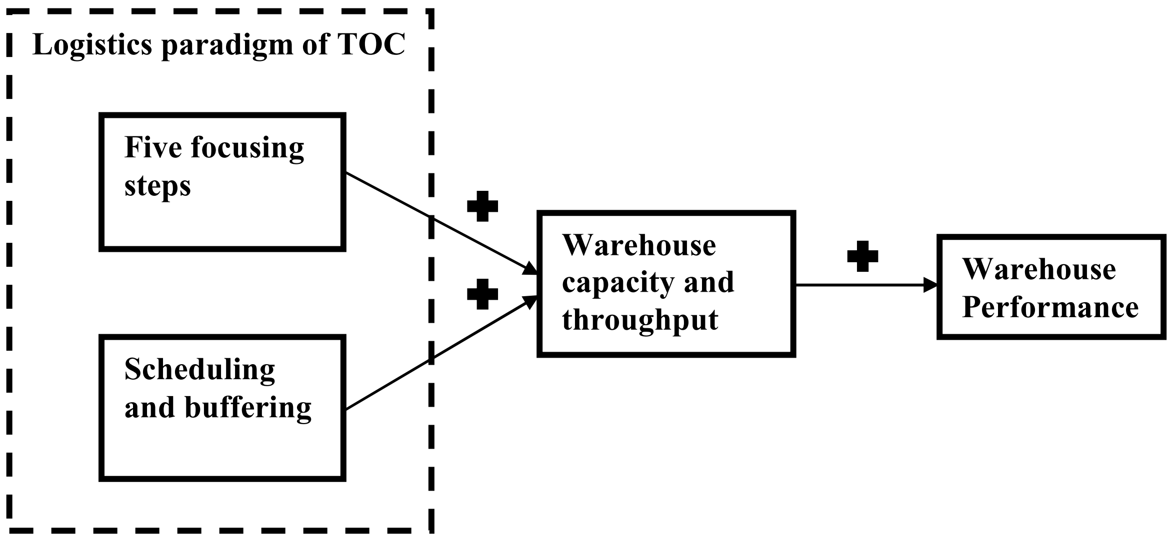

Figure 6: Contextualized general model.

TOC elements: five focusing steps

We now proceed to further develop the model by looking at concrete TOC elements of the two blocks. To fit TOC to the warehousing context and use TOC's constructs in an empirical study some adjustments are necessary even if we intend to follow the original theory as close as possible. Let us consider the five focusing steps first.

We propose no changes to step 1 ("Identify the constraint"). To apply in the warehousing context, for clarity, three other focusing steps (2, 3 and 5) are renamed with little or no change in meaning as explained below.

Step 2 ("Exploit the constraint") implies maximization of the constrained resource capacity in its existing system configuration (Reid, 2008). To avoid ambiguity, the construct corresponding to this step is renamed *Better utilization of existing resource capacity*.

Step 3 ("Subordinate all resources to the global decision"), in addition to using other non-constrained resources to increase the capacity of the constrained resource, included an additional meaning of not putting forth any effort to increase throughput of non-constrained resources because it is pointless:

> "The level of utilization of a non-bottleneck is not determined by its own potential but by some other constraint in the system… An hour saved at a non-bottleneck is just a mirage" (Goldratt and Fox, 1986, p. 179).

In this study, step 3 is used in a more specific meaning of exchanging the capacity of non-constrained resources for an increase of the constrained resource (trade-offs). The original TOC implies that there is no extra cost in implementing the first 3 focusing steps (Roybal et al., 1999). This narrow understanding of step 3 contradicts the findings in the warehousing design and operations literature reviewed in Chapter II. It has been shown that it is not possible to optimize more than one resource in a warehouse at the same time (e.g., Berry, 1968). Optimizing one resource is always a trade-off with the others which creates an opportunity cost at the design stage and extra expenses in operating the warehouse. Thus, in this study, we extend the meaning of trade-offs to include extra inefficiencies and costs in other resources in order to remove the bottleneck due to the constrained resource and change the name of the construct for step 3 from "Subordinate all resources to global decision" to *Trade-offs with other resources*.

Step 4 ("Elevate the constraint") presents a unique challenge since it combines an action and an outcome. In the original TOC literature (e.g., Goldratt and Cox, 1986) step 4 has two meanings: (a) continue the actions of steps 2 and 3 until the constraint is relaxed ("broken"), and (b) add more capacity directly to the constrained resource. Moreover, this step is also viewed as an outcome when the constraint is lifted ("elevated") and stops being the most restrictive bottleneck in the system.

Most subsequent academic literature on TOC does not go into enough detail on step 4 to determine its specific treatment, however, both interpretations are found in some academic papers. Gardiner et al. (1994) and Peschke (2001) emphasize the idea of a goal or result in step 4. Rahman (1998), who provided an extensive review of TOC literature, shares the same understanding when presenting an on-going nature of the focused improvement process as a circle (p. 338):

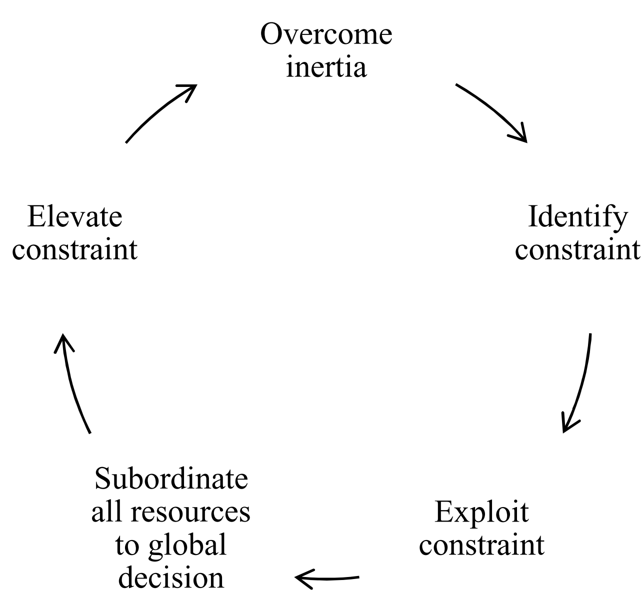

Figure 7: Rahman's (1998) representation of the on-going cyclical nature of the 5-step process.

This representation, following the original idea of Goldratt and Cox (1986), implies a strict sequence of steps, each of which appears to be dependent on the previous step. This may be helpful for managers but is not compatible with the conventions of an academic study.
The combined treatment of Step 4 as an action and outcome as illustrated by Reed (2007) is presented in Figure 8.

In empirical research, constructs should be distinct from each other, so to preserve the construct expressed in step 4 we must rid it of the additional meaning of continuation of the previous steps and separate from its meaning of a statement of outcome. Thus, what is left of step 4 is the meaning of acquiring additional capacity for the constrained resource, and, accordingly, in our model is named: *Acquisition of additional resource capacity*.

Step 5 ("Overcome inertia") stresses the fact that once the previous constraint is eliminated, a new one will appear somewhere in the system that will limit further growth of throughput. Thus, there is a need to repeat all the steps. As has been stated before, the five focusing steps are in fact a continuous process of improvement focusing on one or a limited number of constraints (Gardiner et al., 1994). The continuous process of going through these steps is what makes it a management strategy and differentiates it from a simple management reaction to a critical resource capacity situation. While we do not change this original meaning of step 5, we rename it *Continuity of focused approach to constraint management*, to more clearly represent its essence.

The five focusing steps form a second order construct: *Focused resource capacity management*, which reflects the key idea of focused improvement built into the five steps and represents the first part of TOC's logistics paradigm.

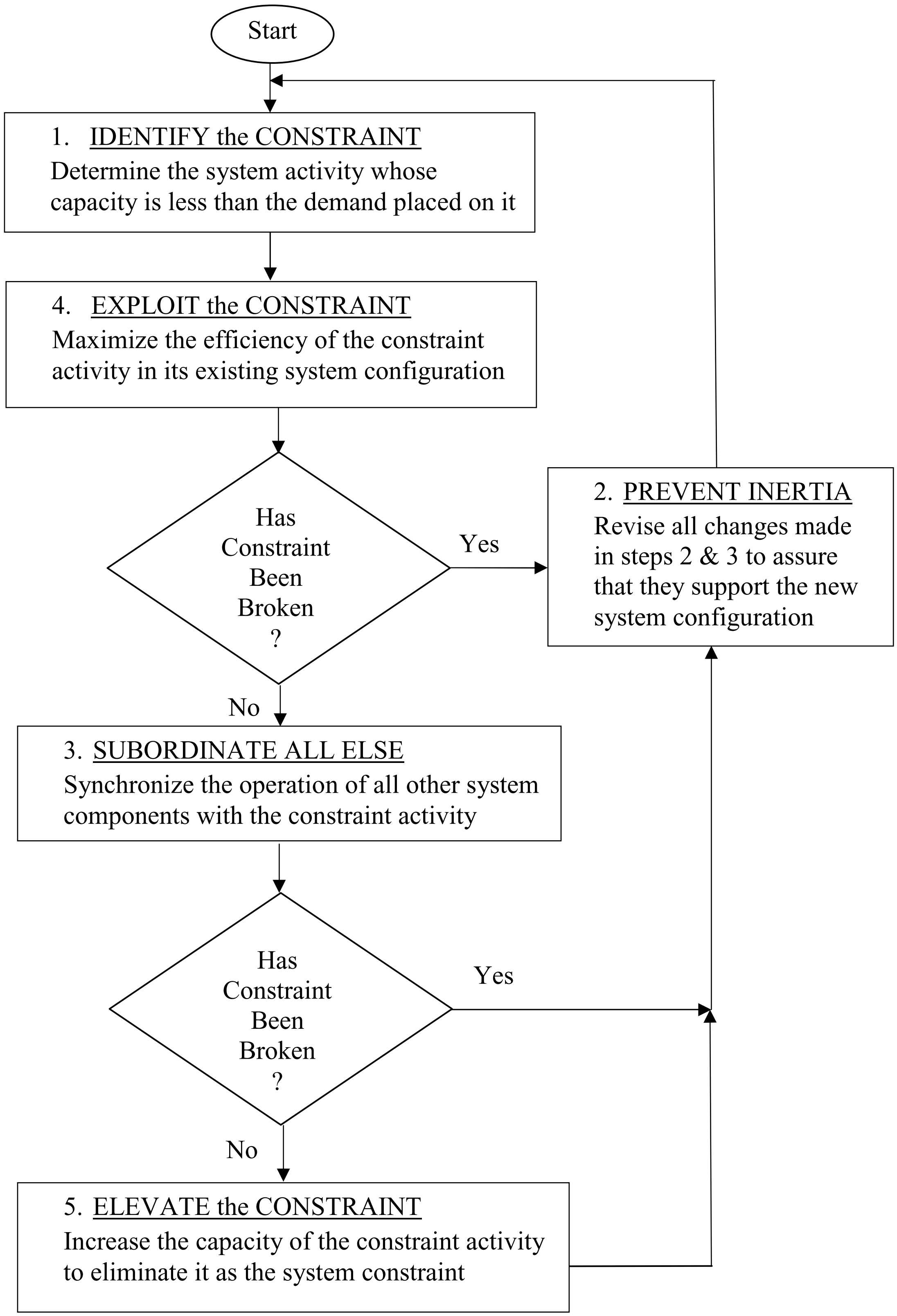

Figure 8: TOC focusing process flowchart from Reid (2007).

TOC elements: buffering and scheduling

The second component of the logistics paradigm, the drum-buffer-rope scheduling technique and buffer management, is best applied to the warehousing context when it is understood to be somewhat broader, including workflow management in addition to inventory management. In this case we consider not only buffer manipulations with inventory to ensure that the constrained resource is never idle, but also include a potential opportunity to decrease peaks in the flow of goods through a constrained resource by actively engaging with suppliers and customers in efforts to smooth fluctuations in incoming and outgoing shipments. This view of buffer management is fully in line with TOC; it simply extends goods flow scheduling and buffer management to supply chain partners immediately adjacent to the warehouse upstream and downstream. This is consistent with the goods flow through the warehouse shown earlier in Figure 3 and in the supply chain literature on warehousing. McGinnis and Kohn (1988) identified the external warehouse logistics interfaces as carriers, suppliers, buyers, and third party providers. They note, "warehousing may coordinate its activities with carriers (for inbound and outbound shipments), suppliers (for inbound shipments), buyers (for outbound shipments), and third-party providers (for inbound and outbound shipments)" (McGinnis and Kohn 1988, p. 35). Since a particular warehouse may or may not deal with third party-providers, we collapse this detailed classification into three broader categories: upstream supply chain partners, downstream supply chain partners, and carriers.

The drum-buffer-rope buffer management and scheduling technique, generally considered to be one component of the logistics paradigm, is separated into two distinct constructs and renamed *internal scheduling and buffering* and *external scheduling coordination. Internal* refers to the fact that the buffering of workflow occurs completely within the warehouse, whereas *external* means that workflow schedules are coordinated with adjacent partners up or down the supply chain, as has been explained above. The need for splitting the original construct into two new distinct construct follows TOC's logic of treating separately constructs requiring different levels of effort. It is obvious that it is a lot easier to schedule operations internally than to coordinate inbound and outbound flow of goods with other firms even if they speak the same language and are in the same time zone (and that may not even be the case). To clarify, this construct covers the *degree* of shipment schedule coordination between supply chain partners, not the variability of transit time. The latter should be managed internally using buffers, for example.

TOC outcomes

The generic construct of TOC outcomes that appears in the Inman et al. (2009) model shown in Figure 4 should also be specified more precisely for the warehousing context. Since we exclude TOC's Thinking Processes designed to deal with constraints outside the system and only use TOC's logistics paradigm as TOC elements that focus on the internal parameters of the system, the construct of TOC outcomes for warehousing simply means storage capacity and warehouse throughput, which are the two primary dimensions of warehouses as discussed in the previous chapters. Thus, instead of the generic label, *TOC outcomes, Warehouse capacity and throughput* will be used. As has already been explained, according to TOC, the capacity of the most constrained resource(s) will determine the overall throughput of the system, thus the positive direct effect of TOC elements on warehouse capacity and throughput is expected and is reflected in the model.

Warehouse performance

It has been noted that measuring performance may take several approaches and it is frequently a challenge (Fawcett et al., 1996; Rogers et al., 1996; Min and Mentzer, 2004), so it is discussed in more detail.

The final construct (*Organizational performance*) in this study is named *Warehouse performance*. The *Warehouse performance* construct used in this study is somewhat different from TOC's *Organizational performance*. The latter uses specific global financial and operational performance metrics for the whole organization (Rahman, 1998). However, one warehouse included in the sample may have little impact on the whole organization that may include dozens of warehouses that were not surveyed. Additionally, some warehouses may be cost centers while others are profit centers. This issue was recognized in an empirical study of warehouse measurement systems by Kiefer and Novack (1998).

Inman et al. (2009), whose approach to research design we are largely following, encountered the same problem of paucity of constructs associated with performance within TOC framework. Inman et al. (2009) accepted the suggestion made by Mabin and Balderstone (2003) to combine the three TOC operational measurement items (throughput, inventory and operational expense – all three in TOC understanding of the terms) and the three global financial performance measurement items (profit, return on investment and cash flow) with other usual operational and financial reporting measures as applicable.

We followed the same approach and decided to use metrics that reflect more closely the performance of a particular warehouse rather than the whole firm based on available literature. Swamidass and Newell (1987) noted that organizational performance is best evaluated through industry and context specific measures. Krauth et al. (2005) reviewed the literature and published a list of more than 130 performance indicators potentially applicable to warehouse operations. Upon reviewing the list and the summaries of available scales in logistics research literature compiled by Keller et al. (2002) and Keller et al. (2013), the scale developed by Stank et al. (1999) was chosen as the basis. Following this approach, traditional performance metrics for logistics and warehousing were reviewed using two industry publications (CSCMP, 2010; WERC, 2014) and additional applicable items were added to the questionnaire forming the potential scale for logistics performance.

The financial performance metrics presented an additional difficulty. As we noted above, only 3PL warehouses may qualify as profit centers; most warehouses are cost centers. This dramatically reduces the number of applicable measures for financial performance and raises a question of whether a good quality financial performance measure of a warehouse can be developed at all. We left this question to be answered during the pretest phase.

As we built the framework and model based exclusively on TOC manufacturing literature but found no prior TOC literature on warehousing, we felt that we needed some additional input from industry experts to validate the model or make some changes in it as the case may be. The insights we received from interviews with warehouse professionals – and the implications for the model - are discussed in the next section. Now that we have defined and briefly discussed all relevant constructs, the conceptual model initially presented in Figure 4 is expanded into the full model in Figure 9 below.

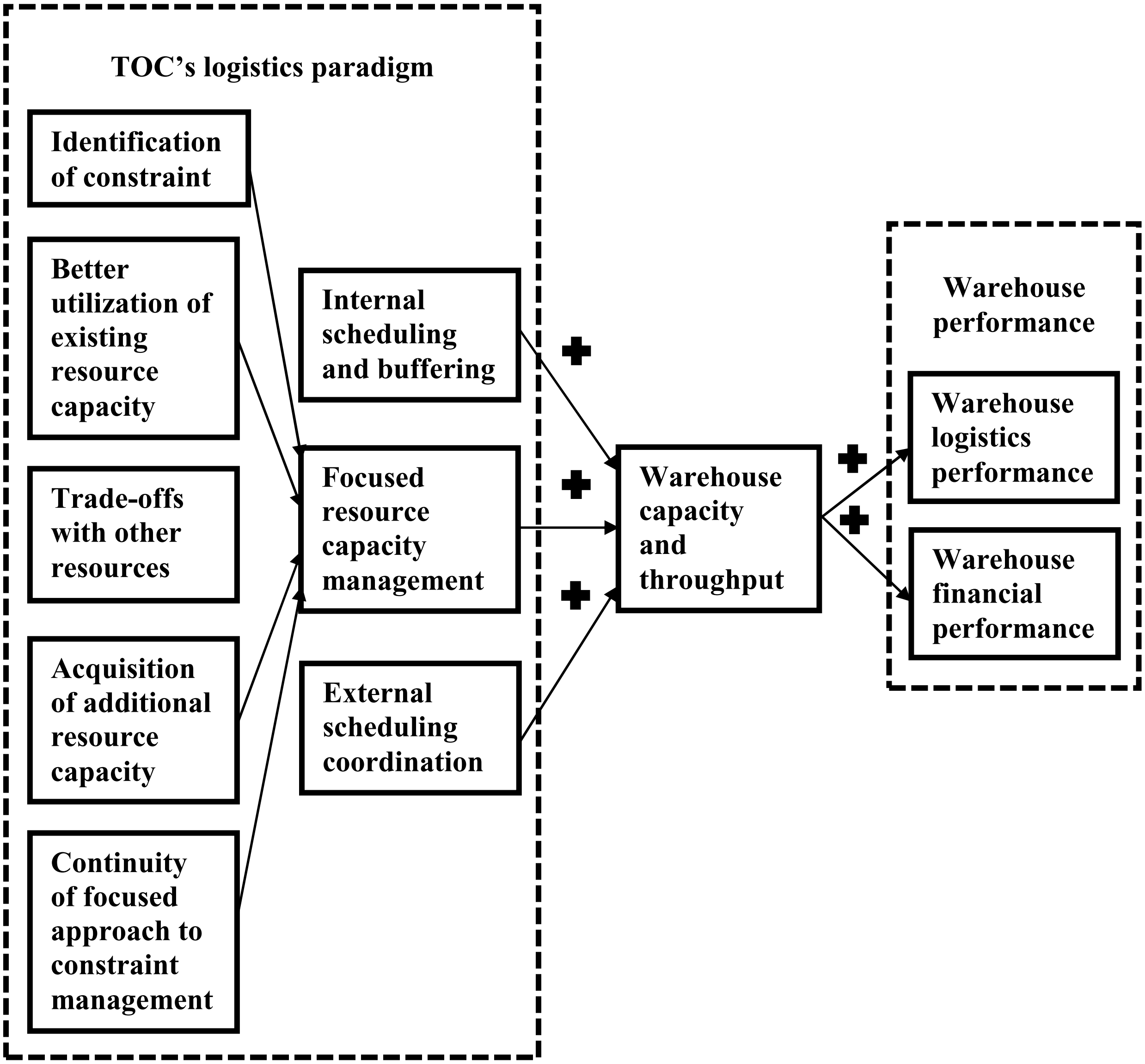

Figure 9: Full conceptual model.

Initial model validation

There does not appear to be a single academic paper that links TOC with traditional routine warehousing operations. The closest we were able to find was a brief discussion of capacity in manufacturing operations management in a conceptual TOC paper by Gupta and Boyd (2008), who note that capacity treatment is often divided into short-term, medium-term and long-term issues. TOC's five-step process implies that short-term capacity issues are addressed before long-term ones (Gupta and Boyd, 2008). But does it really happen like that in the warehouse?

To clarify this issue and get additional insights, the author met in person and conducted telephone interviews with warehouse managers and logistics directors of companies operating warehouses in a variety of industries (e.g., consumer electronics, food, automotive, industrial chemical products, books, beverages, furniture, etc.) and a variety of settings (traditional private warehousing, 3PLs, mixed (private and third party), consolidated church non-profit distribution, etc.).

During the discussions, several important findings emerged. First, the six key warehouse resources derived from the literature were recognized by the participating managers as the principal resources they manage in their warehouses. It is extremely rare that one of these resources should completely be absent in a warehouse. Second, it became apparent that while many managers were handling warehouse resource constraints in a manner consistent with TOC, they were not aware of TOC and did not realize that they used some of its elements. No managers were thinking in the categories of the computer algorithm that gave rise to the five focusing steps of the logistics paradigm of TOC. Identifying a constraint was rarely a problem; apparently traditional warehouses have less complex flow of goods than manufacturing enterprises. In most cases, however, more than one constraint was present at a time, even though the constraints might be of different severity. For example, the picking operation may be experiencing a chronic shortage of specialized lift trucks, while the receiving is frequently short on dock space.

We had recognized the problem of TOC's 5-step process being an artificial algorithm that was potentially impossible to follow exactly in practice and test in empirical research, and we mentioned our specific concerns when describing Step 4 and at the end of the previous section. The interviews with the managers confirmed our apprehensions. Rather than following the strict TOC sequence of steps to deal with shortages and identifying at which step the constraint would be overcome, warehouse managers evaluated the severity of each constraint and applied remedies they deemed to be most likely to resolve the matter effectively and with minimum cost and effort. This view is not in contradiction with the TOC steps. Steps 2 (better utilization of existing capacity of the constrained resource), 3 (capacity trade-offs with other resources) and 4 (acquisition of additional capacity) can be viewed as a hierarchy of focused actions that increase in cost and effort. The managers perceive them all as potentially available tools and may decide to simply "jump in the middle" of this continuum, use a combination of actions from different steps or just spend cash to attack the constraint at the very top. After all, if the constraint is in bad need of a highly specialized order picking truck, to really solve the problem you may just have to order this piece of equipment bypassing numerous other less efficient alternatives – a strategic decision to add capacity, or Step 4.

While not entirely falling into the sequence of TOC steps, the managers' actions were not lacking a structure. They viewed their actions in terms of 3 categories: (1) things that can be done within the existing standard operating procedures and required only a small amount of extra effort and no extra cost; (2) things that required some changes in operations resulting in improvements that came at some costs and necessitated efforts to use the existing resources in a different way; and (3) more radical strategic actions that usually resulted in substantial cash spending on acquisition of extra capacity and considerable administrative effort.

Some warehouse managers of larger facilities saw their constraint improvement actions as split over areas of responsibility: things a foreman or team leader can do, actions that an operations manager can authorize, and finally, additional resource capacity that a warehouse manager, often with the approval of superiors, can acquire.

This view does not change the structure described above, which is by no means unique. More commonly it is known as tactical, operational and strategic management. The principal difference that TOC introduces in it is that all three types of management must be squarely focused on constraint elimination.

There is also indirect evidence from the literature supporting the need to preserve the essence of TOC while relaxing the rigidity of its original framework. Vogt (2010) reviewed cross-docking operations and reported that when it came to implementation of TOC, the "approach was not formal, but the principles were actually in use" (p. 111).

Churchill's (1979) well-known procedure for scale development calls for construct domain (re-)specification after a major insight has been received. Our major finding from the interviews reshaped the first order constructs of the logistics paradigm of TOC while leaving the second order construct in the model (*Focused resource capacity management*) unchanged. To illustrate with a culinary example, the change made is akin to changing the description of borsch from the sequence of cooking instructions to a restaurant menu description highlighting the salient features and key ingredients. However, the dish itself has not changed. We believe that the transition from the original, computer algorithm-like sequence of steps to more traditional theoretical time-neutral constructs supported by actual industry practices is a sizable contribution to the development of TOC.

Finally, the interviews with warehouse managers touched upon warehouse performance metrics. The original intent to measure overall warehouse performance was to use the traditional logistics performance scale with items from supply chain literature and WERC studies. It would be of interest, of course, to learn about the effect of using TOC on financial performance of a warehouse and its impact on the financial performance of the whole firm, but the apprehension was that warehouse managers simply would not know it, given that a warehouse is just one organizational unit of a firm.

The interviews confirmed this apprehension. Most interviewed managers confessed that they neither knew whether their warehouse made a positive or negative impact on the performance of the firm, nor were they aware of the magnitude of that impact. However, it was also established that most warehouse managers used some financial metrics to evaluate their warehouse operations. Many warehouses track their unit costs, dollar amounts of claims paid due to picking and shipping mistakes (and mistakes-related costs such as urgently shipping a “shorted” item) and amounts paid as demurrage and detention claims when not being able to load or unload transportation vehicles on time.

Thus, it was decided to preserve in the full final model the separation of financial performance of the warehouse from its logistics performance, while explicitly recognizing two limitations of the measure. It is narrow in scope and is substantially correlated with logistics performance by design because it is comprised of dollar-sign items that essentially mirror the logistics performance items, such as on-time performance, picking and shipping mistakes, etc.

The adjusted full model is shown in Figure 10.

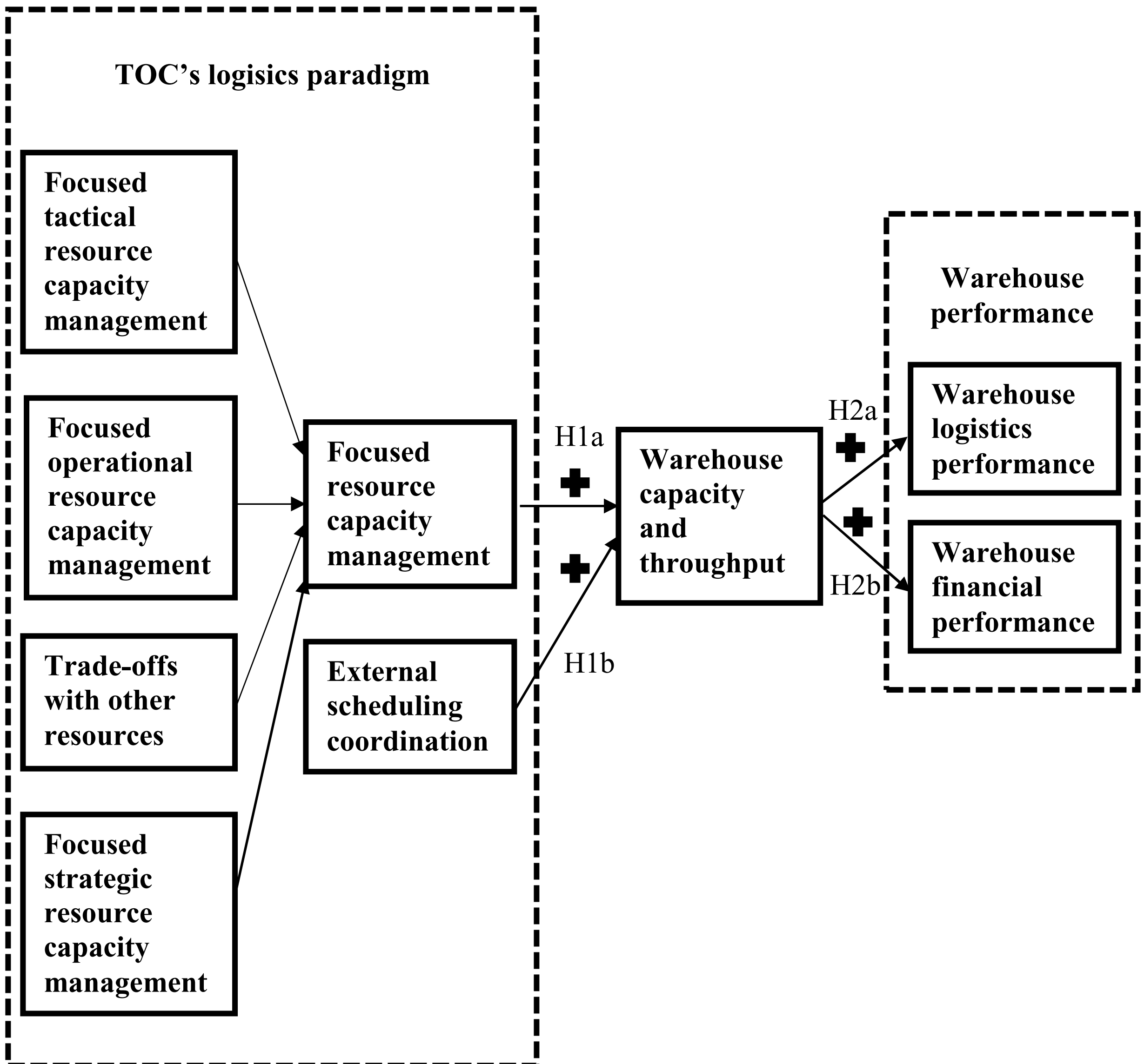

Figure 10: Adjusted full conceptual model.

An argument can be made that the TOC elements remaining from the original model (*Trade-offs with other resources* and *External scheduling coordination*) may well be absorbed by the three levels of focused resource capacity management (tactical, operational and strategic). The *Trade-offs* construct is a modified Step 3 from the original 5 Focusing Steps, and *External* *scheduling coordination* was derived by us by splitting the buffering and scheduling technique into internal and external actions following the logic of the goods flow into, through and out of the warehouse. Internal scheduling and buffering is now absorbed in the resource management levels. However, the interviews indicated that the managers were able to recognize the Trade-offs and External scheduling coordination separately, particularly External scheduling coordination, so it was decided to retain them as separate first-order constructs contributing to the higher-order construct as shown in the model.

Now that we have finalized the theoretical model, we state formal hypotheses.

Hypotheses

TOC predicts positive relationships between the constructs as shown by arrows in the models above. Formally, these relationships are stated as hypotheses below:

H1a. Focused resource capacity management is positively associated with warehouse capacity and throughput.

H1b. External scheduling coordination is positively associated with warehouse capacity and throughput.

H2a. Warehouse capacity and throughput are positively associated with warehouse logistics (operational) performance.

H2b. Warehouse capacity and throughput are positively associated with warehouse financial performance.

H3. Implementation of the TOC logistics paradigm is positively associated with warehouse capacity and throughput.

H4. Warehouse capacity and throughput are positively associated with warehouse performance.

Figure 11 is a reproduction of Figure 10 with the hypotheses overlaid.

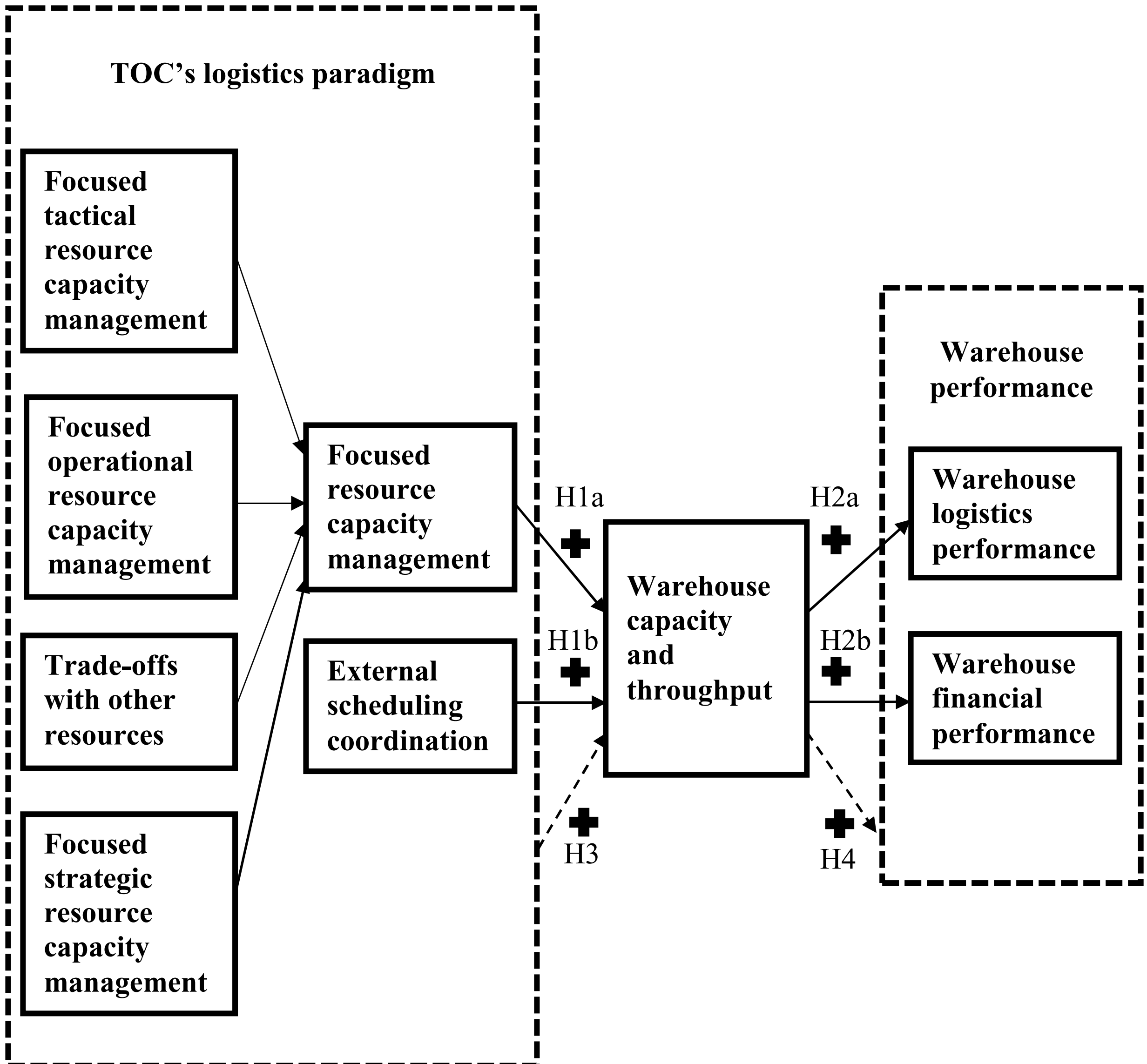

Figure 11: Consolidated model showing all hypotheses.

Hypotheses 3 and 4 are shown with dashed arrows, reflecting the general model, which was previously shown in Figure 5. The general model is again shown below as Figure 12 but with constructs consolidated into TOC elements and warehouse performance, and with the hypotheses overlaid.

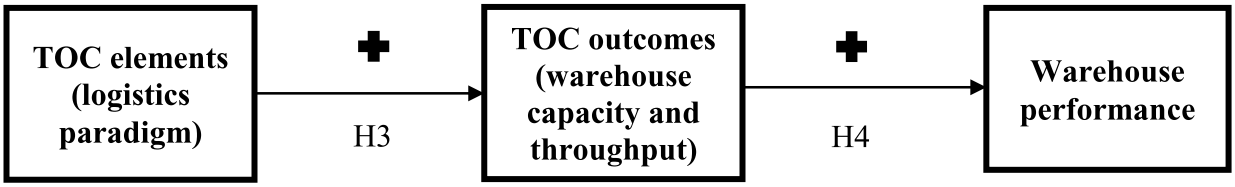

Figure 12: The general model with hypotheses.

It should be noted that this general model for warehousing is not an exact replica of the Inman et al. (2009) model. Our model is narrower in scope. The TOC elements do not include Thinking Processes, and performance is measured at the level of an organizational unit of the firm rather than the whole firm.

The research method used to test the hypotheses is explained in detail in the next chapter.

CHAPTER IV

METHOD

The survey instrument design and administration

Data collection

The data for the study was collected from a survey of warehouse managers. An online version of the survey was developed using a popular survey software application. A paper version was also developed for those respondents wishing to take the survey in that form. Both paper and online responses were solicited directly by the researcher during the pretest phase of the study. Adjustments were made based on feedback from the pretest, and the final version was available in both formats; however, the majority of responses were from the online version. There were no differences in questions between the two versions; only some technical differences necessitated by information presentation formats. However, in the online version, an option forcing the respondent to respond to certain questions was used where appropriate. The online part of the survey was administered by a commercial service.

The choice of the online survey format was dictated by its advantages as described in the literature: ready access to participants, large geographic coverage, speed and timeliness, convenience (including for participants), automated data collection in a ready for analysis form, and meta-data about a respondent's behavior (Schmidt, 1997; Wright, 2005; Evans and Mathur, 2005; Bosnjak and Tuten, 2001). In addition to how the survey is administered, the online format has design advantages: question format diversity, control of answer order, required completion of answers, and response-dependent question pop-up or skipping capabilities (Evans and Mathur, 2005).

Some of the online format disadvantages, such as internet connectivity issues, lack of computer skills, and other problems related to the level of development of the technology and user comfort with it, listed in prior literature (e.g., Goldsby et al., 2001; Boyer et al., 2001) were felt as not being a concern for present-day US-based warehouse managers as the target population. However, other disadvantages, such as questions about data validity, sampling issues and survey design issues (Wright, 2005) appeared to be a legitimate concern. These issues are discussed in the next section of the chapter.

The survey instrument consisted of an introductory page and four parts. The first three parts provide demographic information, measures of TOC elements, and TOC outcomes and warehouse performance measures. The fourth section of the survey collected data for a research question for future research not covered by this study. A copy of the survey instrument is provided in Appendix A, and is discussed briefly below.

The introductory page contains a brief overview of the study and the survey, as well as legal disclosures required by the Institutional Research Board of the University of Arkansas. Respondents were promised confidentiality to the fullest extent allowable by law. The surveys administered online by a commercial survey service were anonymous to the researcher.

The demographic section of the survey collected basic information about the respondent and the respondent's warehouse. The questions were in different formats (a Likert scale, a sliding scale, multiple choice, and free text entry). Formalized responses to these questions were used to create control variables. The questions in the other parts of the survey were on a 7-point Likert scale (from "Strongly agree" to "Strongly disagree").

The initial survey instrument was reviewed by several academics and experts in the warehousing field, upon which further improvements and refinements were made. This step was followed by initial data collection and subsequent measure purification, once enough data were collected for the analysis (discussed further in the next sections). The literature generally recommends that the number of respondents be at least 5 times the number of items desired on the final scale, with sample size of at least 200 being a common rule-of-thumb recommendation (e.g., Hair et al., 2009). Rough guidelines specifically for structural equation modeling (SEM) suggest at least 100 cases for any but the simplest models, with 200 cases samples considered to be “large” and acceptable for most models (Kline, 2005). Therefore, the target number of usable responses for data collection was set at 200 (or more if possible). Target respondents were contacted by a variety of means, including e-mail and phone calls, and were asked to fill out the questionnaire developed for this study. The questionnaire was placed online; however, a paper copy and a Word file copy were made available to those who preferred these options during the pretest phase. The commercial survey service contacted respondents by e-mail.

Data screening

Initially collected data were subjected to screening. Missing data were not an issue for online responses because of the forced response setting for the questions collecting data for all variables. Cases of missing and unusual values in the responses solicited by the researcher directly were rectified by contacting the respective respondents with a request for clarification.

Next, data were reviewed for signs of departure from normality, linearity and homoscedasticity, which are the assumptions of the regression analysis. Data collected from Likert scales often violates normality assumptions (Wu, 2007). Kurtosis and skewness of several predictor variables of interest were particularly far from normal, a common occurrence in Likert scales data. However, many of the issues are known to diminish when the variables are aggregated into scale variables. Following the recommendation of Tabachnick and Fidell (2007), residuals were screened for normality. Visual inspection of histograms and plots of standardized residuals showed that the distributions of standardized residuals of the dependent variables were close to normal. Only minor departures from linearity and homoscedasticity were observed. According to Tabachnick and Fidell (2007), if the residuals plots look normal, there is no need to screen individual variables for normality, besides individually normally distributed variables do not guarantee multivariate normality (p. 83). Two of the control variables, however, were transformed into a logarithmic form to improve normality.

Addressing potential bias

General considerations

In this section we explain how we addressed issues associated with common method variance. For the following discussion, we rely largely on the influential work of Podsakoff et al. (2003) as well as papers by Williams et al. (2010) and Craighead et al. (2011).

One of the biggest threats to validity of any research is measurement error. It consists of two parts: random error and systematic error. One way to reduce random error is to use multiple items measuring the same construct, an approach we employ in this study where appropriate.

Systematic error is believed to be a bigger problem, “because it provides an alternative explanation for the observed relationships between measures of different constructs” (Podaskoff et al., 2003, p. 879) and may lead the researcher to erroneous theoretical conclusions. Systematic error may be introduced by a method bias, or variance.

Surveys are particularly prone to the method bias known as common method variance. Common method variance is defined as, “the amount of spurious correlation between variables that is created by using the same method … to measure each variable" (Craighead et al., 2011, p. 578). It may vary in the direction and strength and, "can either inflate or deflate observed relationships between constructs, thus leading to both Type I and Type II errors" (Podsakoff et al., 2003, p. 880).

In survey-based research, the most likely sources for common method bias are effects introduced by the common rater (e.g., consistency motif, implicit theories, social desirability, leniency and acquiescence biases, and mood and transient mood states), item characteristic and context effects (e.g., common scale formats and anchors, and scale length) and measurement context effects (e.g., measuring predictor and outcome variables at the same location or point of time). Several of these factors may play a role at the same time (Podsakoff et al., 2003).

The possibility of presence of common method variance should be taken into account at all stages of the survey-based research process: survey design, administration and evaluation of results. The tools available to the researcher are planning and administering the survey in a way that minimizes common method variance, diagnosing it upon survey completion and taking corrective action if necessary. Podsakoff et al. (2003) grouped the techniques for controlling common method variance into two main categories: procedural and statistical remedies.

The two categories differ in applicability to research designs. Both can be used in reflective models, but formative models effectively preclude the use of currently available statistical remedies. In formative constructs, the effects of the method bias should be measured at the construct level rather than the item level, but unfortunately, available remedies result in identification problems (Bollen and Lennox, 1991; Podsakoff et al., 2003). Thus, when using formative models, Podsakoff et al. (2003) advised researchers to, "be even more careful than normal in designing their research because procedural controls are likely to be the most effective way to control common measurement biases" (p. 900).

Remedies against bias used in this study

Severely crippled in the choices of statistical remedies available for formative models, we have performed a commonly used traditional Harman's single factor test, which involves examining variance accounted for by all variables in an exploratory factor analysis (EFA). Common method variance is said to be present when one factor accounts for the majority of the variance or only one factor emerges from the unrotated solution (Podsakoff et al., 2003; Craighead et al., 2011). While neither was true in our case indicating the absence of a serious common method variance problem, we acknowledge the note in Podsakoff et al., (2003) that Harman's test is a diagnostic procedure rather than a remedy, and it is an insensitive test.

Some of the actual remedies recommended by Podsakoff et al. (2003) in the "procedural" category were employed at the survey design stage. One such remedy is creating a psychological separation between the predictor and outcome variables through a cover story that seem to make their measurements unrelated. This was first attempted in the pretest version of the questionnaire. Its face validity was assessed by academics and industry professionals contacted during an annual meeting of a major supply chain membership-based organization. Several comments received indicated that the lack of match of the paragraph explaining the purpose of the study and the composition of the questionnaire to the questions asked in it was too noticeable and raised questions. Thus, it was adjusted to closer reflect the contents; however, any mention of warehouse performance measures was omitted from that paragraph.

Another recommended remedy is guaranteeing anonymity to respondents. The majority of responses were received online through the commercial survey service company, and anonymity of responses (to the researcher) was a condition of the service known to the respondents. However, respondents contacted by the researcher directly could only be promised confidentiality. The means of several items of the resulting subsamples were found to be significantly different in statistical terms, and a binary control variable had to be used in subsequent analysis of the combined dataset. While we report it, we do not make a claim about the reasons for the difference. An unknown underlying factor could be the reason, and a theoretical probability of obtaining several statistically different means of items of two random subsamples from a relatively small sample also exists.

Conflicting advice exists on question order. Randomizing questions is suggested to avoid some of the item context and consistency effects. On the other hand, Posakoff et al. (2003) cautioned about intermixing bias, another type of item context effect that may increase correlations between constructs and decrease correlations within a construct due to an item from a different construct mixed in the group of same construct items. Control of the answer order is believed to reduce bias (Evans and Mathur, 2005). With a few exceptions, the survey was constructed in a way that items were grouped by constructs. The exceptions were mostly to preserve question order when items were deleted and added during the initial pretest. Following advice of Evans and Mathur (2005), a graphical progress indicator was employed to avoid an impression of an endless number of questions on the respondents.

One remedy recommended by Podsakoff et al. (2003) without reservations is improving scale items by eliminating ambiguity. The six ways to do it listed in the paper focus on clarity, simplicity and definitions or explanations where warranted. We took this recommendation seriously from the start and further improved the instrument based on the review by academics and industry professionals during the initial pretest. We report here several examples as an illustration:

- Abbreviations (e.g., WMS) and complex terms (e.g., internal order cycle) were explained.
- Discrepancies between industry jargon (referring to any type of a lift truck as a forklift, the most common material handling machine in the warehouse) and official language were explained at the first encounter with the term.
- TOC specific terminology (e.g., constraint) was avoided, except where necessary as a validation check for respondents claiming to use TOC (following the approach of Inman and Sale (2003)).
- Each question was edited to fit on one line for the paper version of the survey (the online version had exceptions due to survey software limitations)

Behavioral issues in data validation

Survey data screening on behavioral grounds is not often performed or reported in supply chain literature. We hope that this section that details our efforts to reduce potential data quality problems in the study introduced through behavioral issues by respondents will have a merit on its own as a mini-case example of specific actions in this respect. The difference from the issues discussed in the previous section is that this section deals with measurement error that can be introduced through respondents' disregard of expected survey taking procedures or intent to distort data.

Uncertainty about data validity is noted as a primary concern in online survey research by Wright (2005). Some of the issues are not different from those that occur in traditional mail surveys (Schmidt, 1997). The identity of the respondent cannot be guaranteed, and it is just as easy for respondents to misrepresent any demographic information or their feelings towards the matter of the survey (Wright, 2005). However, Schmidt (1997) notes that the online survey research validity is likely to be stronger for specific narrowly defined populations that can also be screened online and offline. He suggests (p. 275) that "conservative researchers" employ a screening questionnaire for respondents to demonstrate that they meet certain criteria, a recommendation we followed.

Since the main survey was to be administered by a third party anonymously online, the respondents were asked qualification questions to establish that they were warehouse managers and they were familiar with the daily operations of their warehouses for at least three preceding years (the period covered by the survey). Those replying negatively to any of the screening questions were taken directly to the survey exit screen, and their responses were automatically disqualified by the software.

However, we were aware that a screening block of questions at the start of the survey to eliminate participants who have truthfully reported their demographic data indicating their ineligibility for the survey is not sufficient to ensure quality data collection. There are accounts in the literature of cases of grotesque abuse of web-based surveys, such as one individual submitting 65 responses (6% of the total number of responses) in a survey conducted by Konstan et al. (2005). The paper recommends a rigorous data validation protocol that includes both automatic software checks and manual response review. Using some of their recommendations applicable to our study, we have developed our own protocol, presented below.

In addition to the starting qualification questions discussed above, our online screening method employed a built-in attention check to prevent responses from respondents not reading or thinking through questions from entering the data set. First, a polite cautioning message against answering the questions without reading or thinking was displayed as a separate screen to ensure that it catches attention. The message was followed in the next section by an attention check requiring a respondent to select a particular answer ("Strongly disagree"). The answer was chosen in contrast to the prevailing responses in that block of questions as determined from the online survey pretest. Failure to select this answer led to an automatic survey attempt termination. It was believed that after the specific warning message, the respondent's apparent disregard for the request to pay attention indicated his or her openly defiant attitude and behavior that was deemed incompatible with obtaining reliable data from such participant.

Bosnjak and Tuten (2001), who studied response behaviors in web-based surveys, pointed out the ability of survey software to collect meta-data about respondents' survey taking behavior such as a chosen order of answers or time between survey start and survey completion for each respondent. Boyer et al. (2001) raised concerns about data obtained in superfast responses (in their case, 1.5 minutes compared to approximately 18-minute average) and concluded that, "the ability to track the time spent filling out the survey offers some value to researchers who seek to balance and optimize both quantity and quality of respondents" (p. 6) implying that unreasonably fast responses need to be deleted as unreliable. We followed this suggestion.

During the online pretest phase, a reasonable response time was determined to be near 20 minutes. The website of the commercial service administering surveys employing this software recommended an automatic cut-off time (if used) to be set as one third of the average time recorded during the pretest. To ensure higher quality of data, a more conservative cut-off was set at 13 minutes. Responses that took less time to complete were disqualified by the software.

Several additional manual checks of data consistency were built in. For example, the same question (about change in business over a 3-year period) was asked twice in two different formats: as a sliding scale in the opening demographic section of the survey and on a Likert scale towards the end of the survey. Following the approach of Sale and Inman (2003), several questions were paired with immediately following validation questions asking the respondent to enter information explaining the choice made on the previous question. Free-text validation responses were particularly useful in identifying a case of multiple attempts to take the survey by one individual using an IP-address manipulation software to bypass the multiple response block of the survey software.

All remaining responses were reviewed manually for instances of “straightlining” (picking the same choice for all questions in the block) and other clear geometrical patterns formed by responses on the screen. In addition, comparisons of responses to objective data questions with the average pretest and industry data, where available, helped flag suspicious responses for further scrutiny. For example, respondents reported their warehouse square footage and number of employees as separate questions. During response review, a ratio of workers per square foot was calculated and compared to other independently obtained data. Ridiculously small or large numbers were a reason for suspicion and counted as one failed check.

Finally, modern survey software offers some automatic response validation for certain types of questions (e.g., the expected number of characters in the entry), and it provides an option that *requires* the respondent to make a correction, or to *request* it, but still allow them to proceed. We want to point out that the second option (the request), was used to set up a response-dependent activated question. This offers indirect information about a “bad” attitude of a respondent who chooses to ignore it and proceed without making a correction to their previous response.

Responses, failing more than one soft check, were disqualified in a simple approach. A second review assigned weights (in points) to the different checks, and a penalty point threshold was established as a criterion for response elimination.

A generalized summary of our data validation protocol is shown below:

1. Eligibility criteria through demographic questions at survey start.

2. Warning message + attention check question.

3. Minimum completion time cut-off (if there are not enough pretest data to calculate a standard deviation for good quality responses with confidence, we recommend 2/3 of the average time for good pretest responses as a conservative cut-off and 1/3 as liberal).

4. Same objective data question asked in different formats in different parts of the survey.

5. Free-text validation questions automatically activated for unusual or out of expected range responses.

6. Automatically tracked deliberate failures to follow specific instructions when requested.

7. Manual review for "straightlining" and geometrical patterns in responses.

8. Separate objective data collection for a construction of an index to be compared with industry or pretest averages.

9. Assigning weights to the data quality checks (e.g., in points) and setting up a cut-off number of points for response elimination.

It is important to note that response screening and elimination of poor quality data due to respondents' survey taking behavior was based on carefully determined parameters and took place before any statistical analysis. In many ways it is akin to outlier deletion on statistical grounds and should not be interpreted as data manipulation.

While we believe that the extra diligence in setting up the survey instrument and reviewing the received responses for any problems has definitely reduced the amount of systematic bias and noise in the resulting data, it is impossible to eliminate the problem completely. Some bias may be inherently present because we use self-reported measures of warehouse performance. The warehousing industry is very diverse and a single universally accepted set of performance metrics simply does not exist. In situations when preferred objective performance measures are not available, the use of perceived measures of performance is acceptable (Dess and Robinson, 1984). Sale and Inman (2003), who used perceived performance measures in their empirical TOC research, noted that, "[a]lthough self-rating scales are criticized for potential bias, this is less a concern when such bias is generic and where the ratings are used in a relative, rather than absolute, measure" (p. 836). We use the same 3-year period for performance comparison as Sale and Inman (2003) as a relative performance measure to minimize the potential bias. The development of measures for the constructs for this study is explained in more detail in the next section.

Model specification and measurement

General considerations

In this study, we followed widely recognized recommendations of Churchill (1979) and Gerbing and Anderson (1988) for conducting empirical research. According to Churchill (1979), the starting step of scale development is construct domain specification. Our work on this step was explained in the previous chapter. In the next step, items to measure constructs were generated based on literature and other sources.

While earlier empirical work for manufacturing relied on respondents direct statements acknowledging the use of TOC (e.g., Sale and Inman, 2003), we could not use this approach because very few warehouse managers were aware of TOC, even though they used some of its elements, as our interviews showed. Similar evidence came from the literature based on field work (Vogt, 2010). Other empirical TOC papers (Inman et al., 2009; Moss, 2007) also employed scales to establish TOC use. That is why we chose to treat all TOC elements as latent constructs that could be measured by reflective items. The second order *Focused resource capacity management* construct was modeled as a formative construct.

Initial measurement items for TOC constructs were borrowed from empirical TOC literature, specifically, Inman et al. (2009) and Moss (2007). The scale items were adapted to reflect the warehousing context where necessary. Following the approach of Kocabasoglu and Suresh (2006), several additional warehouse specific items were added to the scales based on theory to reflect modifications to the constructs described in the previous sections. Finally, extensive interviews with industry professionals resulted in additional adjustments.

Scale structure analysis and purification

Churchill (1979) suggests that after an initial data collection, purification of measures should take place. These and the preceding steps may be repeated as a cycle as needed. In addition to reviewing the inter-item correlation matrix when practical, a common way to analyze the structure of the scale to establish construct validity is by using factor analysis (Clark and Watson, 1995), also recommended by Churchill (1979). There are arguments in the literature both in favor of exploratory (EFA) and confirmatory (CFA) factor analysis for the purpose. This study followed the recommendation of Kelloway (1995) and Hurley et al. (1997) to use EFA in the early stages of scale development because EFA may show loadings of items on non-hypothesized factors.

Kaiser-Meyer-Olkin tests of sampling adequacy of above 0.8 (as recommended by Hair et al., 1998) and significant Bartlett tests of sphericity indicated that it was appropriate to perform factor analysis on these data. The factors were extracted using the principal component analysis. The Promax oblique rotation allowing the factors to be correlated was used with the default parameter kappa = 4. Guidelines by Hair et al. (1998, p.112) for identifying significant factor loadings based on the sample size and customary statistical assumptions indicate that loadings of 0.40 and above, are significant for sample sizes of 200 and greater. A more conservative approach was adopted to retain loadings above 0.5 with no cross loadings on other factors higher than half of the loading on the "correct" factor. Per Hair et al. (1998, p. 113), communalities, which represent the amount of variance accounted for by the factor solution for each variable, were deemed acceptable for variable retention if they were 0.5 or higher.

Validity and reliability of scaled variables

An important part of an empirical study is evaluating psychometric properties of the employed scales: validity and reliability. Validity assesses how well a measure or a set of measures represents the concept of the study; reliability assesses the consistency of the measurement (Hair et al., 1998, p. 3). In other words, validity refers to *what* is measured, whereas reliability relates to *how* it is measured (Hair et al., 1998, p. 3). It is customary to evaluate validity of the measures first since their validity is an assumption for calculations of reliability (Hair et al., 1998, p. 611).

There are several types of validity and ways to evaluate them applicable to empirical research that uses a method of statistical analysis. To understand whether the theoretical meaning of the concept is captured in the operational definition of a variable, researchers look at construct validity and its two measures: convergent and discriminant validity.

Convergent validity tests the closeness of association of related measures in a scale by the strength of its inter-item and item-to-factor correlations (factor loadings). Inter-item correlations were reviewed first and found acceptable. While higher inter-item correlations are desirable as they will indicate that items measure the intended concept, very high correlations are an indication of redundancy in the scale (Clark and Watson, 1995). Convergent validity during EFA was established by following the procedure of eliminating items with low loadings on the factor (below 0.5).

Discriminant validity, as the name implies, tests if two unrelated factors do indeed appear as unrelated when measured by proposed scales. This is evidenced by very low cross-loadings of the items on the unrelated factors. Items with high cross-loadings above half of the principal loading were removed.

Reliability also lends itself to assessment with a variety of means. The most common one is Cronbach's alpha that measures the consistency of the whole scale and ranges in values from 0 to 1. The recommended lower limit is 0.70, with 0.60 acceptable in exploratory research (Hair et al., 1998, p. 118; Kocabasoglu and Suresh, 2006). Other possibilities to assess scale reliability are composite reliability (same as Cronbach's alpha but with unequal weights of items) and average variance extracted, which can be estimated by modern software packages. In this study, we used Cronbach's alpha with a cutoff value of 0.60 to assess reliability of the scales.

Scaled variables construction

To obtain factor score estimates, Tabachnick and Fidell (2007, p. 650) recommend a simple summation of scores of variables that load highly on the factor as an adequate procedure for common research applications. They also point out that standardizing variables is not necessary if the standard deviations of variables are roughly equal, as was the case with our data. Hair et al. (1998, p.116) note that averaging the scores is more common than combining them. We chose to average the scores also to ensure equal representation of the factors in higher-order scaled variables (*Focused resource capacity management, TOC logistics paradigm* and *Warehouse performance*). If combined scores were used, factors with more items would have contributed more to the higher-order variable.

Since *Warehouse performance* was created as a two-item scale, its reliability was assessed by Cronbach's alpha (0.689). The other two composite constructs are discussed in the next subsection.

Formative constructs

An important latent construct specification decision for a researcher is modeling a construct as reflective or formative. The primary difference is in the direction of causality. While reflective measures are caused by the latent construct, formative measures cause it (Freeze and Raschke, 2007). It is critically important to distinguish between the two types of constructs (MacKenzie et al., 2005). Construct misspecification of this type (a reversal of causality direction), particularly in models estimated by structural equations, leads to misleading results, which in turn may result in erroneous theoretical conclusions (Jarvis et al., 2003; MacKenzie et al., 2005). It is possible to define a latent variable as mixed, i.e., having both causal and effect items however, in most cases defining a latent variable with item paths going in just one direction is more practical (MacCallum and Browne, 1993).

To distinguish reflective and formative perspectives in construct design, it is common to refer to a formative latent variable as a composite, a scale as an index and a model containing at least one formative construct as a formative model (Diamantopoulos and Winklhofer, 2001; Bollen and Lennox, 1991). We followed this convention where it was necessary to avoid ambiguity.

In addition to the primary difference in the direction of causality, there are several other special traits that distinguish formative constructs from reflective constructs and are taken into consideration in this study. Most authors (e.g., Freeze and Raschke, 2007; MacCallum and Browne, 1993; Jarvis et al., 2003) note that (1) dropping an item may change the conceptual domain of the composite; (2) a change in an index variable will cause a change in the composite but not necessarily vice versa; (3) causal items do not have to be correlated with each other or have low correlations with items of other constructs. Based on the causality direction and the additional criteria above, we have originally specified as formative two constructs: *Focused resource capacity management* in the full detailed model and *TOC logistics paradigm* in the general model.

External scheduling coordination, a construct that emerged from our consideration of physical warehouse transportation interfaces, was initially specified as being measured by a five-item scale. After the pretest, one item was deleted. It was also recognized that the construct was specified as mixed: out of four remaining items three were formative, and one was reflective. For practical reasons and following the advice of MacCallum and Browne (1993), it was decided to remove the reflective item and specify the construct as completely formative.

While we have modified the original logistics paradigm of TOC by removing the temporal, sequential organization of its elements and adding an extra element (*External scheduling coordination*), we have not changed the principal relationship between the elements and the underlying construct. Whether reflective or formative, the validity of all constructs must be established to assure that theoretical interpretation is based on sound results. Unfortunately, the traditional means to establish validity and reliability of scales (Cronbach's alpha, CFA, etc.) are not applicable to indexes (Bagozzi, 1994, Diamantopoulos and Winklhofer, 2001). While conceptual consideration plays a major role in affirming validity of formative constructs, Diamantopoulos and Winklhofer (2001) propose several validity checks by creating and testing mini models of specific configuration. We performed one of the checks applicable to our model that tests the direction and significance of the beta coefficient from the composite construct to another latent construct with which it should be logically linked in the full model. While the conceptual considerations are given the main weight in the construct and item specification, where we are clearly guided by TOC, the formative constructs in our model passed the tests as an extra indication of external (nomological) validity of the constructs.

Control variables

Finally, several control variables were used in the model estimation. The traditional control variables are warehouse size (square footage or number of employees), warehouse type (3PL or cost center), and prevailing picking type (case or pallet) (WERC, 2014; Stank et al., 1999). For a measure of size the number of employees was chosen over the square footage, because headcount is much more easily changed than the warehouse surface area and, thus, more accurate for the purposes of this study.

We also controlled for the degree of automation and cross-docking activities in the warehouse because more rigidly structured operating contexts reduce the flexibility of resources, and therefore limit a manager's ability to affect warehouse measures of capacity and throughput.

Additionally, a growth (or decline) of business over the past 3 years, the time span chosen for this survey following the work of Sale and Inman (2003), may have an effect on our outcome constructs. Particularly, in a situation of business decline, the resulting excess capacity in warehouse resources may limit the appeal of using TOC in the warehouse. Parenthetically, we will remark that TOC still applies, but the constraint is external to the warehouse (e.g., lack of demand), and TOC has a component (Thinking Processes) to deal with external constraints, however, it is not considered in this study focused on operations inside the warehouse.

Means of several variables for two groups of survey participants, "anonymous" (received through the commercial survey service) and "confidential" (solicited by the researcher directly) were found to be statistically significantly different. A control binary variable was introduced into the regression models to account for the variance associated with these differences.

The final control variable was a constraint index, which needs a more detailed explanation. No prior TOC literature was found applicable to constructing a measure of how badly constrained resources are in a warehouse. Our survey used a 7 by 7 matrix that requested respondents to select which of the six key resources and an additional "other" resource, if applicable, for which they experienced a shortage for at least six months in any 12-month period over the preceding 3 years. They were then asked to rate the severity of the shortage on a scale from 1 ("Not severe at all") to 7 ("Extremely severe"). Even though TOC states that each system has at least one constraint, a forced response option was not chosen for this question in the online version of the survey to allow for a possibility of a system constraint outside the warehouse. However, the few responses with nothing selected were completely excluded from analysis.

The original TOC does not prohibit multiple constraints. The number of constraints is limited, "by the number of independent 'chains'" (Goldratt, 1990, p.124). It was shown earlier that a regular warehouse typically has two disjoint flows, each of which may have different constraints. However, more than two constraints are possible in each flow. For example, it is feasible that a picking operation may not reach its goal because of a shortage of personnel, forklifts, and dock space at the same time. Theoretically, any one of the three constraints could be the worst and the most limiting one, and they may switch among themselves as capacity is added to them at a different rate. However, the managers comparing the capacity of available resources with calculations of needed capacity to reach the order preparation target (i.e., the number of people, order picking trucks, and square footage for prepared orders on the dock) are likely to perceive that they have multiple constraints even in one chain. Hence, multiple selections were possible and expected in the survey question matrix. The difficulty for the researcher was how to combine multiple constraints of different severity into just one variable in order to effectively measure the overall level of constraint within the warehouse.

In a situation similar to this, Geri and Ahituv (2008) applied TOC to joint IT systems implementation in the supply chain. They used a 7 by 11 cell matrix with 3 levels to choose from in each cell. They assigned numerical values of 0, 1, and 2 for each of the cell choices and constructed an index based on the sum of all numerical values plus an arbitrary 50 points for another condition that deemed to be very important. This simple summation approach plus an arbitrary correction for another condition was deemed not appropriate for our study. Clearly, 7 resources mildly constrained at the level of 1 are not the same condition as having one level-7 severely constrained resource. Instead, a common statistical practice of squaring values and summing them was chosen. This resulted in a constraint index (CI) with the range of potential values from 1 to 343 (for 6 plus one resources); however, it was difficult to predict *a priori* if the CI of the warehouse will significantly impact any of the predicted variables. To improve normality, the CI variable was transformed into a logarithmic form.

Choice of an estimation technique

Due to the latent nature of constructs in the model, the recommended technique for statistical analyses normally would be Structural Equation Modeling (SEM) (Hair et al., 1998; Kline, 2005). SEM is not a single technique but a collection of confirmatory statistical procedures to examine relationships between one or more independent variables and one or more dependent variables (Ullman, 2007; Kline, 2005). As previously mentioned, CFA is considered a special case of SEM (Ullman, 2007), just as is PLS (Kocabasoglu and Suresh, 2006). The primary advantage of SEM is that it allows one to evaluate multiple relationships between the construct in the measurement model simultaneously.

However, for the covariance-based SEM estimation there is an identification requirement for formative models that our model does not comply with: any composite variable must emit at least two paths to unrelated latent constructs (Jarvis et al., 2003). The possible alternatives to the two latent constructs are a minimum of two theoretically appropriate reflective indicators or a combination of latent constructs and reflective indicators. Our model does not satisfy any of these conditions. There is only one path emanating from the composite variables to the *Warehouse capacity and throughput* latent construct. Thus, SEM was deemed inappropriate as a model estimation method.

Instead of SEM, hierarchical multiple linear regression, which is the most common technique, was used to test the model. We used it to estimate the function Y = f (**X**, **Z**), where **X** is a vector of dependent variables of interest, and **Z** is a vector of control variables. The hierarchical (sequential) variety of regression allows entering the covariates (controls) on the first step followed by the independent variables of interest.

CHAPTER V

RESULTS

Sample overview

The final sample from all sources included 215 responses, which roughly corresponds to a 2% response rate Profiles of a typical respondent and warehouse in the sample are presented in Table 1 and discussed in more detail further.

Table 1: Profiles of a typical respondent and warehouse

Category	Value
Warehouse	
Size (employees)	45
Years operated	17
Growth of business over 3 years, %	26
Place in supply chain	distributor or wholesaler
Primary goods stored	fininshed
Industry by primary product	consumer
Predominant picking type	by case
Manager	
Scope of responsibility, warehouses	1
Years in charge, period	3 to 6

While respondents were specifically requested to respond to all questions about one warehouse, they were also asked to select how many warehouses they managed. More than half of the respondents (57%) were in charge of just one warehouse, but 21% were in charge of two, and the remaining 22% of respondents were responsible for more than two warehouses.

One survey question asked respondents about how many years they were responsible for their warehouse. In addition to simply collecting demographic information, respondents who selected the answer “0 – 2 years” were shown an additional question asking if they were familiar with the operations of their warehouse for the past three years, and those answering negatively were automatically disqualified from the survey because it covered a three-year period of warehouse operations. This affected the demographic distribution of respondents to this question by reducing the share of those who had been responsible for their warehouses for less than 3 years (but had a good knowledge of operations there for the full 3 year period) to 11%. The largest category of managers (39%) were in charge of their warehouses from 3 to 6 years, the next largest (30%) – from 7 to 10 years, with the remaining 20% having managerial responsibility for their warehouses for more than 10 years.

In addition to questions about warehouse managers, the survey collected basic information about the warehouses as well. The average warehouse employed 45 people not counting the management, with a standard deviation (SD) of 73, and was operated by the respondent’s company for 17 years (SD = 14). Over the three years, an average warehouse experienced a 26% growth of business (SD = 31; the question was in the format of a sliding scale allowing a decline as well as growth).

For control purposes, the warehouses were split into four categories. When respondents were involved in more than one type of business, they were asked to indicate the one most applicable. Fifteen (7%) were for profit third-party logistics providers, 72 (33%) were primarily manufacturers, 108 (50%) were wholesalers, and 20 (10%) were predominately retailers. In a binary division by product type, 116 (54%) of the respondents handled primarily industrial goods, and 99 (46%) dealt in consumer products. Another binary category, type of picking (predominantly by case or predominantly by pallet) resulted in a split of 140 (65%) to 75 (35%), respectively. As expected, the largest storage category was finished goods (125 warehouses; 58%).

Arguably, the most interesting part of the descriptive statistics of the demographics section of the survey was the constraint index (CI). Its logarithmic transformation used as a control variable in a regression of *Warehouse capacity and throughput* (TOC Outcomes) on its predictors was statistically significant with a positive coefficient. While it played its intended role, it is meaningless to interpret a log-transformed control variable. Instead, we offer a brief discussion of individual constraints data that were used in the construction of the index.

To remind, respondents were asked to identify among six key warehouse resources the one(s) they were short on in the preceding three years and rate the severity of their constraint on a 7-point Likert scale, where 7 was the most severe condition. Additionally, respondents had an option of selecting and rating an "other" resource (as well as identifying it in a conditionally activated subsequent question). Table 2 illustrates the distribution of the constraint incidence frequencies and severities among the key warehouse resources.

Table 2: Frequency and severity of constraints

Constrained resource	Number of warehouses	Percentage in sample	Mean severity	SD
Doors	133	62	2.30[a]	1.69
Dock space	162	75	3.55	1.87
Storage	184	86	4.09	1.93
Personnel	168	78	3.79	1.91
Lift trucks	150	70	2.87	1.77
WMS	140	65	3.19	1.94
Other	101	47	2.63	1.93
Average CI	215	100	**70.64**[b]	**56.38**

a. On a Likert scale from 1 (lowest) to 7 (highest); only the warehouses that reported a shortage of this resource were included in the calculation of this statistic.
b. Allowed range from 1 (lowest) to 343 (highest).

As seen from the table, the biggest constraint for warehouses in the sample is lack of storage space, followed in the descending order of severity by a shortage of human resources, dock space, IT resources (WMS), lift trucks, miscellaneous other resources and doors. These rankings agree with anecdotal evidence from industry. Constraints due to lack of the two key warehouse resources, storage space and work force, have always been the primary concern in the business growth scenarios and a focus of much of the academic research as has been shown in the literature review in Chapter II. Not only do these problems occur most frequently (the largest share of warehouses that reported them), but also their negative impact is perceived as the greatest (highest mean severities).

A close third in the rankings list is dock space, a resource that is barely mentioned in the literature. However, industry professionals know it is the easiest one to trade off when there is a shortage of storage space by storing some product on the dock. This is likely the reason for its high spot in the hierarchy of constraints.

At the bottom of the list are doors and miscellaneous other resources. More than half of the warehouses in the sample reported that they did experience a shortage of doors in the preceding three years, but the severity of it appears to be very mild. Again, doors were overlooked in academic research, but the industry evidence shows that it is easy to increase this resource by simply working overtime or restructuring the shifts (going from one to two, or switching to a 6- or 7-day working week). This is a trade-off with personnel, the most flexible warehouse resource.

The respondents' choices of the miscellaneous "other" category, when examined in detail through the supporting text, appeared to contain some external constraints as well as many extensions of the previous six key resources when respondents used it as a way to explain their problem in more detail. The lack of a common theme in this category is an indirect supporting evidence of the fact that the six key warehouse resources identified in this study appear to completely cover the typical constraint problems in a warehouse.

If the "Other" category is excluded from the average warehouse CI, it assumes a value of 65.65 (SD = 51.74), only 5 points below the full CI. While a pairwise t-test of the means was statistically significant, the replacement of the full CI by the adjusted CI (both in the logarithmic form) had virtually no effect on the regression results in terms of coefficient of determination, regression coefficients and t-values significance. The results of this study are reported with the full CI.

It is also worth noting that in the three-year period an average warehouse reported experiencing constraints in four different key warehouse resources out of six (Mean = 4.36; SD =

1.92). The average adjusted CI value of 65.65 is an equivalent of having all six key resources constrained at a medium level (between 3 and 4 on the 7-point Likert scale), or of having two severe constraints (between 5 and 6). Therefore, a conclusion follows that warehouse managers have to deal with constraints in the key warehouse resources on a regular basis.

To conclude the review of the descriptive statistics, we will have a brief look at the level of implementation of TOC elements in our sample. The respondents were asked to express their degree of agreement with the positively worded statements that made up the items on a scale from 1 ("Strongly agree") to 7 ("Strongly disagree"). The items were averaged to obtain the elements of TOC's logistics paradigm. They are displayed in Table 3. Descriptive statistics for the other variables are reported in Appendix C.

Table 3: Descriptive statistics for the elements of TOC's logistics paradigm

TOC Element	Mean	SD	Min	Max
Focused resource capacity management	2.76	0.68	1.35	5.04
Focused tactical resource capacity management	2.34	1.00	1.00	7.00
Focused operational resource capacity management	2.36	0.83	1.00	5.83
Trade-offs with other resources	2.96	1.15	1.00	6.33
Focused strategic resource capacity management	3.37	1.13	1.33	7.00
External scheduling coordination	2.48	1.24	1.00	7.00

In our sample of warehouses, the components of *Focused resource capacity management* that require less effort appear to be more popular. At the top of the list are the tactical and operational management (no statistically significant difference between the means). Explicit trade-offs between the resources are used to a lesser degree as they imply acceptance of inefficiencies at nonconstrained resources. Even less popular is the strategic management of resource capacity, which largely implies spending cash on acquiring the needed extra capacity of the constrained resource. However, external scheduling coordination appears to be widely accepted.

Scales

Scales structure analysis and purification performed as described in the respective section of Chapter IV, resulted in the items and factors presented in Table 4. Results of the EFA (pattern matrix and communalities) are reported in Table 5 and reliability of the scales in Table 6.

Table 4: Factors and item descriptions

Factor	Item	Notation
	TOC Elements	
Focused tactical resource capacity management	Know peak usage times of CRs*	FTM1
	Monitor the use of CRs	FTM2
	Always enough work to do for CRs	FTM3
	Use time standards for CR operations	FTM4
Focused operational resource capacity management	Maximum utilization a CR a priority	FOM1
	Use a variety of ways to increase CR utilization	FOM2
	Know the most critical point in operations	FOM3
	Problem prioritization	FOM4
	Changes in operations to increase CR utilization	FOM5
	Conduct periodic bottleneck reviews	FOM6
Trade-offs with other resources	Tolerate inefficiency of a non-CR to help a CR	RTO1
	Actively trade-off capacity among resources	RTO2
	Use of other resources based on the most limited	RTO3
Focused strategic resource capacity management	Purchased additional capacity of a CR	FSM1
	Accept higher costs to increase capacity of a CR	FSM2
	Implemented a long-term solution	FSM3
External scheduling coordination	Schedule coordination - downstream	ESC1
	Schedule coordination - upstream	ESC2
	Schedule coordination - carriers	ESC3
	TOC Outcomes	
Warehouse capacity and throughput	Successful in overcoming constraints	WCT1
	The most critical constraint no longer a problem	WCT2
	Experienced increased throughput	WCT3
	Experienced increased capacity	WCT4
	Warehouse Performance	
Warehouse logistics performance	Picking & shipping mistakes down	WLP1
	Internal order cycle time down	WLP2
	Order processing time variability down	WLP3
	Handling damage down	WLP4
	Dock-to-stock cycle time down	WLP5
Warehouse financial performance	Unit costs down	WFP1
	Paid quality claims down	WFP2
	Transportation penalties down	WFP3

* CR – constrained resource

Table 5: EFA pattern matrix and communalities

Item	FOM	WLP	FTM	WCT	ESC	RTO	FSM	WFP	Communalities
FOM1	.876								.653
FOM2	.800								.685
FOM4	.640								.627
FOM5	.637								.640
FOM3	.618								.688
FOM6	.506								.660
WLP1		.833							.527
WLP2		.793							.604
WLP4		.629							.518
WLP5		.613					.303		.576
WLP3		.550							.652
FTM1			.890						.695
FTM2			.769						.537
FTM4			.699						.580
FTM3			.688						.594
WCT1				.828					.696
WCT3				.750					.791
WCT2				.732					.703
WCT4				.593					.628
ESC1					.899				.758
ESC2					.755				.677
ESC3					.738				.671
RTO1						.795			.609
RTO2						.779			.667
RTO3						.524			.681
FSM1							.741		.500
FSM2		.308					.697	-.303	.549
FSM3							.625		.582
WFP1								.819	.712
WFP2								.629	.689
WFP3								.568	.626

Loadings below .300 not shown. All resulting factors reflective, except ESC, which was later specified as formative. Factor and item labels:

FOM Focused operational resource capacity management
WLP Warehouse logistics performance
FTM Focused tactical resource capacity management
WCT Warehouse capacity and throughput
ESC External scheduling coordination
RTO Trade-offs with other resources
FSM Focused strategic resource capacity management
WFP Warehouse financial performance

Table 6: Reliability of the scales

Scale	Cronbach's alpha
Focused tactical resource capacity management	.783
Focused operational resource capacity management	.809
Trade-offs with other resources	.656
Focused strategic resource capacity management	.601
Warehouse capacity and throughput	.775
Warehouse logistics performance	.790
Warehouse financial performance	.719

Tests of hypotheses

Hypotheses 1a and 1b

In the first set of hypotheses we test the sign and strength of the relationship between the elements of TOC's logistics paradigm and *Warehouse capacity and throughput*:

H1a. Focused resource capacity management is positively associated with warehouse capacity and throughput.

H1b. External scheduling coordination is positively associated with warehouse capacity and throughput.

Both hypotheses were supported. The multiple regression step on which the two predictors of interest were entered produced a statistically significant model with $F(10,214) = 6.046$, $p < 0.001$) and a significant change in the F-statistic ($F_{change} = 15.821$, $p < 0.001$). The adjusted coefficient of determination R^2 for the whole model was 0.191, and the change in R^2 was 0.120. Thus, 12% of the variance in the *Warehouse capacity and throughput* was accounted for by the *Focused resource capacity management* and *External scheduling coordination*. Additional statistics for regression analysis are reported in Table 7.

Table 7: Regression results for hypotheses 1a and 1b

Predictor	Unstandardized Coefficients and (Standard Error)	t-statistic	Correlations Zero-order	Partial	Semi-partial
Focused resource capacity management	0.396** (0.114)	3.468	0.381	0.236	0.213
External scheduling coordination	0.159* (0.065)	2.444	0.325	0.169	0.150

Dependent Variable: Warehouse capacity and throughput
* Significant at 0.05 level
** Significant at 0.01 level

Hypotheses 2a and 2b

In the second set of the hypotheses, tested by two separate multiple sequential regressions, we examine the relationship between *Warehouse capacity and throughput* and the two components of warehouse performance: *Warehouse logistics performance* and *Warehouse financial performance*:

H2a. Warehouse capacity and throughput are positively associated with warehouse logistics (operational) performance.

H2b. Warehouse capacity and throughput are positively associated with warehouse financial performance.

In each regression, covariates were entered on the first step, followed by *Warehouse capacity and throughput* on the second. The second steps resulted in a statistically significant models with respective $F_{H2a}(9,214) = 6.983$, $p < 0.001$ and $F_{H2b}(9,214) = 6.502$, $p < 0.001$, and a statistically significant change in the F-statistics ($F_{changeH2a} = 45.581$, $p < 0.001$ and $F_{changeH2b} = 44.678$, $p < 0.001$). Summarizing the results of the two regressions, *Warehouse capacity and throughput* accounts for 17% of variance in *Warehouse logistics performance* (R^2 change = 0.170; total model adjusted R=.201) and 17% of variance in *Warehouse financial performance* (R^2 change =0.170; total model adjusted R = 0.188). Both hypotheses are supported. A summary of the results is shown in Table 7.

Table 8: Regression results for hypotheses 2a and 2b

Predictor: Warehouse capacity and throughput	**Unstandardized Coefficients and (Standard Error)**	**t-statistics**	**Correlations**		
			Zero-order	**Partial**	**Semi-partial**
Hypothesis 2a	0.396** (0.054)	6.751	0.381	0.236	0.213
Hypothesis 2b	0.159** (0.064)	6.684	0.325	0.169	0.150

H2a Dependent Variable: Warehouse logistics performance
H2b Dependent Variable: Warehouse financial performance
** Significant at 0.01 level

Hypothesis 3

In hypothesis 3 we wanted to check the relationship of the overall construct of *TOC logistics paradigm* and *Warehouse capacity and throughput*:

H3. Implementation of the TOC logistics paradigm is positively associated with warehouse capacity and throughput.

Similar to the previous hypotheses, the predictor of interest was entered on the second step of the hierarchical regression. The overall model and the change in the F-statistic were significant: $F(9,214) = 6.412$, $p < 0.001$ and $F_{change} = 29.080$, $p < 0.001$. The adjusted R^2 for the whole model was 0.185, with the R^2 change = 0.111 (11% of variance in *Warehouse capacity and throughput* is explained by *TOC logistics paradigm*). Table 8 contains coefficients and correlations of the independent variable.

Table 9: Regression results for hypothesis 3

Predictor	Unstandardized Coefficient and (Standard Error)	t-statistic	Correlations: Zero-order	Correlations: Partial	Correlations: Semi-partial
TOC logistics paradigm	0.467** (0.087)	5.393	0.401	0.352	0.333

Dependent Variable: Warehouse capacity and throughput
** Significant at 0.01 level

Thus, we confirm the support of hypothesis 3 by the regression analysis.

Hypothesis 4

In the last hypothesis, H4, we test the relationship of *Warehouse capacity and throughput* and the overall warehouse performance.

> H4. Warehouse capacity and throughput are positively associated with warehouse performance.

The regression analysis confirmed the existence of a statistically significant relationship between the two constructs with the hypothesized sign of the relationship ($F(9,214) = 8{,}932$, $p < 0.001$; $F_{change} = 62.097$, $p < 0.001$). The adjusted R^2 for the whole model was 0.250 and the R^2 change was 0.218, implying that approximately 22% of the variance in *Warehouse performance* is accounted for by *Warehouse capacity and throughput*. Regression coefficients and correlations are shown in Table 9.

Table 10: Regression results for hypothesis 4

Predictor	Unstandardized Coefficient and (Standard Error)	t-statistic	Correlations Zero-order	Partial	Semi-partial
Warehouse capacity and throughput	0.399** (0.051)	7.880	0.516	0.482	0.466

Dependent Variable: Warehouse performance
** Significant at 0.01 level

To summarize the hypotheses testing, all hypotheses were supported by the regression analysis. These results largely agree with those we received later using partial least squares (PLS), an alternative correlation-based technique in the family of structural equation modeling (Kocabasoglu and Suresh, 2006). The details of the PLS procedure and the results are described in Appendix D.

Summary of findings

In this study, we have found that contemporary warehouses routinely experience multiple and severe shortages (constraints) of their key resources, which prevents the warehouses from fully reaching their performance objectives. However, we also found that managing resources using the approach of TOC logistics paradigm leads to higher warehouse capacity and throughput and in turn to higher warehouse logistics and financial performance. Moreover, favorable outcomes occur in application of either of the two components of TOC logistics paradigm: focused resource capacity management and external scheduling coordination. From the way the conceptual domain of these two components was defined, it follows that coordination of schedules of operations at the warehouse interfaces with supply chain partners allows to adjust the inbound and outbound flow of goods to better match the available warehouse resources, whereas an internal focus on resource constraint elimination at the tactical and operational levels as well as resources trade-offs and strategic decisions to acquire additional capacity allows to bring up the capacity of the most constrained resources to the levels where the whole system capacity and throughput increases to make a significant positive impact on warehouse performance. The positive effect manifests itself in higher logistics performance reflected in a decrease of picking and shipping mistakes and handling damage and reduction of several warehouse cycle metrics (dock-to-stock, internal order, and order variability). The positive impact also extends to financial performance of the warehouse reflected in decreasing unit costs and reduction of amounts paid for quality and transportation related claims.

Overall, our research clearly demonstrates that not only TOC can be adapted to a warehouse setting, but that management of key warehouse resources based on it is a powerful tool for warehouse management to improve performance of the whole warehouse as a system.

CHAPTER VI

CONCLUSIONS

Contributions made by this study

Contributions to theory

One of the most important contributions of this study to theory is a further development of TOC as a resource management theory and its adaptation to the context of warehousing operations. This study answers the call for investigation of, “more granular issues regarding the management and allocation of [supply chain management] resources” (Esper and Crook, 2014).

TOC has been challenged as a theory on the grounds of being built on a computer algorithm of a very narrow application. The debate over TOC legitimacy as a theory took a conciliatory turn when the later developed problem solving paradigm of thinking processes (in 1994) received more attention in research and was hailed as the main and most useful part of TOC (Rahman, 2002). In this study, we take the focus back to the original logistics paradigm of TOC and rebuild it. We eliminate the temporal, sequential nature of the 5 focusing steps and recast them and the drum-buffer-rope internal scheduling and buffering technique as a set of more commonly recognized management constructs without losing the idea of the focus on the constraint and the hierarchy of their application. The hierarchy is different from the previous algorithm in that it recognizes the different levels of cost and effort associated with their application but allows the flexibility to start from any level as well as combine them to achieve a mix of measures that have the highest likelihood of efficiently eliminating the constraint.

The internal scheduling and buffering technique expectedly blends with the different levels of focused resource capacity management that is focused on operations inside the warehouse, but we have identified a construct that impacts the flow of inventory through the warehouse at its interfaces with other supply chain members. Our study shows that coordinating schedules with upstream shippers, downstream consignees, and carriers helps to alleviate resource constraints inside the warehouse and in this way to increase warehouse capacity and throughput. This conclusion also extends to the full logistics paradigm when this construct is incorporated in it. Thus, our research suggests that when capacity and throughput of a system are considered its interfaces warrant inclusion in such analysis, and TOC is a theory that allows this to be done.

The adaptation of TOC we have undertaken in this study and the confirmation we have received from the empirical results may be considered an answer to the question raised in TOC literature of whether TOC tools "should be followed 'blindly'" (Kim et al., 2008, p. 174). Our effort falls in line with the future research suggestions of Inman et al. (2009) to whose empirical work we have made comparisons throughout this study. Inman et al. (2009) see TOC as a constantly evolving entity and suppose that, "the TOC elements or outcomes within the model … probably should be updated over time" (p. 353).

Contributions to applied research

This study has made several contributions to applied research in warehousing. We offered a definition, two tests and a list of six key warehouse resources: doors, dock space, storage, personnel, lift trucks, and WMS. Previous resource classifications in academic literature did not seem to be based on a single definition or clearly spelled-out logic. Moreover, two of the resources, doors and dock space were largely ignored. We include them in the list because they are part of warehouse interface with transportation, the beginning and ending points of warehouse goods flows that create throughput. Doors and dock space have common characteristics with the other four key warehouse resources mentioned in the key warehouse resource definition: they are a component of warehouse design or operation, they are not easily acquirable or modifiable, and their capacity is finite or limited at least in the short term. They pass both the goods flow impact test and the time-effort-cost tests of a key warehouse resource.

Is the list of six key warehouse resources exhaustive? For most warehouses in the US, evidence from our study suggests an affirmative answer. The survey responses to the optional "other" resource choice lacked any common theme and were mostly extensions or specifics of the previous six. Several respondents mentioned cash or financial resources. However, there are two types of "cash." The money required to run a regular warehouse operation does not affect the product flow *directly* and is just a necessary condition for an operation, just like electricity. Prolonged lack of operating cash (e.g., not being able to pay workers' wages or perform repairs to forklifts, storage racks or doors) essentially reduces the capacity of the key resources and makes the whole operation not sustainable. However, the negative effect is indirect, through the same key warehouse resources.

The other type of financial resources, investment capital for resource capacity upgrades, falls under focused strategic resource capacity management, and again has only indirect influence on the warehouse capacity and throughput through the same key warehouse resources.

It is possible to imagine a different context where another resource, pallets or something else that comes in contact with the goods and is routinely available to most warehouses in the United States, is in chronic short supply there. But the key warehouse resource definition and the two tests that we offered should provide the right answer for that context as well.

We believe that this study has made another contribution to warehousing research by testing and confirming the general TOC model of Inman et al. (2009) developed by them for manufacturing. Our study is not an exact replication of their research. We have changed the model in two ways: only the logistics paradigm of TOC is examined in our study, but not the Thinking Processes; and performance is measured at the level of an organizational unit, not the firm level.

The findings of our study confirm the importance of considering warehouse interface with supply chain partners when examining antecedents of warehouse capacity and throughput and ultimately warehouse performance. The confirmation of applicability of TOC to warehousing and a specific model of how it applies is a contribution to both TOC and warehousing research.

Contribution to methodology

We believe we have made several contributions to methodology of TOC and supply chain research by rising to the challenge of, "pairing research methods and research questions in new ways" (Waller and Fawcett, 2011, p. 209).

There are many TOC case studies, but there are only a handful of empirical papers testing hypotheses (Kim et al., 2008). Our study is a step on the way to bridge that gap.

The customary tools for warehouse operations research are simulations, which have a drawback of very limiting assumptions and a very narrow focus (Rouwenhorst et al., 2000), typically considering one warehouse resource at a time. Our study goes another way. We use a survey instrument to collect data about traditional warehouse operations. We consider all six key warehouse resources and view the warehouse as a system allowing flexible internal allocation and manipulation of resources. We also include outside interfaces of this system in the scope of this study.

In a new approach for TOC empirical research, we have presented several TOC constructs as formative with a justification for the choice. In contrast to traditional supply chain literature that typically stays at the level of a whole firm as the smallest unit of research, we descend to the level of one of its organizational units, while retaining and using all of the traditional supply chain research perspectives and tools.

Finally, we took extra caution to prevent data from contamination by respondents with improper attitudes and behaviors toward survey taking. The detailed description of our earnest effort in this respect may serve as a mini-case example of approaching the issue and the protocol we developed as a practical tool.

Contributions to practice

Based on this study, we are happy to provide warehouse managers with several pieces of specific advice that goes beyond very general "managerial implications" often seen in academic papers. Our advice is presented in the following narration.

Every warehouse can be viewed as a system whose primary dimensions are overall capacity and throughput. They influence logistics and financial performance of the warehouse. As operations grow, most warehouses will experience constraints in their operations. The constraints will limit the system's throughput and will have a negative effect on overall warehouse performance. Actively managing available resources will allow to alleviate and eliminate those constraints. This study suggests that six resources are critical to operations of a warehouse: doors, dock space, storage capacity, personnel, lift trucks, and WMS. Our research shows that in a typical warehouse more than one resource may be constrained at the same time, and some of the constraints may be severe.

But the good news is that in the warehouse, TOC works! The adaptation of TOC's logistics paradigm in this study presents a particular way of key resource management. The management philosophy should have a strong focus on constraint elimination. There is a hierarchy of actions that can be undertaken to overcome the constraint(s). The hierarchy of actions has several tiers based on the cost and implementation effort, and while the easiest and least expensive action is the most desirable, it may take a combination of actions from different levels to overcome the constraint(s). We do not suggest as a requirement following a particular pattern of action application, i.e., from easiest and cheapest to the most difficult or expensive. We recognize that the pressure of not meeting the capacity and throughput goals and jeopardizing overall warehouse performance may call for an immediate "overkill" solution. However, the manager should be aware of the whole set of tools available to manage resource capacity.

Focused tactical resource capacity management implies squeezing the most of the constrained resource within the existing operational process and is usually the task of a foreman or team leader. It is perceived as a no cost and low effort solution, but the effect may not be sufficient to overcome the constraint.

Focused operational resource capacity management is a maneuver that may involve a change in operational processes, resource allocation or a change in internal operations scheduling. It may take more managerial effort, but still at no or little direct financial cost.

Trade-offs between the resources should be explored. There are many ways to get some extra capacity of the constrained resource by trading it off with existing resources. This implies that as part of trade-off some inefficiency or a direct cost of extra capacity in the nonconstrained resources must be incurred and tolerated as long as this adds capacity in a better (quicker, cheaper) way to the constrained resource. Personnel is believed to be the most flexible warehouse resource. The anecdotal evidence collected from industry shows that it is normally easy to get extra lift truck and door time and potentially dock space by asking workers to work overtime. The extra labor cost incurred is cheaper (at least in the short term) than that of acquiring an extra lift truck or installing an extra door in the wall (if at all feasible).

In our adaptation of TOC to warehousing, process management should be viewed in the context of warehouse resource management. For example, a process change allowing picking full units (e.g., pallets) directly from the reserve is considered a trade-off between labor that is being freed up and the WMS that will require an upgrade to manage the new process. It is mostly a matter of activation and training effort if the WMS already possesses this functionality, but there may be a direct cost if the upgrade needs to be purchased. Again, the cost incurred is not in the resource whose capacity is being freed up.

A strategic decision may be made to directly acquire (purchase, lease, rent, hire, transfer from another unit of the firm) additional capacity of the constrained resource. This is the essence of the focused strategic resource capacity management. Capacity of some resources may be easier to increase compared to others. Hiring an extra person is usually easier than making more doors, getting more storage capacity or migrating to an advanced WMS. Nevertheless, all these actions are viewed as a strategic decision to add capacity directly and they may be the best choice under certain circumstances.

The previous actions were focused on operations inside the warehouse. One additional option that may be available to warehouse managers is to coordinate product flow at warehouse interfaces with supply chain partners to better utilize the most constrained resources (to avoid idle time and to smooth peaks).

Conclusion

This study has revealed the mechanisms of how the adjusted TOC's logistics paradigm can be used to address resource constraints in operations inside the warehouse and its physical interfaces. Another major component of TOC, Thinking Processes (TP), was specifically designed to apply to nonphysical and external constraints (such as company policies and market conditions) (Rahman, 2002; Simatupang et al., 2004). TP is very broad in scope by design and has been praised over the logistics paradigm because of that (Rahman, 2002). By transforming the logistics paradigm we have increased its potential. The transformed logistics paradigm can now be used broadly, on the par with TP, and its constructs are suitable for survey-based empirical research. Together, TOC's two paradigms present an outstanding opportunity for research and practice.

Limitations

This study has a number of limitations. One comes from the use of the survey method. Surveys are known to introduce bias. Electronic surveys may introduce additional bias (Boyer et al., 2001). We have taken many precautionary measures to minimize it, yet we cannot guarantee its absence.

Since few scales were available for us to use as is in this study, and only some of the items borrowed from the previous research fit out study, we had to substantially modify the existing scales and develop new scales and indexes. The reliability of some of the scales, while above the minimum cutoff level, was lower than in the comparable study of Inman et al. (2009).

Our study was relatively narrow in scope. We examined only one component of TOC – its logistics paradigm. Some of the constructs we used were also narrow in scope (i.e., warehouse financial performance and external scheduling coordination).

Future research

Some of the suggestions for future research come from the limitations of this study. One direction is expanding the scope of TOC warehousing research. Thinking Processes, the problem solving paradigm, could be tested together with a replication of the logistics paradigm test to empirically prove our proposition that the whole TOC is applicable to warehousing. The boundaries of TOC application to warehousing can be tested on subsamples from warehouses with high shares of cross-docking or automation.

For example, Vogt and Pienaar (2007) note that in the warehouses where cross-docking is treated as a warehouse extension, the cross-docking operation competes for the same warehouse resources, and is typically not very efficient. On the other hand, a properly organized cross-docking operation integrated into its supply chain is conducive to the application of TOC (Vogt and Pienaar, 2007).

We relied on self-reported performance measures. Some further scale development work can be done to improve the scales used in this study. It is also of definite value to conduct a comparable study relying on objective performance data, despite the challenges of big diversity in warehousing operations.

We have mentioned before that our research design was largely influenced by prior work of Inman et al. (2009). It primarily sought to examine the more general relationships between TOC constructs and performance. A more granular view of individual constructs is also a logical extension of our research. For example, individual trade-offs may be considered between different resources, and their impact on constraint elimination may be evaluated separately.

Alternatively, the new construct of external scheduling coordination that was limited to physical goods flow coordination at warehouse external interfaces may be raised in scope to the level of all types of supply chain partner coordination traditionally considered in supply chain research. The cooperation with direct effect on capacity of warehouse resources may include activities associated with information sharing and cooperative planning, forecasting and replenishment (CPFR) as well as joint work to find win-win solutions for the whole supply chain, examples of which may include shifting order cutoff times for early picking operation start, switching from trailer floor loading to palletized freight, picking in larger units, optimizing order types and frequencies, etc.

The condition of being constrained in one or more warehouse resources can be explored in more detail. Answers should be found to the questions about its moderating effect, if any, on the efficacy of particular levels of focused resource capacity management.

Other research questions and methods may offer a completely new perspective on the place of TOC in warehousing. Qualitative methods may provide deeper insights into issues of warehouse resource management. Differences in propensity of warehouse managers to favor some TOC elements over others based on organizational and national cultures may provide another avenue for warehouse-focused TOC research effort. Behavioral aspects largely ignored in operations research hold a big potential for future academic quest for a full spectrum of factors underlying warehouse operations management.

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APPENDIX A

SURVEY (ONLINE VERSION)

You are invited to participate in a research study about warehouses because you are a warehouse manager or are in a similar position in charge of warehouse operations.

WHAT YOU SHOULD KNOW ABOUT THE RESEARCH STUDY

Study title: Managing Warehouse Resources

Contact information:

Researcher: Vitaly Brazhkin Adviser: Dr. John Ozment 475 Business Bldg. 1 University of Arkansas Fayetteville, AR 72701 479-575-7674 vbrazhkin@walton.uark.edu	*Compliance person:* Ro Windwalker, CIP IRB/RSC Coordinator Research Compliance 210 Administration Bldg. 1 University of Arkansas Fayetteville, AR 72701 479-575-2208 irb@uark.edu

Study description:

As volume of business increases, warehouses are often unable to easily upgrade their operation to the new level because of a limited availability of necessary resources. The purpose of this study is to explore effectiveness of certain strategies to deal with the shortage of warehouse resources. The survey collects basic demographic data about your warehouse (size, industry, etc.) and asks to identify resources in short supply in you warehouse and rate applicability to your warehouse of specific strategies dealing with shortages of these resources first in general and then individually for each resource in short supply.

Legal disclosure:

A large number of warehouse managers are asked to fill out this 20-minute survey online or on paper. There is neither a cost nor a direct benefit to you to participate in this study, however, you can request the generalized results of the study when it is completed by contacting the researcher using the contact information above. There are no risks involved in filling out the survey. Your participation is voluntary and your refusal to participate will not have any adverse effects on you. The researcher will not disclose any identifying information of any kind to other study participants, research community or the public. All information will be kept confidential to the extent allowed by applicable State and Federal law. You may also contact the University of Arkansas Research Compliance office listed above if you have questions about your rights as a participant, or to discuss any concerns about, or problems with the research. By participating in this survey you will not waive any rights. Your completion of the survey constitutes your consent to the terms above.

Part 1. Warehouse demographics.

Are you a warehouse manager or in a similar position in charge of daily warehouse operations?
- Yes (1)
- No (2)

How many years have you been in charge of your warehouse?
- 0-2 (2)
- 3-5 (3)
- 6-10 (4)
- >10 (5)

Are you familiar with the operations of your warehouse in the past 3 years?
- Yes (1)
- No (2)

Have there been any major changes in your strategy to deal with resource shortages in the past 3 years?
- Yes (1)
- No (2)

Please describe briefly what changed in your strategy to deal with resource shortages

How many warehouses are you responsible for?
- 1 (2)
- 2 (3)
- 3-5 (4)
- 6-10 (5)
- >10 (6)

Please answer all further questions of this survey for just one warehouse with whose operations you are familiar for at least 3 years.

Does your warehouse have an AS/AR (Automated Storage/Automated Retrieval) system installed (computerized physical movement of goods to/from storage without direct human involvement)?
- Yes (9)
- No (10)

What type of goods go through it?

What % of goods by volume ("cube") go through it? (enter number only)

Do you perform value-added activities in your warehouse (activities beyond receiving, storage, picking and shipping, e.g., light assembly from components)?
- ❍ Yes (9)
- ❍ No (10)

What value-added activities do you perform?

What % of the total labor hours do you spend on value-added activities? (enter number only)

Do you use cross-docking in your warehouse?
- ❍ Yes (9)
- ❍ No (10)

What % of goods by volume ("cube") go through it? (enter number only)

Is the number of full-time workers in your warehouse 5 or more?
- ❍ Yes (1)
- ❍ No (2)

Please tell us more about your warehouse:

	Please enter numbers only (1)
Size in sq ft (1)	
Number of full-time employees, excluding management (2)	
How many years has your company operated this warehouse? (3)	

Which category of business is best applicable to your company?
- ❍ 3 PL (1)
- ❍ Manufacturer (2)
- ❍ Wholesaler or distributor (3)
- ❍ Retailer (4)

What do you store primarily?
- ❑ Raw materials (1)
- ❑ Work-in-process inventory (2)
- ❑ Finished goods (3)

What are the primary products stored in your warehouse? (e.g., automotive spare parts)

Type of picking

	% of item/broken case (1)	% of full case (2)	% of partial pallet (3)	% of full pallet (4)
Please enter numbers only; must add up to 100% (1)				

What % is the volume of business in your warehouse now compared to the level 3 years ago (no change = 100%)? Use the cursor to move the slider along the scale.
______ % (1)

Does your warehouse use the 5-step continuous improvement process based on the theory of constraints (TOC)?
- ❍ Yes (1)
- ❍ No (2)
- ❍ Not sure (3)

How many years have you been using TOC?
- ❍ (1)
- ❍ 1-2 (2)
- ❍ 3-5 (3)
- ❍ 6-10 (4)
- ❍ >10 (5)

What is your constraint in the warehouse operations now?

Does your warehouse use elements of the lean philosophy?
- ❍ Yes (1)
- ❍ No (2)
- ❍ Not sure (3)

Which elements of the lean philosophy are used in your warehouse?

Part 2. Management of limited resources.

Have you had a shortage of any resources in the warehouse for 6 months or more in any 12-month period in the past 3 years?

❍ Yes (9)

❍ No (10)

Which resources did you have a shortage of? Please select and rate the severity of shortage

	Severity of shortage of the resources selected on left							Resources in short supply
	1 = Not severe at all (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 = Extremely severe (7)	Select applicable (1)
Dock doors (1)	❍	❍	❍	❍	❍	❍	❍	❑
Dock space (staging area) (2)	❍	❍	❍	❍	❍	❍	❍	❑
Storage capacity (3)	❍	❍	❍	❍	❍	❍	❍	❑
Warehouse personnel (4)	❍	❍	❍	❍	❍	❍	❍	❑
Forklifts (lift trucks of all types) (5)	❍	❍	❍	❍	❍	❍	❍	❑
WMS (warehouse management system): availability, speed or functionality (6)	❍	❍	❍	❍	❍	❍	❍	❑
Other resource (7)	❍	❍	❍	❍	❍	❍	❍	❑

You must select (with a check mark) the resources that you rated. Please go back to correct.

Please specify "Other resource" you selected above

Notice: This survey has multiple data consistency checks. Each response is reviewed and validated manually by a warehousing expert. Please do not attempt to answer the questions without reading or thinking as this will disqualify your complete response.   Thank you!

For the resources in short supply you selected before [piped text], please rate the statements below (Page 1 of 2).

	Strongly agree (1)	(2)	(3)	(4)	(5)	(6)	Strongly disagree (7)
We monitor the use of these warehouse resources (1)	❍	❍	❍	❍	❍	❍	❍
We know their peak usage times (2)	❍	❍	❍	❍	❍	❍	❍
We make sure that there is always enough work to do for these resources (3)	❍	❍	❍	❍	❍	❍	❍
We have time standards for operations using these resources (4)	❍	❍	❍	❍	❍	❍	❍
If during a shift a problem occurs with one of these resources, fixing it will be considered a priority (5)	❍	❍	❍	❍	❍	❍	❍
If there is a problem with one of these resources, we have an established process to address it (6)	❍	❍	❍	❍	❍	❍	❍
This is an attention check. Please select Strongly disagree for this statement (15)	❍	❍	❍	❍	❍	❍	❍
We are always aware of the most critical point in our operations (7)	❍	❍	❍	❍	❍	❍	❍
Maximizing utilization of a limited warehouse resource is considered a priority in my warehouse (9)	❍	❍	❍	❍	❍	❍	❍
We use a variety of ways to increase utilization of a warehouse resource with limited capacity (10)	❍	❍	❍	❍	❍	❍	❍
We have made changes in the way we use a limited warehouse resource to increase its utilization (11)	❍	❍	❍	❍	❍	❍	❍
The way we use other resources in the warehouse is based on the needs of the most limited resource (12)	❍	❍	❍	❍	❍	❍	❍
We use capacity of some warehouse resources to compensate for the lack of other resources (13)	❍	❍	❍	❍	❍	❍	❍
We tolerate less efficient use of some resources if it helps increase capacity of the most limited resource (14)	❍	❍	❍	❍	❍	❍	❍

For the resources in short supply you selected before, please rate the statements below (p. 2 of 2).

	Strongly Agree (1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**Strongly Disagree (7)**
We purchased additional capacity of the most limited resources (1)	❍	❍	❍	❍	❍	❍	❍
We used a temporary solution to increase capacity of the most limited resources (2)	❍	❍	❍	❍	❍	❍	❍
We have implemented a long-term solution for the most limited warehouse resources (3)	❍	❍	❍	❍	❍	❍	❍
We will accept higher incremental costs to acquire additional capacity for the most limited resources (4)	❍	❍	❍	❍	❍	❍	❍
Once a shortage of the most critical resource is overcome, we shift our improvement efforts to other areas (5)	❍	❍	❍	❍	❍	❍	❍
We have periodic reviews to identify bottlenecks in our operations (6)	❍	❍	❍	❍	❍	❍	❍
We prioritize our problems and apply our improvement efforts to the highest priority problem first (7)	❍	❍	❍	❍	❍	❍	❍
We manage the flow of goods in a way that eliminates or minimizes idle time of the most limited resource (8)	❍	❍	❍	❍	❍	❍	❍
Schedules are set to maximize the capacity or throughput of the most limited warehouse resources (9)	❍	❍	❍	❍	❍	❍	❍
We use workload buffers or make contingency plans so that our most limited warehouse resources are never idle or underutilized (10)	❍	❍	❍	❍	❍	❍	❍
In short term work planning we take into account available capacity of our most limited resources (11)	❍	❍	❍	❍	❍	❍	❍
We coordinate our shipping schedules with our customers or downstream partners (12)	❍	❍	❍	❍	❍	❍	❍
We coordinate our incoming shipment schedules with our suppliers (13)	❍	❍	❍	❍	❍	❍	❍
We coordinate transportation schedules with transportation providers to level our workload	❍	❍	❍	❍	❍	❍	❍
We require appointments for truck drivers to pick up or deliver a shipment (15)	❍	❍	❍	❍	❍	❍	❍

Part 3. Management outcomes.

This section refers to the most recent 3-year period. Please rate your agreement with the statements below (Page 1 of 2).

	Strongly agree (1)	(2)	(3)	(4)	(5)	(6)	Strongly disagree (7)
We have been able to substantially increase capacity of our most limited resources (1)	❍	❍	❍	❍	❍	❍	❍
Capacity of our most limited resources is no longer a problem. (2)	❍	❍	❍	❍	❍	❍	❍
We feel that we are successful in overcoming constraints in our warehouse resources (3)	❍	❍	❍	❍	❍	❍	❍
We were able to increase warehouse throughput (4)	❍	❍	❍	❍	❍	❍	❍
Satisfaction of the top management with the performance of our warehouse has increased (5)	❍	❍	❍	❍	❍	❍	❍
Satisfaction of other units or departments of our firm with the performance of our warehouse has increased (6)	❍	❍	❍	❍	❍	❍	❍
The morale of our warehouse employees has increased (7)	❍	❍	❍	❍	❍	❍	❍
Our warehouse work force turnover has decreased (8)	❍	❍	❍	❍	❍	❍	❍
The satisfaction of our customers with the service of our warehouse has increased (9)	❍	❍	❍	❍	❍	❍	❍
The satisfaction of our logistics partners with the work of our warehouse has increased (10)	❍	❍	❍	❍	❍	❍	❍
Our flexibility to meet customers' special requirements has improved (11)	❍	❍	❍	❍	❍	❍	❍
The situation with bottlenecks in our warehouse operations has improved (12)	❍	❍	❍	❍	❍	❍	❍

This section refers to the most recent 3-year period. Please rate your agreement with the statements below (Page 2 of 2).

	Strongly Agree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Disagree (7)
Our warehouse has experienced an increase in the percentage of shipments to customers leaving of on-time (1)	❍	❍	❍	❍	❍	❍	❍
The percentage of picking and shipping mistakes has decreased (2)	❍	❍	❍	❍	❍	❍	❍
The material handling damage in our warehouse has decreased (3)	❍	❍	❍	❍	❍	❍	❍
The internal order cycle time (from order release time to ship time) has decreased (4)	❍	❍	❍	❍	❍	❍	❍
The dock-to-stock cycle time has decreased (5)	❍	❍	❍	❍	❍	❍	❍
Our warehouse has achieved a decrease in total order cycle time for our customers (6)	❍	❍	❍	❍	❍	❍	❍
The variability of the order processing time in our warehouse has decreased (7)	❍	❍	❍	❍	❍	❍	❍
Our warehousing unit costs have decreased (8)	❍	❍	❍	❍	❍	❍	❍
Amounts paid for claims for late deliveries or quality problems have decreased (9)	❍	❍	❍	❍	❍	❍	❍
Amounts of detention/demurrage charges and other transportation related penalties have decreased (10)	❍	❍	❍	❍	❍	❍	❍
The volume of business going through our warehouse has increased (11)	❍	❍	❍	❍	❍	❍	❍
Our warehouse has made a positive impact on profitability of our company (12)	❍	❍	❍	❍	❍	❍	❍

APPENDIX B

RESEARCH PROTOCOL APPROVAL LETTER
(MOST RECENT MODIFICATION)

April 24, 2014

MEMORANDUM

TO:	Vitaly Brazhkin John Ozment
FROM:	Ro Windwalker IRB Coordinator
RE:	PROJECT MODIFICATION
IRB Protocol #:	13-05-721
Protocol Title:	*Upgrading Existing Warehouses*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 04/24/2014 Expiration Date: 06/05/2014

Your request to modify the referenced protocol has been approved by the IRB. **This protocol is currently approved for 500 total participants.** If you wish to make any further modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

Please note that this approval does not extend the Approved Project Period. Should you wish to extend your project beyond the current expiration date, you must submit a request for continuation using the UAF IRB form "Continuing Review for IRB Approved Projects." The request should be sent to the IRB Coordinator, 210 Administration.

For protocols requiring FULL IRB review, please submit your request at least one month prior to the current expiration date. (High-risk protocols may require even more time for approval.) For protocols requiring an EXPEDITED or EXEMPT review, submit your request at least two weeks prior to the current expiration date. Failure to obtain approval for a continuation *on or prior to* the currently approved expiration date will result in termination of the protocol and you will be required to submit a new protocol to the IRB before continuing the project. Data collected past the protocol expiration date may need to be eliminated from the dataset should you wish to publish. Only data collected under a currently approved protocol can be certified by the IRB for any purpose.

If you have questions or need any assistance from the IRB, please contact me at 210 Administration Building, 5-2208, or irb@uark.edu.

APPENDIX C

FULL REGRESSION TABLES FOR MULTIPLE REGRESSION ANALYSIS

1. Hypotheses 1a and 1b

1.1. Variables used in regression:

Variable type	Variable	Notation
Dependent	Warehouse capacity and throughput	M_WCT
Independent of interest	Focused recourse capacity management	M_TOCEL4
Independent of interest	External scheduling coordination	M_ESC3
Control	3-year change in business volume	Bus_3YR
Control	Degree of automation	ASAR
Control	Warehouse type dummy	D_3PL
Control	Picking type	dPICK
Control	Constraint index	LnCI
Control	Warehouse size	LnEmpl
Control	Share of cross-docking	XDock
Control	Type of respondent	Respondent

Note: Same control variables were used in all regressions for all hypotheses.

1.2. Descriptive statistics

Variable	Min.	Max.	Mean	Std. Dev.
Warehouse capacity and throughput	1.00	6.00	3.04	1.06
Focused recourse capacity management	1.35	5.04	2.76	0.68
External scheduling coordination	1.00	7.00	2.48	1.24
3-year change in business volume	41.00	250.00	125.61	30.78
Degree of automation	0.00	100.00	11.33	26.39
Warehouse type dummy	0.00	1.00	0.07	0.26
Picking type	0.00	1.00	0.35	0.48
Constraint index	0.00	5.72	3.81	1.13
Warehouse size	1.10	6.55	3.17	1.05
Share of cross-docking	0.00	100.00	14.97	22.88
Type of respondent	0.00	1.00	0.87	0.34

1.3. Model summary

Model	R	R^2	Adj. R^2	S.E. of the Estimate	Change Statistics				
					R^2 Change	F Change	df1	df2	Sig. F Change
1	.330	.109	.074	1.02204	.109	3.149	8	206	.002
2	.478	.229	.191	.95560	.120	15.821	2	204	.000

1.4. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	26.314	8	3.289	3.149	.002
	Residual	215.182	206	1.045		
	Total	241.496	214			
2	Regression	55.208	10	5.521	6.046	.000
	Residual	186.288	204	.913		
	Total	241.496	214			

1.5. Regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	S.E.	Beta		
1	(Constant)	3.580	.491		7.285	.000
	Respondent	-.298	.225	-.095	-1.324	.187
	LnEmpl	-.162	.070	-.161	-2.313	.022
	LnCI	.162	.065	.172	2.510	.013
	ASAR	-.007	.003	-.175	-2.613	.010
	XDock	-.001	.003	-.018	-.260	.795
	dPICK	.153	.149	.069	1.027	.306
	Bus_3YR	-.003	.002	-.080	-1.164	.246
	D_3PL	-.019	.285	-.004	-.065	.948
2	(Constant)	1.512	.608		2.486	.014
	Respondent	-.017	.221	-.005	-.078	.938
	LnEmpl	-.109	.067	-.108	-1.628	.105
	LnCI	.132	.062	.140	2.118	.035
	ASAR	-.005	.003	-.125	-1.969	.050
	XDock	.000	.003	.009	.134	.893
	dPICK	.123	.141	.055	.876	.382
	Bus_3YR	-.001	.002	-.020	-.301	.764
	D_3PL	-.150	.268	-.036	-.561	.576
	M_TOCEL4	.396	.114	.253	3.468	.001
	M_ESC3	.159	.065	.186	2.444	.015

2a. Hypothesis 2a

2a.1. Variables used in regression:

Variable type*	Variable	Notation
Dependent	Warehouse logistics performance	M_WLP
Independent of interest	Warehouse capacity and throughput	M_WCT

* For control variables, see 1.1.

2a.2. Descriptive Statistics

Variable	Min.	Max.	Mean	Std. Dev.
Warehouse logistics performance	1.00	5.60	2.69	0.89
Warehouse capacity and throughput	1.00	6.00	3.04	1.06

2a.3. Model summary

Model	R	R^2	Adj. R^2	S.E. of the Estimate	Change Statistics				
					R^2 Change	F Change	df1	df2	Sig. F Change
1	.254	.064	.028	.87941	.064	1.774	8	206	.084
2	.484	.235	.201	.79735	.170	45.581	1	205	.000

2a.4. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.977	8	1.372	1.774	.084
	Residual	159.313	206	.773		
	Total	170.289	214			
2	Regression	39.956	9	4.440	6.983	.000
	Residual	130.334	205	.636		
	Total	170.289	214			

2a.5. Regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	S.E.	Beta		
1	(Constant)	3.269	.423		7.731	.000
	Respondent	-.236	.194	-.089	-1.219	.224
	LnEmpl	-.046	.060	-.054	-.763	.446
	LnCI	.061	.056	.077	1.092	.276
	ASAR	-.005	.002	-.160	-2.330	.021
	XDock	.000	.003	.000	.004	.997
	dPICK	.066	.129	.035	.510	.610
	Bus_3YR	-.003	.002	-.121	-1.714	.088
	D_3PL	.270	.245	.077	1.100	.273
2	(Constant)	1.955	.430		4.548	.000
	Respondent	-.127	.176	-.048	-.719	.473
	LnEmpl	.013	.055	.016	.243	.808
	LnCI	.001	.051	.002	.023	.981
	ASAR	-.003	.002	-.084	-1.319	.189
	XDock	.000	.002	.008	.126	.900
	dPICK	.009	.117	.005	.080	.937
	Bus_3YR	-.002	.002	-.086	-1.338	.182
	D_3PL	.276	.222	.079	1.244	.215
	M_WCT	.367	.054	.437	6.751	.000

2b. Hypothesis 2b

2b.1. Variables used in regression:

Variable type*	Variable	Notation
Dependent	Warehouse financial performance	M_WFP
Independent of interest	Warehouse capacity and throughput	M_WCT

* For control variables, see 1.1.

2b.2. Descriptive statistics

Variable	Min.	Max.	Mean	Std. Dev.
Warehouse financial performance	1.00	5.33	3.05	1.05
Warehouse capacity and throughput	1.00	6.00	3.04	1.06

2b.3. Model summary

Model	R	R^2	Adj. R^2	S.E. of the Estimate	Change Statistics				
					R^2 Change	F Change	df1	df2	Sig. F Change
1	.229	.053	.016	1.04132	.053	1.774	8	206	.187
2	.471	.222	.188	.94586	.170	45.581	1	205	.000

2b.4. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.383	8	1.548	1.427	.187
	Residual	223.375	206	1.084		
	Total	235.757	214			
2	Regression	39.956	9	5.817	6.502	.000
	Residual	130.334	205	.895		
	Total	170.289	214			

2b.5. Regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	S.E.	Beta		
1	(Constant)	4.115	.501		8.219	.000
	Respondent	-.330	.229	-.106	-1.439	.152
	LnEmpl	-.150	.072	-.151	-2.095	.037
	LnCI	.020	.066	.022	.306	.760
	ASAR	-.003	.003	-.073	-1.059	.291
	XDock	-.001	.003	-.024	-.348	.728
	dPICK	.159	.152	.073	1.046	.297
	Bus_3YR	-.003	.002	-.089	-1.261	.209
	D_3PL	-.100	.290	-.024	-.344	.731
2	(Constant)	2.572	.510		5.044	.000
	Respondent	-.202	.209	-.065	-.964	.336
	LnEmpl	-.080	.066	-.080	-1.214	.226
	LnCI	-.050	.061	-.053	-.819	.414
	ASAR	.000	.003	.003	.050	.960
	XDock	-.001	.003	-.017	-.263	.793
	dPICK	.093	.139	.042	.672	.502
	Bus_3YR	-.002	.002	-.055	-.844	.400
	D_3PL	-.092	.264	-.022	-.348	.728
	M_WCT	.431	.064	.436	6.684	.000

3. Hypothesis 3

3.1. Variables used in regression:

Variable type*	Variable	Notation
Dependent	Warehouse capacity and throughput	M_WCT
Independent of interest	TOC logistics paradigm	M_TOCEL2

* For control variables, see 1.1

3.2. Descriptive Statistics

Variable	Min.	Max.	Mean	Std. Dev.
TOC logistics paradigm	1.25	5.39	2.62	0.83
Warehouse capacity and throughput	1.00	6.00	3.04	1.06

3.3. Model summary

Model	R	R^2	Adj. R^2	S.E. of the Estimate	Change Statistics				
					R^2 Change	F Change	df1	df2	Sig. F Change
1	.330	.109	.074	1.02204	.109	3.149	8	206	.002
2	.469	.220	.185	.95879	.111	29.080	1	205	.000

3.4. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	26.314	8	3.289	3.149	.002
	Residual	215.182	206	1.045		
	Total	241.496	214			
2	Regression	53.046	9	5.894	6.412	.000
	Residual	188.450	205	.919		
	Total	241.496	214			

3.5. Regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	S.E.	Beta		
1	(Constant)	3.580	.491		7.285	.000
	Respondent	-.298	.225	-.095	-1.324	.187
	LnEmpl	-.162	.070	-.161	-2.313	.022
	LnCI	.162	.065	.172	2.510	.013
	ASAR	-.007	.003	-.175	-2.613	.010
	XDock	-.001	.003	-.018	-.260	.795
	dPICK	.153	.149	.069	1.027	.306
	Bus_3YR	-.003	.002	-.080	-1.164	.246
	D_3PL	-.019	.285	-.004	-.065	.948
2	(Constant)	1.893	.557		3.398	.001
	Respondent	.026	.220	.008	.119	.905
	LnEmpl	-.126	.066	-.125	-1.905	.058
	LnCI	.113	.061	.121	1.851	.066
	ASAR	-.006	.003	-.138	-2.184	.030
	XDock	.000	.003	.006	.088	.930
	dPICK	.150	.140	.067	1.067	.287
	Bus_3YR	-.001	.002	-.027	-.412	.681
	D_3PL	-.161	.268	-.039	-.598	.550
	M_TOCEL2	.467	.087	.363	5.393	.000

4. Hypothesis 4

4.1. Variables used in regression:

Variable type*	Variable	Notation
Dependent	Warehouse performance	M_WP
Independent of interest	Warehouse capacity and throughput	M_WCT

* For control variables, see 1.1

4.2. Descriptive statistics

Variable	Min.	Max.	Mean	Std. Dev.
Warehouse performance	1.27	5.30	2.87	0.86
Warehouse capacity and throughput	1.00	6.00	3.04	1.06

4.3. Model summary

Model	R	R^2	Adj. R^2	S.E. of the Estimate	Change Statistics				
					R^2 Change	F Change	df1	df2	Sig. F Change
1	.253	.064	.028	.84572	.064	1.763	8	206	.086
2	.531	.282	.250	.74272	.218	62.097	1	205	.000

4.4. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.088	8	1.261	1.763	.086
	Residual	147.339	206	.715		
	Total	157.427	214			
2	Regression	44.343	9	4.927	8.932	.000
	Residual	113.084	205	.552		
	Total	157.427	214			

4.5. Regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.692	.407		9.080	.000
	QP Respondent	-.283	.186	-.111	-1.520	.130
	LnEmpl	-.098	.058	-.120	-1.687	.093
	LnCI	.040	.053	.053	.756	.450
	ASAR	-.004	.002	-.128	-1.863	.064
	XDock	-.001	.003	-.015	-.213	.832
	dPICK	.112	.124	.063	.909	.364
	Bus_3YR	-.003	.002	-.117	-1.667	.097
	D_3PL	.085	.236	.025	.360	.719
2	(Constant)	2.264	.400		5.653	.000
	QP Respondent	-.164	.164	-.065	-1.000	.319
	LnEmpl	-.033	.052	-.041	-.643	.521
	LnCI	-.024	.048	-.032	-.509	.611
	ASAR	-.001	.002	-.042	-.676	.500
	XDock	.000	.002	-.006	-.099	.921
	dPICK	.051	.109	.029	.471	.638
	Bus_3YR	-.002	.002	-.078	-1.256	.211
	D_3PL	.092	.207	.027	.446	.656
	M_WCT	.399	.051	.494	7.880	.000

APPENDIX D

ESTIMATES VALIDATION BY PLS

Estimates by multiple linear regression analysis were subjected to validation by partial least squares (PLS) using SmartPLS software. The modeling and estimation followed guidelines in Becker et al. (2012) and Vinzi et al. (2010). PLS is a variance-based technique that estimates model parameters by a sequence of ordinary least squares regressions in a way that maximizes the variance explained for all endogenous constructs (Reinartz et al., 2009, p. 332). PLS was chosen over covariance-based structural equation modeling (SEM) because PLS is better suited to handle formative constructs (Reinartz et al., 2009), which is especially important given the nature of our model. Instead of using latent variables, PLS operates with block variables that are weighted averages of their indicators (Reinartz et al., 2009). Since PLS takes into account factor loadings (for reflectively modeled constructs) and path weights (for formatively modeled constructs), the estimates depend on the quality of the construct measures chosen (Haenlein and Kaplan, 2004; Reinartz et al., 2009).

To compare the PLS analyses to the initial results, the model was intended to be as close as possible to the that of the analyses performed in SPSS. However, due to unacceptable average variance extracted (AVE) and communality (both below 0.5), one item (RTO1) had to be deleted, leaving the *Resource Trade-Off* construct with just two items, which is still acceptable but places a higher requirement on the sample size for high confidence estimates (Reinartz et al., 2009).

There were several choices available for modeling higher order formative constructs. In the first approach, we used the summated scores from individual regressions in SPSS to determine the differences between the PLS estimates for the whole model and individual regression estimates in SPSS. For this analysis higher-order constructs were given the scores of summated (equally weighted) items from the SPSS regressions. When the summated scores were applied to the respective higher-order variables, the PLS estimation produced results similar to those of individual regressions confirming all hypotheses. However, the path coefficients were lower and their bootstrapped t-statistics indicating significance was smaller. These results are consistent with observations, including empirical comparisons noted in the literature that the PLS method tends to underestimate path coefficients, for some models as much as 25% (Becker et al., 2012; Reinartz et al., 2009).

Next, we used methods specific to PLS modeling to create models with higher-order formative constructs. There are three approaches discussed in the literature: (1) the two-stage; (2) the repeated indicator; and (3) the hybrid approaches. The repeated indicator approach was not appropriate, because our model included block variables with different number of indicators (Becker et al., 2012), which left us with the two remaining approaches to consider.

According to Becker et al. (2012, the two-stage approach, "estimates the construct scores of the first order constructs in a first-stage model without the second order construct present, and subsequently uses these first-stage construct scores as indicators for the higher-order latent variable in a separate second-stage analysis" (p. 365). Under the hybrid approach the indicator variables of each first-order construct are split into two halves. The items in the first half are used with their original constructs, while the items in the other half are "assigned" together to the higher-order construct and are used to estimate its scores (Becker et al., 2012). The hybrid approach is an improvement on the repeated indicators approach from the theoretical perspective in that it avoids artificially correlated residuals by using each indicator variable only once

(Becker et al., 2012); however, it obviously shares the same problem of bias due to the different number of indicators, a fact that seems to be overlooked in the popular PLS literature.

When using these two approaches to modeling higher-order constructs, we received similar results confirming all hypotheses with the exception of the significance of one path: *Focused Resource Capacity Management* → *Warehouse Capacity and Throughput* (Hypothesis 1a). Hypothesis 1a was significant in the model with the hybrid approach to modeling higher-order constructs and insignificant using the two-stage approach. In the original SPSS regression analysis, this hypothesis was significant at the 95% confidence level, while all others were significant at the 99% confidence level.

Moreover, the hybrid method allowed a number of options of how to split indicator variables, including those with unequal number of indicators (*Focused Strategic Resource Capacity Management*), and it also affected the significance level. The possible explanations for the drop in significance of this path coefficient are the inherent downward bias and inconsistency of estimates of the PLS method (Reinhartz, et al., 2009) and its sensitivity to certain features of our model that make it less appropriate for estimation with PLS. Specifically, *Focused Strategic Resource Capacity Management* has too few indicators (three), and displays a lack of internal consistency when they are spit. PLS is known for inconsistency and bias due to the reliability issues in the construct measures and the low number of indicators (Reinartz et al., 2009). Fortunately, these effects are isolated; they are limited to specific paths and do not affect other parts of the model (Reinartz et al., 2009).

In conclusion, we were able to validate all hypotheses but one by using an alternative estimation method (PLS). For one hypothesis (H1a) we were unable to provide a definite validation due to the limitations of the method and the model.