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Just-in-Time Retail Distribution: A Systems Perspective on Cross-Docking

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Cross-docking is a just-in-time strategy for distribution logistics. It is aimed at reducing inventory levels and distribution lead times by creating a seamless flow of products from suppliers to customers. Prior supply chain literature has argued that creating such a seamless product flows requires a holistic view on cross-docking management, aimed at synchronizing cross-docking operations at the distribution center with its inbound and outbound network logistics. This paper provides an in-depth case study illustrating how cross-docking operations can be managed more holistically in a retail distribution context. A discrete event simulation model has been developed to understand and improve the cross-docking operations of a large grocery retailer in the Netherlands. The model is used to quantitatively evaluate two proposed changes that exploit opportunities in the design and control of the retailer's distribution network. An extensive real-world data set is used as input to the model. Overall, the case and simulation results show that a holistic cross-docking management approach can indeed improve system-wide performance, which further stresses the importance of making cross-dock operational decisions making and network decisions together.

Keywords: cross-docking; supply chain design; logistics planning and control; simulation

INTRODUCTION

Cross-docking is a just-in-time strategy for distribution logistics. It is aimed at realizing a seamless flow of products from suppliers to customers by moving products through the distribution network without storing them as inventory in distribution centers. Therefore, cross-docking should result in improved distribution lead times and reduced inventory levels. Dating back to the 1990s, cross-docking has been applied in a range of industrial settings, predominantly in parcel delivery (Forger 1995), less-than-truckload trucking (Gue 1999), retail distribution (Stalk et al. 1992), and the automotive industry (Witt 1998). In a recent survey, over two-thirds of the respondents—embodying a cross-section of the logistics industry—stated that cross-docking is part of their distribution strategy portfolio (Saddle Creek Logistics Services 2011). Another 15% expected to start cross-docking in the near future. Following its sustained popularity in industry, cross-docking has become a prominent topic in academic literature (Van Belle et al. 2012; Buijs et al. 2014).

This paper considers cross-docking in the context of retail distribution. In that context, cross-docking is often deployed in combination with the more traditional warehousing strategy. Warehousing is part of a make-to-stock replenishment strategy, in which distribution centers are used as a push-pull boundary. In contrast with cross-docking, products are stored as inventory to accommodate for demand variability and enable the consolidation of products for transportation. Inventory levels are controlled according to demand forecasts. The concept of holding products in inventory allows for decoupling: the warehousing operations inside the distribution center can be managed largely in isolation from the inbound and outbound network logistics

processes. Accordingly, distribution center operations and network logistics are often the responsibility of different managers—each with a distinct set of performance indicators. At the distribution center level, the performance indicators are typically focused on material handling efficiency. At the network level, the focus is on delivery service levels and cost-effectiveness of transportation.

Cross-docking fundamentally differs from warehousing. In cross-docking, distribution centers are purposefully not used as a push-pull boundary. Products are either moved directly from inbound to outbound trailers or temporarily placed on the floor (Apte and Viswanathan 2000). Moreover, cross-docked products are not stored as inventory. As a result, the cross-docking operations inside a distribution center are tightly coupled with the corresponding inbound and outbound logistics processes. Accordingly, supply chain management literature has stressed the need for a holistic cross-docking management approach (Napolitano 2000), aimed at synchronizing the cross-docking operations inside a distribution center with inbound and outbound network logistics (Apte and Viswanathan 2000; Vogt 2010).

Despite these fundamental differences, cross-docking management in retail distribution is often organized according to traditional warehousing principles, that is, with separated management responsibilities and distinct performance indicators for cross-docking operations at the distribution center versus the network level. Given the just-in-time nature of cross-docking, this comes as a surprise. From lean and just-in-time production theories, one would expect cross-docking performance indicators to be geared toward the flow of goods, distribution lead times, and the amount of work in progress (e.g., Hopp and Spearman 2011). A reason for the contrary could be that retail distribution centers are often used for both cross-docking and warehousing. Arriving truckloads can either be partially or entirely put away in storage or cross-docked. At the outbound side of the distribution center, the warehousing and cross-docking product flows are consolidated just before shipment to the retail stores. In this paper, we focus on the internal distribution center and network

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logistics processes that are directly related to the cross-docking product flow, that is, those products that do not enter inventory records.

The need for a holistic view on cross-docking management is grounded in systems thinking (e.g., Ashmos and Huber 1987). Thus far, academic cross-docking studies have not used real-world data sets to empirically verify this need in detail. Studies with a supply chain or operations management focus have relied on logical argumentation and anecdotic evidence (e.g., Apte and Viswanathan 2000; Napolitano 2000; Vogt 2010). In Operations Research literature, cross-docking papers have focused on efficiently solving well-defined isolated subproblems—addressing either the design and planning of cross-dock facilities or the design and planning of distribution networks with cross-docks (Van Belle et al. 2012; Buijs et al. 2014). As a result, it remains unclear how managers in retail distribution can organize and manage their cross-docking operations more holistically. Owing to the limitations in academic literature and practice, in this paper, we address the following research objectives:

- 1 Investigate how cross-docking operations can be managed holistically for a representative real-world case.
- 2 Empirically test if a more holistic management approach can indeed improve cross-docking operations.
- 3 Propose performance measures that can reflect system-wide changes in cross-docking performance.

Specifically, we study the case of a grocery retailer in the Netherlands. Within that case, we introduce two changes to the current cross-docking operations that illustrate how cross-docking operations can be managed more holistically. First, we propose a policy that dynamically assigns trailers to dock doors at a distribution center, while carefully considering the inbound and outbound transportation planning characteristics. Second, we study the relocation of preparatory cross-docking activities from a distribution center to a logistics facility upstream in the distribution network. Both proposed changes exploit opportunities in the design and control of the retailer's distribution network to realize system-wide cross-docking performance improvements. A discrete event simulation model is developed to evaluate the effects of the proposed changes.

The paper is organized as follows. First, the methodology section justifies the use of a case study with discrete event simulation modeling to attain our research objectives. The paper continues with a description of the case and conceptual model. Descriptions of the simulation model, experimental factors, and performance measures are provided in the simulation design section, which is followed by a section presenting the simulation results. More detailed information about the simulation model and the real-world data used are presented in a separate Online Supplement. In the conclusions and discussion section, we discuss the practical and theoretical implications that can be derived from our study.

METHODOLOGY

In order to attain the research objectives described in the Introduction, a large grocery retailer in the Netherlands was

approached for a case study on the cross-docking operations in their distribution network. The case company—henceforth referred to as “the retailer”—is considered to be leading with regard to the design and control of its distribution network, in which the broad implementation of cross-docking plays an important role. During the research project, the retailer facilitated many interviews and observation sessions and allowed unrestricted access to operational data and archival documents. Accordingly, our case selection can be justified by the unique research opportunity it provided (Yin 1994; Eisenhardt and Graebner 2007) to identify, investigate, and describe examples illustrating the need for a holistic cross-docking management approach. A detailed description of the case is provided in the subsequent section, which also elaborates how the case is represented in a conceptual model.

The main purpose of our case study is to understand and improve the retailer's cross-docking operations while maintaining a systems perspective. For this purpose, we adopted a discrete event simulation research approach. Robinson (2004) defines simulation as the “experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system.” Simulation is a research method that is particularly well-suited to represent the variability, interconnectedness, and complexity often encountered in such systems (Law and Kelton 2000; Robinson 2004; Evers and Wan 2012). Accordingly, several prior cross-docking studies have used simulation methods (e.g., McWilliams et al. 2005; Wang and Regan 2008; Yang et al. 2010).

In order to address our first research objective, discrete event simulation modeling has been used to propose and test new holistic cross-docking management solutions. To that end, the model simulates the retailer's cross-docking operations inside a distribution center as well as the inbound and outbound logistics processes. This simulation model also allows to address the second research objective, that is, investigate if holistic cross-docking management can indeed lead to better performance. A large real-world data set has been used as input to the simulation model. For example, these data included a full year of actual product flows through one of the retailer's distribution centers (including truck arrival and departure times). Assessing the need for more holistic cross-docking management, requires performance indicators that can reflect system-wide changes in cross-docking performance. The definition of these performance indicators constitutes our third research objective. While developing the case, we introduce new performance indicators related to the flow of products through the distribution network.

The validity of our simulation design has been determined by assessing the conceptual model validity and experimental validity and by performing white-box and black-box tests on the simulation model (Robinson 2004). To that end, we visited several logistics facilities throughout the retailer's distribution network and conducted interviews with employees and managers that play a key role in the cross-docking operations—with due attention being given to triangulation with the collected quantitative data. In total, we logged 110 hr of observations and performed 11 interviews (which lasted between 1 and 2 hr each). Conceptual model validity has been assessed through interviews discussing the scope, level of detail, and correctness of the conceptual

model. In order to ensure input data validity, all data sets were retrieved directly from the responsible department and were checked for inconsistencies. Experimental validity has been addressed by applying the confidence interval method to determine the appropriate run-length and number of runs for each experiment (Robinson 2004). Black-box testing involved a comparison of the simulated cross-dock operations and the real-world operational data retrieved from the warehouse management system. White-box testing has been performed through validation sessions with employees and managers involved in the day-to-day cross-docking operations, for example, cockpit-operator, team-leaders, and cross-dock site manager.

Considering the research objectives of this study, the use of discrete event simulation has two advantages. First, it allows testing multiple complex scenarios without interfering with on-going operations. Second, it allows for the monitoring of many performance indicators over time and therefore enables the measurement of cross-docking performance in a holistic way. The main shortcomings of discrete event simulation reside in its inability to solve problems to optimality and the limited generalizability of research findings (Evers and Wan 2012). In the Conclusions and Discussion section, we discuss the effects of these shortcomings on the theoretical implications that can be derived from our study.

CASE AND CONCEPTUAL MODEL

This section describes the current situation at the case company. Moreover, it presents the conceptual model explaining which aspects of the real-world situation are modeled and at what level of detail. As recommended by Robinson (2004), the conceptual

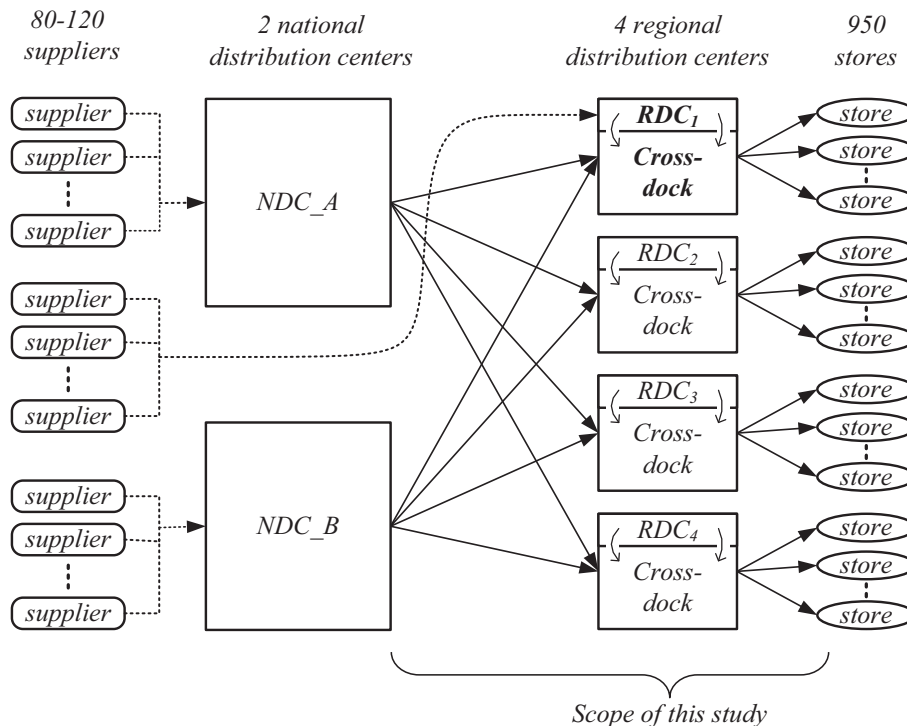
model is represented by means of component lists and a logic flow diagram.

Distribution network level

We study the cross-docking product flows through the retailer’s fresh food distribution network in the Netherlands. The distribution network design is schematically depicted in Figure 1—and is common for retailers in Europe (Bourlakis and Bourlakis 1999). Each of the 950 retail stores is allocated to one of four regional distribution centers (RDCs), roughly dividing the stores into equally sized groups. The RDCs hold a storage facility for fast-moving bulk products. Slow moving products and highly perishable products are stored at one of two national distribution centers (NDCs). Inventory is replenished by 80–120 suppliers. The retailer separates the stock keeping units (SKUs) in three disjoint sets across NDC_A, NDC_B, and the RDCs such that most suppliers either replenish a single NDC or all RDCs. Figure 1 specifies the scope of the conceptual model considered in this research. The model includes the cross-docking operations performed inside RDC₁, including the freight flows to the retail stores and the freight flows from the NDCs to RDC₁. To limit the scope and complexity of the model, the warehousing functions inside RDC₁ (e.g., storage and order-picking) as well as the freight flows supplying the distribution centers are excluded.

The transportation of products from the NDCs to the RDCs and from each RDC to its allocated retail stores is planned by the retailer’s central transportation planning department. The transport plan is characterized by a medium-term horizon (i.e., three months) and is developed based on norm volumes for retail store demand and service level agreements. Norm volumes

Figure 1: The scope of this study within the retailer’s fresh food distribution network.



specify the expected demand associated with each store delivery moment and is based on extensive historical data. Service level agreements are set according to store delivery moments ensuring that each store receives its ordered products within an agreed timespan from ordering. A retail store delivery always departs from an RDC. Figure 2 shows that 65% of the trailers departing an RDC deliver products to two retail stores; 35% of the trailers deliver products to a single store.

A retail store delivery always comprises products from one RDC and both NDCs. Upon store order, the products are retrieved from inventory at the RDC and NDCs and placed onto a load-carrier. Each load-carrier is picked and labeled for a single retail store. Figure 2 shows that 70% of the load-carriers contain products that are picked and labeled at the RDC, the remaining 30% contain products originate at one of the NDCs. At each NDC, load-carriers for several retail store deliveries are consolidated for transportation in full truckloads to an RDC. Those load-carriers are unloaded at a dedicated cross-docking area inside the RDC—referred to as the cross-dock—and quickly recombined with load-carriers picked from inventory at the RDC. The transportation planning from NDCs to RDCs follows the retail store delivery plan. That is, a trailer from an NDC always contains load-carriers bound for the first group of consecutively departing trailers from the RDC to the retail stores. The planning department aims for an arrival of these trailers at the RDC as close as possible to the corresponding departure times of the retail store delivery trailers. Specifically, the latest possible arrival time of an inbound trailer at the RDC is given by the most proximate departure time of the load-carriers inside that trailer minus a fixed time for performing cross-dock operations.

Table 1 shows how the real-world components at the distribution network level are incorporated in our conceptual model. Our conceptual model only considers load-carriers that are transported from an NDC, through RDC_1 , to the retail stores. With regard to the transport plan, the conceptual model exactly follows the retailer's current planning logic. To that end, the retailer provided us with 40 weeks of operational data, including inbound and outbound trailer schedules as well as the corresponding retail store demand volumes. Further details regarding the input data are described in the Online Supplement. Network control is not considered in our conceptual model. The transportation planning department monitors the transport operations in real-time against the medium-term plan. Occasionally, considerable transport delays occur. Moreover, actual store orders deviate from norm volumes, which might cause store delivery loads to exceed the planned trailer capacity. Such problems are handled on a daily basis by ad-hoc measures. In general, the retailer's network control is a fuzzy process that seldom leads to deviations from plan

in terms of adding or reducing trailers for the outbound transportation routes.

Distribution center level

The layout of RDC_1 is depicted in Figure 3, with a particular focus on the cross-dock. In reality, the cross-dock has 31 dock doors, which are all positioned along one side of the squared RDC. There is a staging area behind each dock door, where load-carriers can be temporarily placed. If used as inbound door, the staging area serves as a buffer to unload all load-carriers from an inbound trailer before they are moved through the cross-dock. If used as outbound door, the staging area serves as a buffer to temporarily keep load-carriers while the consolidated outbound trailer load is fully assembled. Staging areas are connected by a pathway for pallet trucks. The distance between staging areas is modeled as the (horizontal) distance between the centers of their corresponding dock doors and two times the (vertical) distance to the pathway.

All load-carriers from the NDCs are cross-docked at the RDCs. Upon arrival at the RDC, an inbound trailer docks at its assigned door and is immediately unloaded. The truck driver moves the load-carriers from the trailer through the dock door, where a dedicated team of material handlers takes over to scan the load-carriers and place them into the staging area. The load-carriers inside inbound trailers are arranged randomly. The material handlers cluster load-carriers according to their destined retail store during the unloading process. When the unloading process is completed, the Warehouse Management System performs a check for the completeness of the inbound load and then generates movement orders for pallet trucks. A pallet truck driver moves the load-carriers from inbound to outbound staging areas in batches of maximum four load-carriers. Around 30 min before the scheduled departure, the truck driver and a dedicated team of material handlers start loading the outbound trailer.

Table 2 shows how the real-world components at the distribution center level are incorporated in our conceptual model. In line with the scope at the distribution network level, all material handling activities related to the warehousing functions inside RDC_1 are not considered. The conceptual model does include the material handling operations performed to unload (and cluster) incoming load-carriers from inbound trailers, move load-carriers to their corresponding outbound dock doors and load them onto the outbound trailers. A logic flow diagram is displayed in Figure A1 in the Appendix.

Dock door assignment policy

Figure 4 displays the retailer's dock door assignment policy. In this policy, each door is exclusively assigned to either inbound or outbound trailers which is referred to as an *exclusive mode of service* (Boysen and Fliedner 2010). The five dock doors in the middle of the cross-dock are dedicated to inbound trailers. Arriving inbound trailers are directly docked to any available inbound door. The other 26 dock doors are dedicated to outbound trailers. The outbound trailer assignment is characterized by the same medium-term horizon as the transport plan (i.e., three months).

Figure 2: Freight flows through regional distribution center 1 (RDC_1).

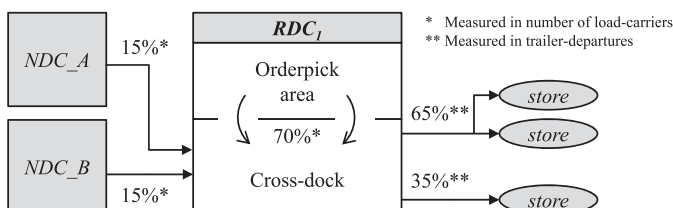
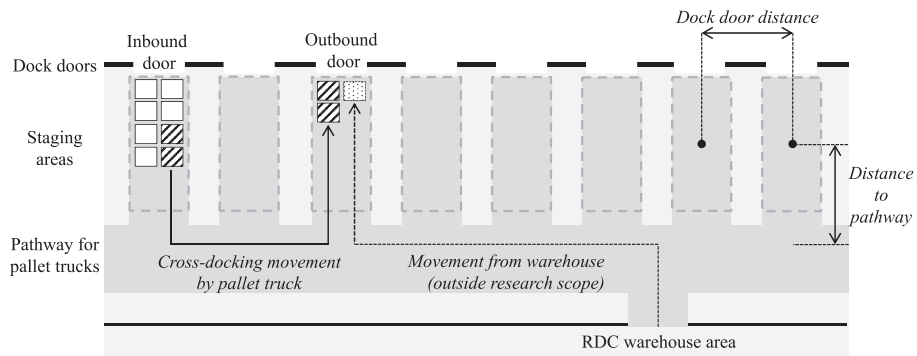


Table 1: Conceptual model: component list at the distribution network level

Component	Level of detail	Include/exclude	Comment
Store demand volumes	Demand volume for stock keeping units (SKUs) at national distribution centers (NDCs)	Include	SKUs that are located at the NDCs are order-picked at the NDC and cross-docked at the regional distribution center (RDC). The corresponding freight flow is the main focus of this study
	Demand volume for SKUs at RDC	Exclude	Excluded to limit model complexity (i.e., particularly its breadth). The corresponding freight flow interferes little with the cross-docking flow
	Demand fluctuation	Include	Demand fluctuation for each store is assumed to be proportional with the normally distributed total demand volume
	Load-carrier level	Include	Retail store demand is considered at the load-carrier level. The load-carrier is the lowest level of granularity for the cross-docking operations. Each load-carrier has a specific origin (NDC), destination (store), and due date (i.e., departure time from the cross-dock)
	SKU level	Exclude	SKU level is only important for order-picking, which is outside the scope of research
Outbound trailer schedule	Departure times	Include	Considered as input to the model. This is justified by the fact that virtually all outbound trailers depart the cross-dock on-time
	Load composition	Include	Store delivery routes are obtained from retailer and considered as input. The actual load compositions depend on the fluctuating store demands
	Arrangement of load	Exclude	The arrangement of load-carriers inside outbound trailers is not considered
	Outbound trailer capacity	Exclude	Outbound trailer capacity issues are rare and dealt with by network control, which is outside the research scope
Inbound trailer schedule	Arrival times	Include	Arrival times are scheduled according to real-world planning logic and added with a stochastic “delay” (normal distribution, mean 5 min, standard deviation 17 min)
	Load composition	Include	Load composition is set according to real-world planning logic
	Inbound trailer capacity	Include	Used as a constraint for determining the load composition
	Arrangement of load	Include	Experimental factor – discussed in subsequent section

Figure 3: Layout of regional distribution center 1 (RDC₁).

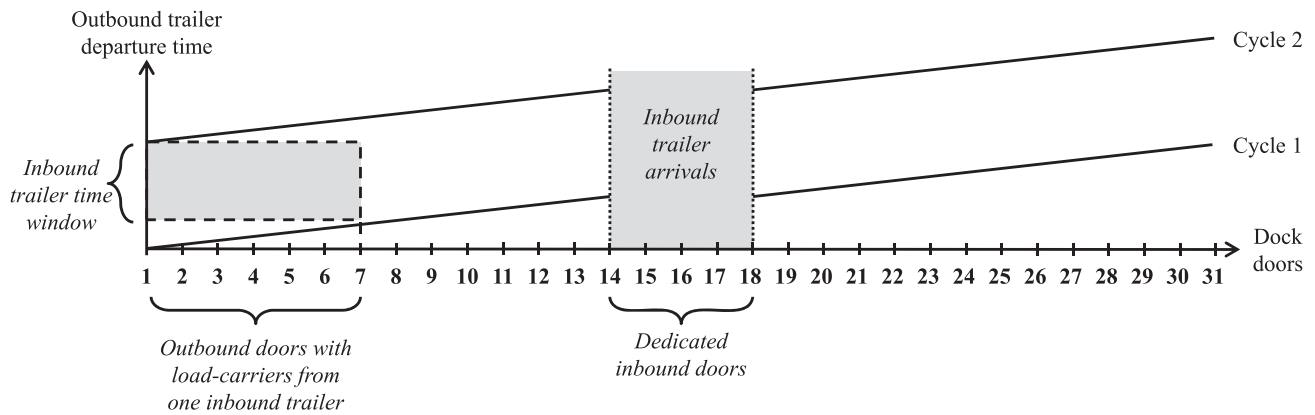


Similar to the transportation planning, we do not consider the real-time monitoring and control decisions regarding the dock door assignment. Following the planned outbound trailer departure times at the RDC, the first departing trailer is assigned to dock door no. 1 (the origin of the graph in Figure 4).

Subsequently, each consecutive outbound door is allocated to the next trailer departure. Each day, there are more outbound trailers than dock doors. Therefore, the dock doors are assigned in cycles: after dock door no. 31 is assigned, the 27th outbound truck is assigned to dock door no. 1.

Table 2: Conceptual model: component list at the local cross-dock level

Component	Level of detail	Include/exclude	Comment
Dock door	Availability	Include	Each dock door is modeled as a parallel inbound and outbound door resource. Hence, when an outbound trailer occupies a door, the processing of an arriving inbound trailer could start. It is not possible for two outbound trailers to be docked simultaneously at the same door
Staging area	Door assignment	Include	Experimental factor – discussed in subsequent section
	Utilization	Include	Staging area is modeled as a single-dimensional buffer (i.e., queue) in which load-carriers can be placed
	Load-carrier location	Exclude	The exact (two-dimensional) location of load-carriers in a staging area is not considered
	Position of areas inside cross-dock	Include	The distance between staging areas is modeled according to Figure 3 and captured in a distance matrix
	Opening time	Include	Set by the outbound trailer schedule, that is, the departure time of the previous trailer at the staging area's dock door
Unload material handling team	Closing time	Include	Set by the outbound trailer schedule, that is, the departure time of the current trailer minus loading time and buffer
	Unloading time	Include	Modeled as a constant for each load-carrier (9 sec) based on observatory measurements
	Clustering time	Include	Incurred when inbound loads are randomly organized. Modeled as a constant for each load-carrier (8 sec) based on observatory measurements
Cross-docking movement material handling team	Material handlers allocation	Exclude	Assumed always available when needed. Justified by the existence of a dedicated team supporting the truck driver in unloading and clustering an inbound trailer load
	Pallet truck availability	Include	Homogeneous set of three pallet trucks dedicated for cross-docking movements. Pallet truck becomes available when load-carriers are dropped-off at the outbound staging area
	Pallet truck capacity	Include	A capacity of four load-carriers in one movement. If a cluster of load-carriers exceeds four, multiple movement orders are generated—loading the pallet truck as much as possible
	Pickup time	Include	Modeled as a uniform distribution (min 30, max 50 sec)
	Drop-off time	Include	Modeled as uniform distribution (min 15, max 25 sec)
	Movement speed	Include	Modeled as a constant speed of 1.5 m/s, as derived from Warehouse Management System data. This speed includes a compensation for congestion—the actual cruising speed is 2.3 m/s
	Moving distance	Include	Variable according to distance between the corresponding inbound and outbound staging areas
Load material handling team	Loading time	Include	The loading time for each outbound trailer is input to the model. It is derived from operational data set
	Material handlers allocation	Exclude	There is a dedicated team of material handlers supporting the truck driver in loading an outbound trailer
Warehousing material handling	Order-picking	Exclude	Considered outside the scope
	Moving regional distribution center load-carriers to staging area	Exclude	Considered outside the scope. Interference between warehouse and cross-docking movements are incorporated into the moving speed

Figure 4: The dock door assignment and outbound trailer departure times.

SIMULATION DESIGN

The simulation design is discussed by describing the experimental factors, simulation model, and performance measures.

Experimental factors

This study includes two experimental factors for the purpose of deriving practical and theoretical insights regarding a holistic cross-docking management approach.

New dock door assignment policy

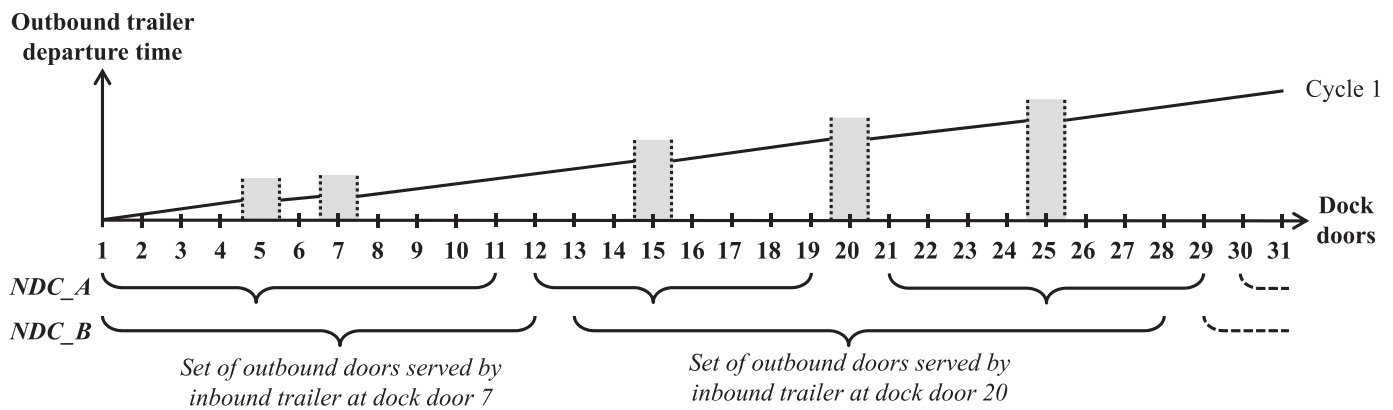
The first experimental factor entails a proposed change to the retailer's dock door assignment policy. In Operations Research literature, the assignment of dock doors is usually seen as a decision for optimizing distribution center operations (e.g., Tsui and Chang 1990, 1992; Gue 1999; Bartholdi and Gue 2000; Bozer and Carlo 2008). Specifically, the aim of those studies is to improve material handling efficiency at the cross-dock. For example, the travel distance of material handling equipment can be minimized by assigning inbound trailers to a dock door close to the outbound doors for which they have most products (Gue 1999). In this paper, our aim is not to improve existing dock door assignment methods. Rather, we investigate the effects of implementing a new dock door assignment policy in the light of joint distribution network and cross-dock operational decision making.

The policy proposed in this paper is inspired by existing dock door assignment models. In contrast with the retailer's current policy, our proposed dock door assignment policy uses a mixed mode of service, where each dock door can serve a mixed sequence of inbound and outbound trailers (Boysen and Fliedner 2010). Dock doors can change from serving inbound trailers to serving outbound trailers multiple times each day. This allows inbound trailers to be assigned closer to the outbound trailers for which they bring load-carriers. Prior studies have shown that the enhanced flexibility associated with a mixed mode of service considerably improves the utilization of the cross-dock in terms of, for example, material handling and dock door utilization (Stephan and Boysen 2011; Bodnar et al. 2015). A potential drawback of a mixed service mode resides in the fact that it requires staging areas to cope with both

inbound and outbound material handling activities. Moreover, a mixed mode tends to result in more ambiguous material flows. For the retailer, these drawbacks have limited impact since all staging areas have the same configuration and material handlers use handheld devices to identify the dock doors. Below, we describe the heuristic used to implement the proposed policy in a few simple steps:

- The *initial assignment of outbound trailers* is similar to the retailer's current policy, that is, all outbound trailers are sorted according to their planned departure times and assigned to consecutively to dock doors. The five dock doors in the middle of the cross-dock are no longer dedicated inbound doors, and can thus be assigned to outbound trailers as well.
- *Associate each inbound trailer with a set of outbound trailers.* The number of outbound trailers receiving load-carriers from an inbound trailer varies according to the specific retail store demand.
- *Assign dock doors.* Inbound trailers are assigned to a door as close as possible to the middle of the set of its associated outbound trailers. The outbound trailer initially assigned to that dock door, as well as all the succeeding outbound trailers, are shifted one dock door to the right. When all doors are assigned once, the next outbound trailer is assigned to the first dock door.

Figure 5 displays our proposed policy. It shows how inbound trailers are always positioned as close as possible to their set of associated outbound trailers. Recall that the retailer's transportation planning logic implies that each inbound trailer contains load-carriers for a set of outbound trailers with consecutive departure times. The proposed dock door assignment policy exploits this transportation planning logic. For example, in Figure 5, the first inbound trailer from NDC_B contains load-carriers for the first 10 departing outbound trailers. This inbound trailer is assigned to dock door no. 7. Note that each outbound trailer contains load-carriers from one NDC_A and one NDC_B inbound trailer. A comparison of the proposed policy (Figure 5) and the retailer's current policy (Figure 4) indicates the material handling improvement potential. In the retailer's current policy, inbound trailers are assigned to one of the dedicated inbound doors, that is, door no. 14 through 18. As a result, the distance a

Figure 5: The new dock door assignment policy.

load-carrier travels from inbound to outbound dock door varies from 1 to 17 doors. That is, if the inbound trailer of a load-carrier is assigned to door no. 18 and its outbound trailer is assigned to door no. 19, it has to travel only one door. When its outbound is assigned to door no. 1, however, it has to travel 17 doors.

Relocating preparatory cross-docking activities

The second experimental factor includes a minor re-design of the retailer's distribution network. In cross-docking literature, strategic and tactical distribution network decision making usually involves determining the optimal number and locations of cross-docks in the distribution network (e.g., Gümüş and Bookbinder 2004) or allocating freight flows to facilities in the network (e.g., Musa et al. 2010). Such optimization approaches are typically aimed at optimizing delivery service levels and cost-effectiveness of transportation. Yan and Tang (2009) and Tang and Yan (2010) reveal that also less substantial changes in the distribution network design can have a large impact on cross-docking performance. Their models support logistics managers in the strategic decision where to label products, that is, at the cross-dock or upstream in the distribution network. The labeling activity marks the point at which interchangeable products are allocated to a specific customer—and hence are no longer interchangeable. Labeling at the cross-dock is advantageous as the postponed allocation of products to customers enhances the ability to respond to last-minute changes in customer demand. They show how this network level benefit results in increased operational costs at the cross-dock.

This paper addresses two other preparatory cross-docking operations: clustering and sorting. Clustering is the process of grouping loads that are bound for the same retail store; sorting arranges clusters of loads according to the due dates of their corresponding outbound trailers. Sorting and clustering can be performed either at the cross-dock (i.e., upon unloading inbound trailers) or at another facility upstream in the distribution network. By performing preparatory cross-docking activities upstream, the inbound trailer loads are readily configured according to the operations at the cross-dock upon arrival. This approach is analogous to the sequenced-part-delivery as commonly applied in the automotive industry (Ding and Sun 2004). Figure 6 illustrates the changes at the inbound staging areas

when the clustering and sorting activities are relocated to an upstream facility, that is, to the retailer's NDCs.

The left hand side of Figure 6 depicts the current situation. Inbound trailers at the cross-dock always contain load-carriers destined for those outbound trailers with the most proximate departure time. The arrangement of load-carriers inside inbound trailers is random, however. Upon unloading, the load-carriers bound for the same retail store are clustered at the inbound staging area. As a result of the complexity of typical inbound trailer loads and the lack of space available at the cross-dock's inbound staging areas, material handlers are not able to sort clusters of load-carriers. Since pallet jacks require considerable maneuvering space to collect a batch of load-carriers, the material handlers work through the queue of clustered load-carriers according to a first come first serve policy. Consequently, movements are performed in an arbitrary sequence that could cause load-carriers with the most proximate due-date to be moved last. The right hand side of Figure 6 depicts the new situation. In this situation, clustering has no longer to be performed locally. More importantly, sorted inbound trailer loads enable material handlers to always unload and handle those load-carriers with the most proximate due date first. As will be explained in detail in the Results section, sorted trailer loads considerably reduce the variability of internal cross-dock operations, which renders the opportunity to postpone inbound trailer arrivals and enhance the just-in-time supply of the cross-dock.

Simulation model

Siemens' software package "Tecnomatix Plant Simulation" is used to develop the simulation model and analyze four scenarios. Scenario A1 represents the retailer's current cross-docking operations and serves as a baseline for the other scenarios. Scenario A2 introduces the new dock door assignment policy. Scenario A3 situates where preparatory cross-dock activities are performed upstream in the distribution network and inbound trailer arrival times are postponed. Scenario A4 combines the changes proposed in Scenarios A2 and A3. Figure 7 shows an overview of the simulation model developed to investigate the scenarios.

The simulation model consists of four modules. Module 1 prepares the simulation run by drawing a sample from the retail

Figure 6: Changes at the inbound staging area due to proposed distribution network re-design.

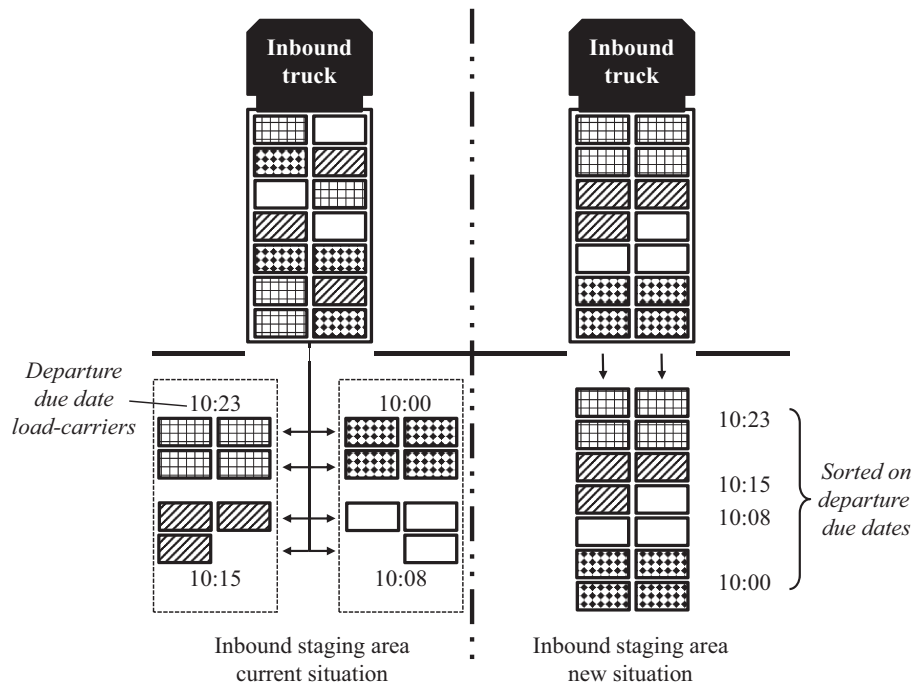
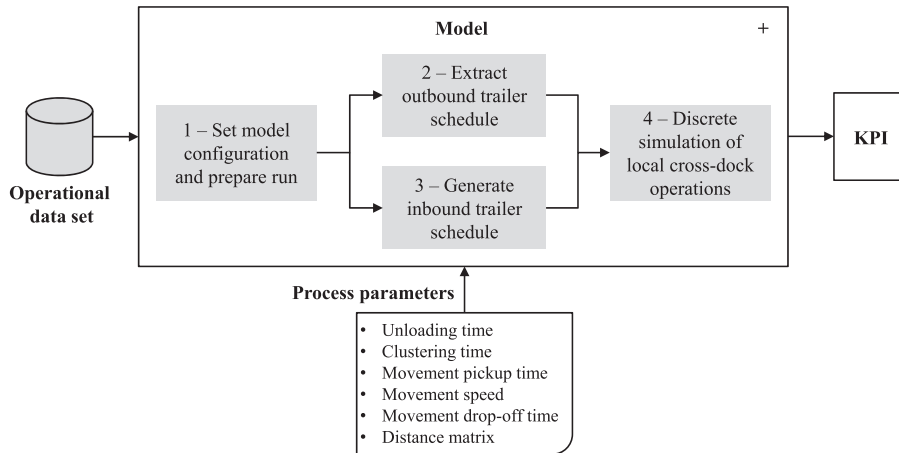


Figure 7: An overview of the simulation model.



store demand distribution and configuring the experimental factors according to the scenario under study. Module 2 extracts outbound trailer departure times from the operational data set. Module 3 applies the retailer’s current transportation planning logic to generate an inbound trailer schedule (i.e., setting inbound trailer load compositions and arrival times at the cross-dock) based on the sample retail store demand. Module 4 comprises the discrete simulation model for the cross-dock operations as described in the conceptual model (Table 2 and Figure A1). The retail store demand volumes and trailer schedules determined by the first three modules are used as input.

Each simulation run simulates a full week of operations. The beginning of the week (i.e., Monday) is set as starting point of the simulation. At that time, the real-world system is empty. At

the end of each day, the system is empty again. Given the large variation in freight flows through the cross-dock from day to day, the natural end point of the simulation run is at the end of the week (i.e., Sunday). Due to the stochasticity in the real-world system not every week of cross-dock operations is the same. In order to account for this stochasticity, multiple runs of the simulation model are needed to generate output data which can be statistically analyzed (Evers and Wan 2012). The retailer provided us with 40 weeks of operational data, including individual retail store demand volumes. We fitted these data into a probability distribution for retail store demand volumes. At the start of each simulation run, the model draws a sample week from this distribution, which is representative for the real-world variability. Pilot tests, for which we applied the confidence

interval method at a significance level of 5% (Robinson 2004), showed that 60 runs were required for each scenario. Since the real-world system starts and ends empty every day, a warm-up period for the simulation is not required (Robinson 2004). Further details about the simulation model and its inputs are provided in the Online Supplement.

Performance measures

One of our research objectives is to propose performance measures that can reflect system-wide changes in cross-docking performance. To that end, we selected performance measures from prior academic cross-docking studies (Boysen and Fliedner 2010) and complemented them with flow-oriented performance measures based on just-in-time theory (Hopp and Spearman 2011). As a result, the output of the simulation

model contains values for eight key performance indicators (KPIs), separated in three types: general cross-dock, material handling, and just-in-time (see Table 3 and Figure 8). All KPIs are measured at the load-carrier level. The set of KPIs was validated by means of expert interviews with the retailer’s logistics managers. A more detailed description of the KPI is provided in the Online Supplement.

At the cross-dock level, the retailer’s main performance objective is to limit the “number of load-carriers on-site” in order to avoid congestion and unsafe labor conditions. Another important performance objective is workforce efficiency. In this study, workforce efficiency is measured by means of the “travel distance” and “movement time” of load-carriers from inbound to outbound dock doors. At a network level, the service level of retail store deliveries is the main performance objective. This service level refers to the extent to which a

Table 3: Overview of the local cross-dock KPI adopted in this study

Type	KPI	Description	Measures (unit)	
General cross-dock	G-1	Number of load-carriers on-site	Number of load-carriers on-site during operations	μ and max (load-carriers)
	G-2	Number of unprocessed load-carriers on-site	Number of load-carriers on site that is not yet moved to their outbound door	μ and max (load-carriers)
	G-3	Load-carrier lifespan	Total time that the load-carrier spend on-site (departure time minus arrival time)	μ and σ (sec)
	G-4	Percentage of un-movable load-carriers	Percentage of the total cross-dock volume that cannot be directly moved to its destination as its outbound dock is still occupied	μ and σ (percentage of total cross-dock throughput)
Material handling	MH-1	Load-carrier internal travel distance	Distance traveled by a load-carrier from inbound to outbound door	μ and σ (meters)
	MH-2	Load-carrier movement time	Time needed to pickup, move, and drop-off a load-carrier	μ and σ (sec)
Just-in-time	JIT-1	Load-carrier waiting time	Time between the arrival of a load-carrier at inbound staging area and its pickup	μ and σ (sec)
	JIT-2	Load-carrier slack	Time between load-carrier drop-off at outbound staging area and its scheduled loading time	μ and σ (sec)

Figure 8: The relation between the different KPIs considered in this study.

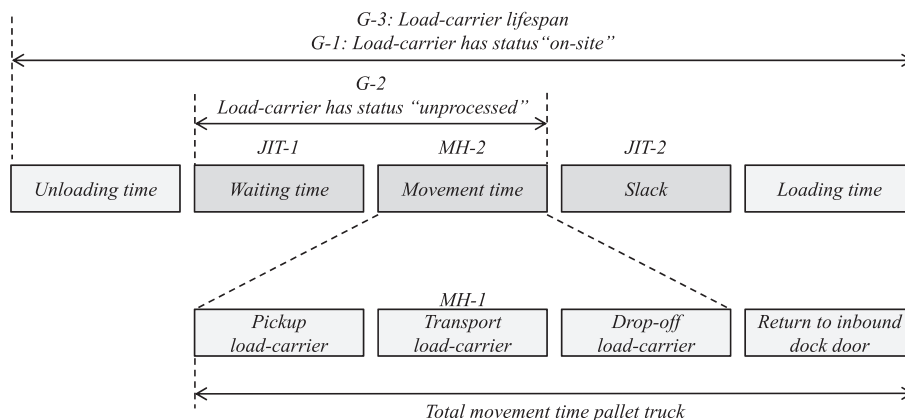


Table 4: Overview of KPI values for Scenario A1

	G-1 Load-carriers (LCs) on-site		G-2 Unprocessed LCs on-site		G-3 Lifespan		G-4 Unmovable LCs		MH-1 Travel distance		MH-2 Movement time		JIT-1 Waiting time		JIT-2 Slack	
A1	μ	275	μ	41	μ	9,568	μ	0.56%	μ	54.9	μ	97	μ	778	μ	5,770
	max	703	max	258	σ	1,829	σ	0.56%	σ	0.51	σ	15	σ	542	σ	1,943

retail store receives all its ordered products within the agreed period of time. At the cross-dock, this implies that each outbound trailer should leave the cross-dock on-time, while loaded with all the ordered load-carriers. Accordingly, we measure delivery service levels at the cross-dock level by means of “load-carrier slack” at the outbound staging area. A negative slack value indicates that a load-carrier has missed its trailer departure. Another important network performance objective is the cost-effectiveness of transportation. Since it is not affected by the changes proposed in this study, however, we do not include a transportation performance measure. The proposed just-in-time performance measures were not used by the retailer prior to this study.

Insights from the simulation outputs are drawn by analyzing KPI changes from one scenario to another. Changes in KPIs for each scenario are statistically tested using a one-way analysis of variance (ANOVA) or Welch ANOVA, both at a 0.05 significance level, depending on the equality of variances. Boxplot inspections revealed no outliers in the data. Normality of the output data-series is assessed by visual inspection of Normal Q-Q Plots. Some of the data-series show skewness or positive kurtosis. Given the fact that the one-way ANOVA is fairly robust to deviations from normality, particularly under equal sample sizes, the ANOVA tests were applied anyway (Lix et al. 1996). In the case of significant KPI changes, a Games-Howell or Tukey HSD post hoc test is performed to identify a significant change in means between individual scenarios. Finally, effect sizes are calculated using Cohen’s *d*, indicating the standardized difference between the two means. All test values can be found in the Online Supplement.

SIMULATION RESULTS

This section starts with an overview of the KPI baseline values in Table 4. Subsequently, we discuss the results of the experimental factors. We limit that discussion to the KPIs showing a considerable change from one scenario to another, that is, >2% or percentage point (pp).

New dock door assignment policy

Table 5 shows that the new dock door assignment policy (Scenario A2) reduces the internal travel distance by 43.5% and movement time by 16.4% on average. The reason that these reductions are not proportional is that the new policy only affects travel distances; whereas the time to move a load-carrier through the cross-dock also includes other material handling activities.

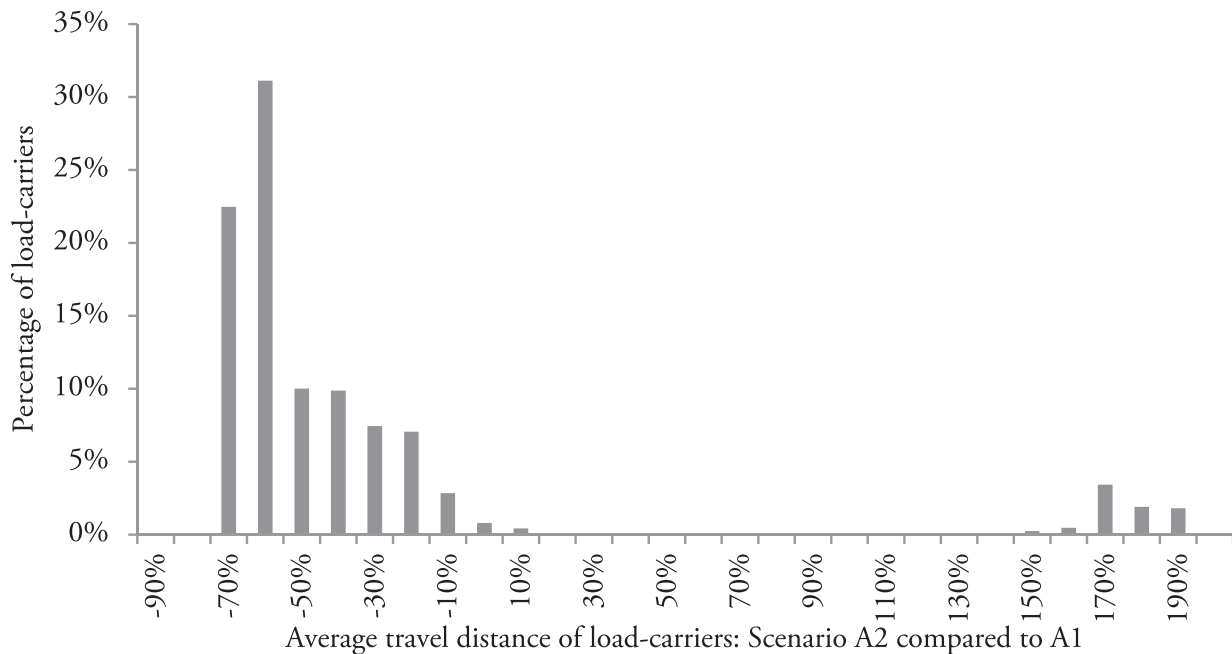
Table 5: Comparison of Scenarios A2 and A1

	G-4 Unmovable LCs		MH-1 Travel distance		MH-2 Movement time		JIT-1 Waiting time	
A2 ↔ A1	Δ	+12.0pp	$\Delta\mu$	-43.5%	$\Delta\mu$	-16.4%	$\Delta\mu$	-3.1%
					$\Delta\sigma$	+58.3%	$\Delta\sigma$	+14.5%

Figure 9 details the travel distance reductions in a histogram. It shows that the new dock door assignment policy results in large travel distance reductions for most movements. Some movements suffer from a considerable increase in travel distance, however, which is inherent to the new policy. When the policy has reached the last dock door at the cross-dock, a new cycle is started. An inbound trailer that is assigned in a new cycle often contains some load-carriers that are bound for outbound trailers from the previous cycle, that is, with a dock door at the other end of the cross-dock. Those load carriers have to be moved almost the maximum distance. This also explains the increased standard deviation for movement time in Scenario A2, that is, $\Delta\sigma = +58.3\%$. The coefficients of variation for the movement time in Scenarios A1 and A2 show that its variability almost doubles, that is, from 0.15 in Scenario A1 to 0.29 in Scenario A2.

A negative effect of the new dock door assignment policy is the considerable increase in unmovable load-carriers, that is, from 0.5% of the throughput to 12.5%. This increase can be explained by the changed service mode for dock doors. The current dock door assignment policy adheres to an exclusive service mode, that is, with dedicated inbound dock doors. Therefore, an arriving inbound trailer can be docked when the preceding inbound trailer at that dock has been unloaded and the inbound staging area has been cleared. On average, this takes 1 hr. In the new policy, there are no dedicated inbound doors. All dock doors are assigned in cycles and a door can only be assigned to an inbound trailer once per cycle. The average cycle time after implementing the new dock door assignment policy is 3:08 hr. Hence, the inbound dock door utilization ratio drops considerably. As a consequence of the reduced inbound dock door utilization ratio, the overall utilization of dock door is reduced as well. Comparing the current and new dock door assignment policies, the average interdeparture time of outbound trailers—and hence the time available for assembling an outbound trailer load—is reduced from 3:21 to 3:08 hr. This results in an increased number of load-carriers that cannot be moved to their outbound dock directly after unloading as the previous outbound truck has not departed yet.

Nonetheless, the new dock door assignment policy results in a travel distance reduction of the pallet trucks in the cross-dock

Figure 9: Histogram of the travel distance reduction per movement.

with 137 kilometers each week on average. It is interesting to note that the new policy results in even greater travel distance reductions when the total retail store demand volume is relatively high. This can be explained by the fact that inbound trailers are assigned to a dock door in the middle of the set of its associated outbound trailers. When retail store demand is high, these inbound trailers contain load-carriers for less outbound trailers. In weeks with a 15% above-average total demand, this essentially eliminates the two farthestmost doors from each set of outbound trailers associated with an inbound trailer, which considerably reduces travel distance. Under the retailer's current dock door assignment policy, higher demand simply adds another cycle of outbound trailer assignments with a similar average travel distance. In weeks with little retail store demand, the new policy performs slightly below the reported average travel distance reduction—albeit still 40% better than the retailer's current policy.

A discussion of the simulation results with the cross-dock managers revealed two additional benefits that are not directly observable from the simulation outputs. First, the congestion of material handling equipment inside the RDC (including the equipment dedicated to the warehousing functions) can be reduced due to the fact that cross-docking freight flows are concentrated to one particular area of the cross-dock at a time. Second, for similar reasons, the safety for material handlers is improved.

Relocation of preparatory cross-docking activities

Supplying the cross-dock with sorted and clustered inbound loads has two effects on operations at the cross-dock. First, the time to unload inbound trailers is reduced as clustering is no longer performed at the cross-dock. This leads to an average

local time-saving of 8 min per inbound trailer. In the new situation, the clustering of load-carriers is performed at the NDC. Although a thorough analysis of the required re-design of NDC operations lies beyond the scope of this study, discussions with the retailer's distribution network managers suggest that the additional time needed to perform the sorting and clustering activities at the NDC is equal to the 8 min saved at the cross-dock at most. Indeed, the managers anticipate that performing those activities closer to the place where the load-carriers are order-picked is more efficient.

Second, the arrival of sorted inbound loads enables the material handlers at the cross-dock to always move the load-carriers with the most proximate outbound departure time first. This results in more stable and predictable cross-docking operations. Accordingly, the standard deviation of the load-carriers' slack at the outbound staging area will be reduced considerably. Recall that this local performance indicator reflects the service level of retail store deliveries. Figure 10 plots the slack of load-carriers for the current situation (A1) and the situation with sorted and clustered inbound loads (A1+ clustered and sorted trailers). In both situations, load-carrier slack fits a normal distribution (Anderson-Darlings test of normality at $p < .01$). The reduced standard deviation renders the opportunity to postpone inbound trailer arrival with almost 14 min, without increasing the probability of load-carriers missing their connection in comparison with the current situation, that is, practically zero.

Due to the combined positive effects of relocating the preparatory cross-docking activities to a facility upstream in the distribution network, inbound trailer arrivals can be postponed with 22 min in Scenario A3. As a result, load-carriers arrive more just-in-time at the cross-dock, which in turn affects multiple KPIs as shown in Table 6. The average lifespan of load-carriers drops by 14.6% and the average slack by 15.4%. As a result, there are

Figure 10: Distribution of load-carrier slack (JIT-2).

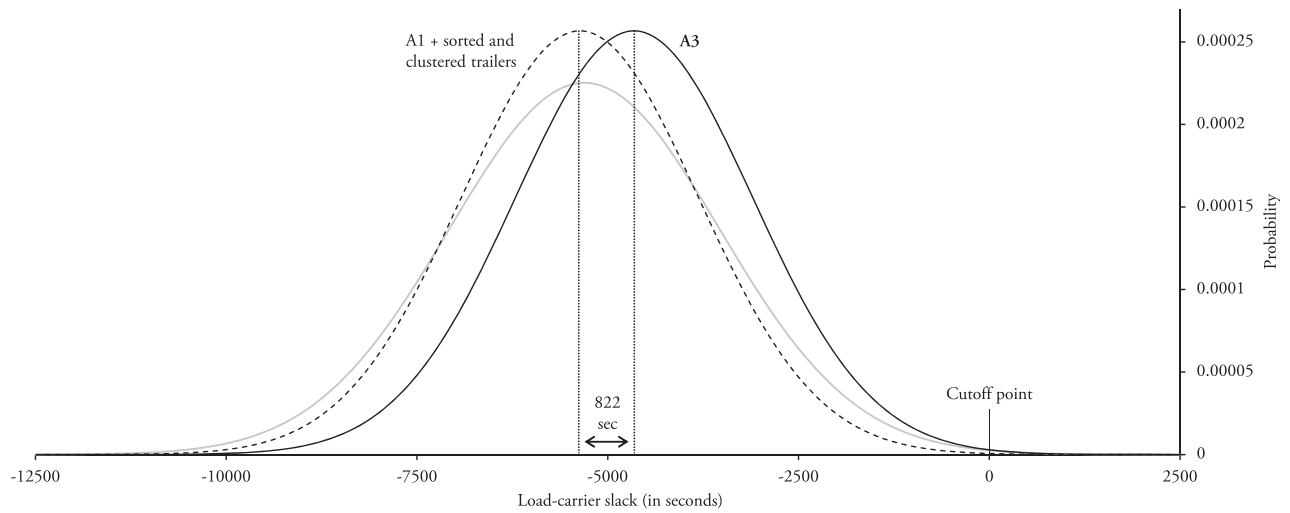


Table 6: Comparison of Scenarios A3 and A1

	G-1 LCs on-site		G-2 Unprocessed LCs on-site		G-3 Lifespan		JIT-1 Waiting time		JIT-2 Slack	
A3 ↔ A1	$\Delta\mu$	-12.9%	$\Delta\mu$	-19.8%	$\Delta\mu$	-14.6%	$\Delta\mu$	-6.7%	$\Delta\mu$	-15.4%
	$\Delta\max$	-9.0%	$\Delta\max$	-8.3%	$\Delta\sigma$	-0.3%*	$\Delta\sigma$	-0.5%*	$\Delta\sigma$	-13.0%

Note: *The mean difference is not significant at the .05 level.

12.9% less load-carriers on-site on average. The shorter unloading processes result in a reduction of the average number of unprocessed load-carriers (work in progress [WIP]) by 19.8%. These KPI improvements translate into an enhanced facility utilization, which postpones the need for large capacity expansion investments.

Applying both changes

Table 7 shows the KPI values when both changes are applied (i.e., Scenario A4). This overview underpins that each change—individually—impacts another set of KPI. Indeed, changes in four KPIs in Scenario A4 can almost be completely attributed to either Scenario A2 or A3 (i.e., G-1, G-3, MH-1, and MH-2).

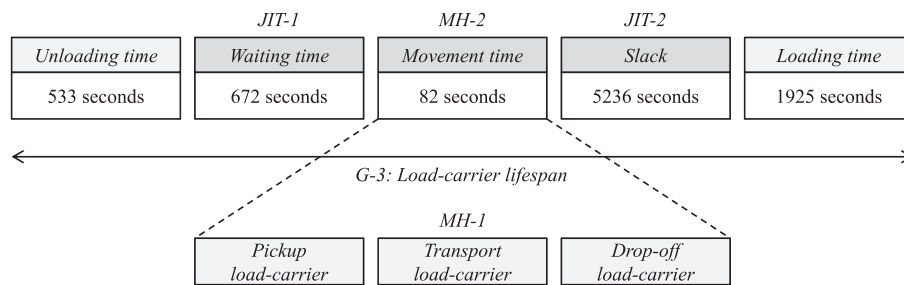
This can be explained by the differences in the targeted performance domains. The new dock door assignment policy (Scenario A2) is aimed at increasing material handling efficiency, which is reflected by improvements in travel distance (MH-1) and movement time (MH-2). The relocation of preparatory cross-docking activities plus the postponed arrival of inbound trailers (Scenario A3) is aimed at improving the predictability and stability of the flow of load-carriers through the cross-dock. As expected, this is reflected by improvements in the number and the lifespan of load-carriers on-site (G-1 and G-3).

The combined effects of both changes provide an even greater improvement to the system-wide cross-docking performance. These synergistic effects are best reflected by the changes in the number of unprocessed and unmovable load-carriers (G-2 and

Table 7: Comparisons of Scenarios A1 through A4

	G-1 LCs on-site		G-2 Unprocessed LCs on-site		G-3 Lifespan		G-4 Unmovable LCs		MH-1 Travel distance		MH-2 Movement time		JIT-1 Waiting time		JIT-2 Slack	
A2 ↔ A1							Δ	+12pp	$\Delta\mu$	-43.5%	$\Delta\mu$	-16.4%	$\Delta\mu$	-3.1%		
											$\Delta\sigma$	+58.3%	$\Delta\sigma$	+14.5%		
A3 ↔ A1	$\Delta\mu$	-12.9%	$\Delta\mu$	-19.8%	$\Delta\mu$	-14.6%	Δ	-0.5pp					$\Delta\mu$	-6.7%	$\Delta\mu$	-15.4%
	$\Delta\max$	-9.0%	$\Delta\max$	-8.3%	$\Delta\sigma$	-0.3%*							$\Delta\sigma$	-0.5%*	$\Delta\sigma$	-13.0%
A4 ↔ A1	$\Delta\mu$	-13.1%	$\Delta\mu$	-29.8%	$\Delta\mu$	-14.6%	Δ	+6.5pp	$\Delta\mu$	-43.3%	$\Delta\mu$	-15.9%	$\Delta\mu$	-20.5%	$\Delta\mu$	-13.1%
	$\Delta\max$	-9.2%	$\Delta\max$	-12.3%	$\Delta\sigma$	-0.1%*					$\Delta\sigma$	+58.8%	$\Delta\sigma$	-10.1%	$\Delta\sigma$	-12.3%

Note: *The mean difference is not significant at the .05 level.

Figure 11: Relations between the time-related KPI values.

G-4) and their waiting time (JIT-1). For example, when applied individually, the new dock door assignment reduces the time that is available for assembling outbound trailer loads, which results in a strong increase in the number of unmovable load-carriers (G-2). This negative effect of the new dock door assignment policy can be mitigated by an enhanced just-in-time arrival of inbound loads, that is, by simultaneously applying Scenario A3. The improvements in the waiting time and the number of unprocessed load-carriers at the inbound staging area (JIT-1 and G-4), as a result of a just-in-time supply of inbound trailers, are amplified by simultaneously introducing the new dock door assignment policy. That is, individually, a just-in-time supply of inbound trailers reduces the average waiting time by 6.7%; the new dock door assignment policy by 3.1%. The synergistic effects of the improved the material handling efficiency (as a result of Scenario A2) and an improved flow of load-carriers through the cross-dock (as a result of Scenario 3) yields a 20.5% reduction in waiting time. As a consequence, also the average and maximum number of unprocessed load-carriers (WIP) is further reduced. Interestingly, the synergistic effects seem to make the waiting time reductions more robust for increased retail store demand volumes. Specifically, in Scenarios A1, A2, and A3, an increase in weekly cross-dock throughput increases the waiting time of load-carriers at the inbound staging area. When both changes are applied simultaneously, however, the waiting time even reduces slightly when the throughput is relatively high.

Last, we analyze the simulation results to put the individual KPIs into a more holistic cross-docking performance context. Figure 11 shows how the lifespan of a load-carrier can be decomposed in individual material handling and just-in-time KPIs—using average values from Scenario A4. Combined, Table 7 and Figure 11 show that the effects of the new dock door assignment on overall cross-docking performance are limited. According to the just-in-time nature of the cross-docking strategy, many KPIs are time related. The reduced internal travel distance as a result of the new dock door assignment, albeit considerable, has little impact on time-related KPIs. Not surprisingly, the time-related KPIs are strongly improved by a more just-in-time arrival of load-carriers at the cross-dock.

CONCLUSIONS AND DISCUSSION

Below, this paper is concluded by listing the practical and theoretical implications that can be derived from our study and by discussing the main limitations.

Practical implications

Overall, our study illustrates the importance of making distribution network decisions and cross-dock operational decisions together to improve system-wide cross-docking performance. First, this paper presents a new dock door assignment policy that exploits the transportation planning logic regarding trailer arrivals at the cross-dock. Our case indicates that a reduction of internal travel distance of over 40% is feasible when applying the proposed policy. Accordingly, the dock door assignment policy results in considerable cost savings, reduced congestion, and improved labor safety. We note that the degree of material handling efficiency improvement may strongly differ from one case to another.

Furthermore, this paper shows how even minor changes in distribution network design can result in considerable system-wide cross-docking performance improvements. We illustrated this by a study to the effects of relocating sorting and clustering activities from the cross-dock to an upstream warehouse facility. Apart from operational benefits at the cross-dock, the relocation of these preparatory cross-docking activities enables the postponement of inbound trailer arrivals at the cross-dock. Consequently, the flow of products through the whole distribution network improves considerably. Specifically, the simulation results indicate a large reduction in the number of unprocessed loads at the cross-dock, a lower average and maximum amount of loads on-site and shorter distribution lead times.

Finally, this paper stresses the importance of adopting performance measures that can reflect changes in cross-docking performance from an overall distribution network perspective. Given the just-in-time nature of cross-docking, improvement efforts should be geared toward the creation of a seamless products flow from the suppliers to the retail stores. We have argued that traditional performance indicators and management approaches in retail distribution are not well-suited to measure the effects of local cross-dock changes on overall distribution network performance. In this article, we propose and use a set of performance measures with a focus on system-wide cross-docking performance and a direct applicability to practice.

Theoretical implications

Our study contributes to systems thinking theory by providing quantitative empirical evidence illustrating the need to adopt a

more holistic view on cross-docking management. Specifically, three important theoretical contributions can be derived from our results.

First, this paper provides a representative case that illustrates how cross-docking operations can be managed more holistically. To that end, we show how opportunities in the design and control of a retail distribution network can be exploited to realize system-wide cross-docking performance improvements. As an example, we propose a policy that carefully considers transportation planning logic in assigning dock doors to inbound and outbound trailers. For our specific case, the proposed dock door assignment policy results in a considerable reduction in the travel distance of material handling equipment through the cross-dock. As another example, we studied the relocation of sorting and clustering activities from the cross-dock to a logistics facility upstream in the distribution network. Relocating these preparatory cross-docking activities reduces the flow variability of inbound trailer loads, which results in more stable and predictable material handling operations at the cross-dock. This renders the opportunity to realize an enhanced just-in-time arrival of inbound trailer loads at the cross-dock—and hence improve the overall flow of goods through the distribution network. When applied together, the relocation of preparatory cross-docking activities and the new dock door assignment policy provide even greater performance improvements.

Second, this paper proposes a set of cross-docking performance measures that can reflect system-wide changes in cross-docking performance. In retail distribution practice and theory, performance measures are often geared toward cost-effectiveness of transportation or material handling efficiency. In our study, we also adopted performance measures from just-in-time theory to better capture changes in the flow of goods through the distribution network. Using this set of performance measures, the simulation results reveal that the inner travel distance reduction associated with the proposed dock door assignment does not translate proportionally into system-wide cross-docking performance. This is due to the fact that inner transport constitutes only a fraction of a product's total distribution lead time. Accordingly, the generally adopted assumption that internal travel distance is a good proxy for overall cross-docking performance is questionable. Rather, it should be considered as one of many performance measures. In contrast, just-in-time related performance measures, such as the distribution lead time and the amount of unprocessed loads at the cross-dock, provide a good indication of cross-dock performance in the context of the entire distribution network.

Third, using the proposed performance measures, our case study confirms that adopting a holistic management approach can indeed improve cross-docking operations. Albeit exploratory, this paper provides quantitative evidence in that regard. In that way, it corroborates and complements the logical arguments and anecdotal evidence from prior supply chain management studies.

Limitations and future research

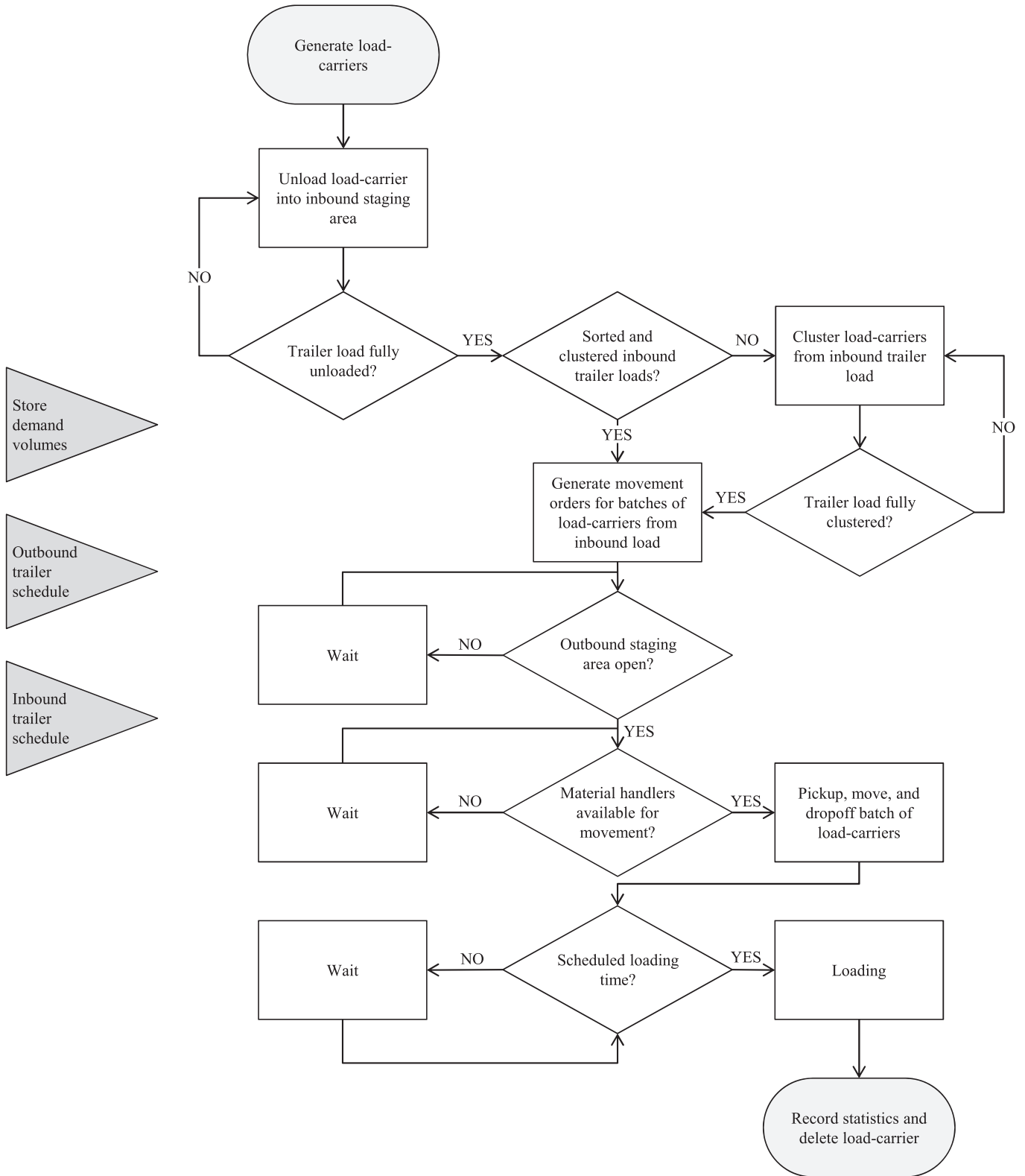
An important limitation of our study resides in the generalizability of the results. Discrete event simulation is known for its inability to solve problems to optimality and the limited generalizability of research findings (Evers and Wan 2012). In addition, the generalizability of our findings is limited by the use of a single case. In the light of these limitations, we revisit the three theoretical implications mentioned above. First, this paper claims to provide a representative case illustrating how cross-docking operations can be managed more holistically. To that end, it presents two specific changes to the cross-docking operations of a large grocery retailer. In future work, the generalizability of these specific changes can be improved by, for example, formalizing the proposed dock door assignment policy into a mathematical model and evaluate its performance against existing policies. Based on the findings in this study, we expect many other possibilities to improve system-wide cross-docking performance by taking a holistic perspective.

Second, the paper proposes a set of cross-docking performance measures that can reflect system-wide changes in cross-docking performance. We do not claim that this particular set could be successfully adopted in any cross-docking context. Rather, we argue that the typical measures used in existing theoretical studies deserve more reflection from a holistic point of view. In future work, network level performance effects should be considered when proposing local cross-dock improvement—and vice versa.

Third, the paper demonstrates that a holistic management approach indeed leads to system-wide cross-docking improvement in one particular case. The generalizability of this finding is limited. However, it does corroborate prior theoretical statements that a holistic approach deserves attention and that local cross-dock optimization has to be scrutinized for its global effects. While acknowledging the limitations, we believe that the results of our study provide sufficient exploratory evidence in generating insights that should be applicable to other cross-docking settings as well—particularly in retail distribution settings.

APPENDIX

Figure A1: Conceptual model: logic flow diagram at the local cross-dock level.



REFERENCES

- Apte, U.M., and Viswanathan, S. 2000. "Effective Cross Docking for Improving Distribution Efficiencies." *International Journal of Logistics Research and Applications* 3(3):291–302.
- Ashmos, D.P., and Huber, G.P. 1987. "The Systems Paradigm in Organization Theory: Correcting the Record and Suggesting the Future." *Academy of Management Review* 12(4):607–21.
- Bartholdi, J.J., and Gue, K.R. 2000. "Reducing Labour Costs in an LTL Crossdocking Terminal." *Operations Research* 48 (6):823–32.
- Bodnar, P., Azadeh, K., and de Koster, R. 2015. "Scheduling Trucks in a Cross-Dock With Mixed Service Mode Dock Doors." *Transportation Science*. <http://pubsonline.informs.org/doi/10.1287/trsc.2015.0612>
- Bourlakis, M.A., and Bourlakis, C.A. 1999. "Deliberate and Emergent Logistics Strategies in Food Retailing: A Case Study of the Greek Multiple Food Retail Sector." *Supply Chain Management: An International Journal* 6(4):189–200.
- Boysen, N., and Fliedner, M. 2010. "Cross Dock Scheduling: Classification, Literature Review and Research Agenda." *Omega* 38(6):413–22.
- Bozer, Y.A., and Carlo, H.J. 2008. "Optimizing Inbound and Outbound Door Assignments in Less-Than-Truckload Crossdocks." *IIE Transactions* 40(11):1007–18.
- Buijs, P., Vis, I.F.A., and Carlo, H.J. 2014. "Synchronization in Cross-Docking Networks: A Research Classification and Framework." *European Journal of Operational Research* 239 (3):593–608.
- Ding, F.-Y., and Sun, H. 2004. "Sequence Alteration and Restoration Related to Sequenced Parts Delivery on an Automobile Mixed-Model Assembly Line With Multiple Departments." *International Journal of Production Research* 42(8):1525–43.
- Eisenhardt, K.M., and Graebner, M.E. 2007. "Theory Building From Cases: Opportunities and Challenges." *Academy of Management Journal* 50(1):25–32.
- Evers, P.T., and Wan, X. 2012. "Systems Analysis Using Simulation." *Journal of Business Logistics* 33(2):80–89.
- Forger, G. 1995. "UPS Starts World's Premiere Cross-Docking Operations." *Modern Materials Handling* 36(8):36–38.
- Gue, K.R. 1999. "The Effects of Trailer Scheduling on the Layout of Freight Terminals." *Transportation Science* 33 (4):419–28.
- Gümüs, M., and Bookbinder, J.H. 2004. "Cross-Docking and Its Implication in Location-Distribution Systems." *Journal of Business Logistics* 25(2):199–228.
- Hopp, W.J., and Spearman, M.L. 2011. *Factory Physics*. 3rd ed. Long Grove, IL: Waveland Press Inc.
- Law, A.M., and Kelton, W.D. 2000. *Simulation Modeling and Analysis*. Boston, MA: McGraw Hill.
- Lix, L.M., Keselman, J.C., and Keselman, H.J. 1996. "Consequences of Assumption Violations Revisited: A Quantitative Review of Alternatives to the One-Way Analysis of Variance F Test." *Review of Educational Research* 66 (4):579–619.
- McWilliams, D.L., Stanfield, P.M., and Geiger, C.D. 2005. "The Parcel Hub Scheduling Problem: A Simulation-Based Solution Approach." *Computers & Industrial Engineering* 49 (3):393–412.
- Musa, R., Arnaout, J.-P., and Jung, H. 2010. "Ant Colony Optimization Algorithm to Solve for the Transportation Problem of Cross-Docking Network." *Computers & Industrial Engineering* 59(1):85–92.
- Napolitano, M. 2000. *Making the Move to Cross Docking – A Practical Guide to Planning, Designing, and Implementing a Cross Dock Operation*. Oak Brook, IL: Warehousing Education and Research Council (WERC).
- Robinson, S. 2004. *Simulation: The Practice of Model Development and Use*. Chichester, UK: John Wiley & Sons.
- Saddle Creek Logistics Services. 2011. "2011 Cross-Docking Trends Report." <http://www.sclogistics.com/news-resources/white-papers>
- Stalk, G., Evens, P., and Shulman, L.E. 1992. "Competing on Capabilities: The New Role of Corporate Strategy." *Harvard Business Review* 70(2):57–69.
- Stephan, K., and Boysen, N. 2011. "Vis-à-vis vs. Mixed Dock Door Assignment: A Comparison of Different Cross Dock Layouts." *Operations Management Research* 4(3–4):150–63.
- Tang, S.-L., and Yan, H. 2010. "Pre-Distribution vs. Post-Distribution for Cross-Docking With Transshipments." *Omega* 38(3):192–202.
- Tsui, L.Y., and Chang, C.H. 1990. "A Microcomputer Based Decision Support Tool for Assigning Dock Doors in Freight Yards." *Computers & Industrial Engineering* 19 (1):309–12.
- Tsui, L.Y., and Chang, C.H. 1992. "An Optimal Solution to a Dock Door Assignment Problem." *Computers & Industrial Engineering* 23(1):283–86.
- Van Belle, J., Valckenaers, P., and Cattrysse, D. 2012. "Cross-Docking: State of the Art." *Omega* 40(6):827–46.
- Vogt, J.J. 2010. "The Successful Cross-Dock Based Supply Chain." *Journal of Business Logistics* 31(1):99–119.
- Wang, J., and Regan, A. 2008. "Real-Time Trailer Scheduling for Crossdock Operations." *Transportation Journal* 47(2):2–20.
- Witt, C.E. 1998. "Crossdocking: Concepts Demand Choice." *Material Handling Engineering* 53(7):44–49.
- Yan, H., and Tang, S.-L. 2009. "Pre-Distribution and Post-Distribution Cross-Docking Operations." *Transportation Research Part E: Logistics and Transportation Review* 45 (6):843–59.
- Yang, K.K., Balakrishnan, J., and Cheng, C.H. 2010. "An Analysis of Factors Affecting Cross-Docking Operations." *Journal of Business Logistics* 31(1):121–48.
- Yin, R.K. 1994. *Case Study Research: Design and Methods*. 2nd ed. Newbury Park, CA: Sage.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

Data S1. Simulation model and statistical test results.

SHORT BIOGRAPHIES

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