Synchronization in cross-docking networks: A research classification and framework

Paul Buijs\textsuperscript{a},*, Iris F.A. Vis\textsuperscript{a}, Héctor J. Carlo\textsuperscript{b}

\textsuperscript{a} University of Groningen, Faculty of Economics and Business, Department of Operations, P.O. Box 800, 9700 AV Groningen, The Netherlands

\textsuperscript{b} Industrial Engineering Department, University of Puerto Rico, Mayagüez, Call Box 9000, Mayagüez, PR 00681, Puerto Rico

\textbf{Abstract.} Cross-docking is a distribution strategy that enables the consolidation of less-than-truckload shipments into full truckloads without long-term storage. Due to the absence of a storage buffer inside a cross-dock, local and network-wide cross-docking operations need to be carefully synchronized. This paper proposes a framework specifying the interdependencies between different cross-docking problem aspects with the aim to support future research in developing decision models with practical and scientific relevance. The paper also presents a new general classification scheme for cross-docking research based on the inputs and outputs for each problem aspect. After classifying the existing cross-docking research, we conclude that the overwhelming majority of papers fail to consider the synchronization of local and network-wide cross-docking operations. Lastly, to highlight the importance of synchronization in cross-docking networks, two real-life illustrative problems are described that are not yet addressed in the literature.

\textit{Keywords:} transportation; cross-dock; cross-docking network; synchronization; literature review

\textsuperscript{*}Corresponding author. Tel: +31 6 430 58 555

\textit{Email address:} p.buijs@rug.nl
1. Introduction

Four commonly used strategies to configure a firm’s distribution activities are direct shipment, milk-runs, warehousing, and cross-docking. In a direct shipment strategy, each shipment is sent directly from origin to destination. A milk-run strategy groups shipments into routes visiting multiple origins and destinations sequentially. These two strategies are associated with low implementation costs as they do not involve intermediary logistics facilities. When shipment sizes are small and customers are geographically dispersed, a direct shipment or milk-run strategy results in partially empty trucks and longer transportation lead times as products are stored further away from their demand points. In response to these shortcomings, firms can employ a warehousing or cross-docking distribution strategy.

Warehousing enables the consolidation of shipments to customers by assembling full truckloads from the products stored in a warehouse or distribution center. Storage can be efficiently replenished by ordering full truckloads from suppliers. At the warehouse, the main operations are to unload inbound trailers with products from suppliers, store the products, retrieve products and assemble them for shipment upon customer order, and dispatch the consolidated loads onto outbound trailers (Gu et al., 2007). The existence of a storage buffer allows local warehouse operations to be considered largely in isolation from activities elsewhere in the distribution network. Hence, warehousing literature primarily addresses local warehouse problems (see, e.g., De Koster et al., 2007; Gu et al., 2007; 2010; Rouwenhorst et al., 2000).

Instead of moving partially empty trailers or assembling loads from storage, a cross-docking strategy groups shipments from multiple adjacent origins into full truckloads, which are then sent to a cross-dock where they are unloaded and immediately recombined with loads sharing the same destination (Bozer and Carlo, 2008). As a result, cross-docking can realize transport efficiencies at reduced material handling and storage costs by eliminating the storage and order picking activities from the main warehouse operations (Apte and Viswanathan, 2000; Gue, 2007). An important implication of employing a cross-docking strategy is that local operations at the cross-dock are tightly coupled with distribution activities elsewhere in the supply chain due to the absence of a storage buffer (Vogt, 2010). Therefore, the design and coordination of cross-docking operations requires a holistic approach, which aims to synchronize local and network-wide operations.
Decision models for the design and coordination of cross-docking operations are proposed in a considerable and fast-growing base of literature. Four recently published papers review this literature. Boysen and Fliedner (2010) focus on one important cross-docking problem, i.e., the scheduling of trailers at the cross-dock. Agustina et al. (2010), Stephan and Boysen (2011a) and Van Belle et al. (2012) present broader literature reviews. In these reviews, cross-docking literature is discussed by considering groups of papers addressing a similar decision problem – ranging from strategic design to operational planning. Despite the inherent interdependencies between local and network-wide cross-docking operations, none of the existing review papers discusses how different decision problems are actually related. The primary objective of this paper is to fill that gap and advance from an understanding of solving isolated problems to an appreciation of the challenges inherent to solving cross-docking synchronization problems. To that end, this paper presents a framework for synchronization in cross-docking networks, which is based on a general classification of cross-docking research.

This paper is organized as follows. Section 2 presents our conceptualization of cross-docking. Section 3 defines six cross-docking problem classes and lists their constituent decision problems. A review and classification of cross-docking research is presented in Section 4. The research classification is used to understand the information needs for, and outputs from, each problem class. Based on this understanding, the framework for synchronization in cross-docking networks is proposed in Section 5. Section 6 demonstrates how the research classification and framework can be used to identify cross-docking synchronization problems with practical and scientific relevance. Lastly, Section 7 presents our conclusions.

2. Conceptualization

Many different definitions of cross-docking can be found in literature. A review thereof reveals three common defining elements. Firstly, cross-docking definitions often contain a description of the basic operations performed at the cross-dock. In essence, incoming products are unloaded from inbound trucks, sorted based on their destination, moved through the cross-dock, and immediately dispatched onto outbound trucks. Secondly, most cross-docking definitions include a specification of the typical constraints and objectives associated with operations at the cross-dock. The most typical constraint in that regard is the limited time products stay inside the cross-dock, e.g., 24 hours. The aim for minimal material handling and the intention to limit the waiting times or tardiness of trailers and products at the cross-dock are frequently mentioned objectives.
Thirdly, several cross-docking definitions address the purpose of a cross-dock in the distribution network. An important purpose of a cross-dock is to enable the consolidation of multiple less-than-truckload shipments to realize economies in transportation costs. At the same time, the rapid transshipment of products at the cross-dock should enhance distribution responsiveness.

In this paper, we emphasize the importance of including a broader network orientation when defining and conceptualizing cross-docking. Accordingly, our conceptualization of cross-docking considers local and network-wide cross-docking operations. *Local cross-dock operations* are conceptualized as the operations performed at the cross-dock; *network-wide cross-docking operations* as those performed elsewhere in the cross-docking network. We define a cross-docking network as the subsystem of a supply chain formed by one or more cross-docks, their inbound and outbound transport routes, and the stakeholders connected to the cross-docks by means of those routes. Various logistics facilities are identified as potential stakeholders in cross-docking networks. These logistics facilities include the typical supply chain entities (e.g., suppliers, manufacturers, warehouses, distribution centers, retailers, and customers) and can be located at the inbound and outbound side of the cross-dock. Below, we present a characterization for different cross-docking network configurations and address some industry specific implementations of cross-docking. For a comprehensive industry-oriented introduction to cross-docking, the reader is referred to Napolitano (2000).

Figure 1 presents three typical configurations for cross-docking networks with a single cross-dock. Cross-docks in a *many-to-few network configuration* are often encountered in a manufacturing context, e.g., the automotive industry. Raw materials and components from many suppliers are consolidated at the cross-dock and sent to one of few nearby located manufacturing plants. The main purpose of the cross-dock in this setting is to enable a just-in-time supply of readily usable materials to the manufacturer. Accordingly, value added logistics activities are often performed at the cross-dock in preparation of the manufacturing operations. Due to the importance of cross-docks in these supply networks, manufacturers often invest in the automation of local cross-dock operations.
A few-to-many network configuration is common for cross-docks in retail distribution. At the cross-dock, incoming truckloads from a few distribution centers are split into delivery loads for a large number of retail stores. The cross-docking strategy of retailers usually originated from opportunistic cross-docking, i.e., products bypassed the storage facilities at distribution centers only if the opportunity occurred. Many retailers have developed their opportunistic cross-docking into a strategy purposely processing large cross-docking freight flows, which are handled at a dedicated cross-dock area inside a distribution center. Operations at retail cross-docks are fully geared towards a reduction of inventory and distribution costs – while maintaining or improving responsiveness. The material handling systems inside retail cross-docks often allow for in-batch movement of shipments, since products are placed onto homogeneous load-carriers, e.g., rolling containers. A many-to-many network configuration is common for cross-docks in the less-than-truckload and parcel delivery industries. Parcel delivery companies transport many relatively small-sized packages, which allows an automated conveyor system for material handling inside the cross-dock. By contrast, the larger sized and strongly varying shapes of products through the cross-docks of less-than-truckload carriers necessitate a flexible material handling system – typically formed by manually operated forklift trucks.

Figure 2 shows two prototypical network configurations including multiple cross-docks. In cross-docking networks with a single layer of cross-docks, shipments are often allocated to one of the cross-docks. Moreover, opportunities can be sought to transport the shipment directly from origin to destination, i.e., bypassing all cross-docks in the network. Variants of this network configuration are often employed in the supply chains of large retailers and manufacturers. Another well-known network configuration with multiple cross-docks is the hub-and-spoke system. In this configuration, shipments can be allocated to multiple cross-docks in succession. Hub-and-spoke networks are often employed by less-than-truckload carriers or parcel delivery companies.
In this paper, we conceptualize synchronization in cross-docking networks as the coordination of local and network-wide operations while acknowledging their strong interdependency. That is, addressing the tight coupling of inbound transportation, local cross-dock operations, and outbound transportation that exists as a result of the absence of a storage buffer inside the cross-dock. In the subsequent sections, this paper builds towards specific suggestions for future research to take these interdependencies into account when developing cross-docking decision models.

3. Cross-docking problem class definitions

This paper is the first to identify and define 24 individual decision problems, which, collectively, reflect the full scope of cross-docking design and coordination. We identified the decision problems by first deriving all decision variables from the models proposed in the journal papers reviewed in this research. Next, a set of distinct decision problems was developed by analyzing whether variables address a similar decision. Finally, we compared the complete set of decision problems with our observations in practice. The decision problems that were observed in practice, but not reflected by a decision variable in cross-docking literature, were formulated based on a review of related research areas, such as warehouse design (De Koster et al., 2007; Gu et al., 2010), warehouse operations and control (Gu et al., 2007; Rouwenhorst et al., 2000), distribution network design (Alumur and Kara, 2008; Melo et al., 2009), and distribution network planning (Crainic, 2000).
The individual decision problems originate either locally at the cross-dock or elsewhere in the cross-docking network. Local and network-wide decision problems can be further distinguished by their decision making level, i.e., strategic, tactical, or operational. We used these distinguishing factors to cluster the individual decision problems into six problem classes as presented in Figure 3. The cross-docking problem classes are described below and defined by their constituent individual decision problem – as summarized in Table 1. References to studies in each problem class are discussed in Section 4.

**Cross-dock design:** Cross-dock design decisions specify the contour of the cross-dock and determine the configuration of its interior. The main aims are to enable rapid transshipment and provide sufficient capacity to meet freight throughput requirements. An important design decision determines the appropriate number of dock doors. *Strip doors* (or inbound doors) are used for unloading arriving trailers; whereas *stack doors* (or outbound doors) are used for loading departing trailers. A typical cross-dock design places dock doors closely together around the perimeter of the facility. Therefore, the shape of the cross-dock dictates the relative distances among dock doors, and hence influences the efficiency at which shipments can be moved from strip to stack doors.

The capacity and efficiency of the cross-dock is also determined by the configuration of the area inside the cross-dock. Usually, not all inbound shipments can be directly reloaded onto an outbound trailer. Inside the terminal, most cross-docks consist of an open area where
shipments can be sorted and temporarily placed on the ground to facilitate consolidation activities. This area is referred to as the staging area. A typical staging area design enables the temporarily stored shipments to be easily accessed and ensures fast movement of those shipments to their outbound trailers. The automation level of the material handling equipment is another important internal cross-dock design aspect.

**Cross-dock planning:** Cross-dock planning decisions address the movement of freight through the cross-dock on the medium-term. A typical objective used by cross-dock managers is to minimize the material handling effort required for moving incoming freight from strip to stack doors. The decision specifying dock doors as either strip or stack door dictates the aggregated freight flows through the cross-dock. More precise freight flows are determined by the dock door assignment, i.e., demining at which dock door a trailer is served. Cross-docks serving a fixed set of origins and destinations with relatively constant freight flows tend to assign dock doors over a planning horizon of 3 to 6 months. In situations with volatile freight flows, stack doors are sometimes assigned from night to night. A more dynamic assignment of docks doors requires contemporary information technology (e.g., RFID) supporting the material handlers in locating the stack doors associated with shipments.

Another important cross-dock planning decision is concerned with determining the appropriate workforce and material handling equipment to efficiently handle all freight within the limited time available. Cross-dock operations start and terminate with little or no shipments in the staging area and usually take place during a part of the day, e.g., overnight.

**Cross-dock scheduling:** Cross-dock scheduling decisions specify the allocation of resources at the cross-dock over time. Scheduling decisions for serving individual trailers at the cross-dock are aimed at facilitating a smooth flow of freight from the strip to the stack doors. As opposed to the assignment of dock doors, trailer scheduling decisions consider highly capacity constraint dock doors, i.e., the number of trailers to be served far exceeds the number of available dock doors. Accordingly, detailed timing and sequencing aspects are taken into account in order to minimize the waiting times of shipments and trailers on-site. Trailer schedules can be completed before the start of operations or developed dynamically during ongoing operations, which is referred to as offline or online trailer scheduling, respectively. In order to align the inbound and outbound activities at the cross-dock, the internal workforce that unloads and reloads trailers and moves freight through the cross-dock has to be scheduled as well.
The utilization of the staging areas (i.e., how shipments are placed in the staging area) influences the total travel distance of the material handling equipment and determines the accessibility of shipments. Lastly, some cross-docks receive inbound shipments that are not yet assigned to a particular outbound trailer. Cross-dock scheduling then involves the assignment of shipments to outbound trailers, i.e., assembling consolidated trailer loads.

**Network design:** Network design decisions determine the physical infrastructure of the cross-docking network such that transportation demand is met at the lowest possible costs. Each transportation order is associated with particular costs, which are incurred depending on how that order is routed through the cross-docking network. An important network design decision is concerned with shaping the general structure of the network and defining the types of logistics facilities that are established. The structure of the network consists of a set of possible facility locations and routes to transport freight. The facility type definitions describe for each type, e.g., the fixed costs to operate the facility, the maximum capacity, and the distribution functions performed. Opportunities for outsourcing may also emerge and are evaluated at the strategic level when shaping the network structure and defining the facility types. Based on the network structure and the expected transportation demand, the appropriate number and locations of facilities in the cross-docking network are determined as part of the network design.

**Network planning:** Network planning decisions are concerned with allocating and utilizing network-wide logistics resources in order to attain economic and customer service level objectives. A primary network planning decision assigns transport capacity (e.g., a fixed number of trailers) to each route in the cross-docking network and, thereby, specifies which of the potential network routes will actually be used to provide transport services. A closely related network planning decision allocates freight to the available transport services.

Collectively, the network planning decisions determine how freight is routed through the network, and thus where opportunities for consolidation occur. If transportation demand is characterized by origin-destination pairs, the destination for each shipment is known prior to solving the network planning problems. Alternatively, transportation demand is expressed by supply and demand figures for one or more product types. The decision to assign a destination to each shipment is then part of the network planning. This is often the case for cross-docking networks in a retail-distribution setting where each retail store demands a certain range of products. Provided that the correct product range is send to each retailer, products from the same
type are interchangeable. The decision latitude that may arise as a result of product interchangeability, effectively, enables additional opportunities for consolidation.

**Network scheduling:** In contrast to network planning decisions, network scheduling considers detailed temporal constraints in routing freight through the cross-docking network. The capacity and time windows for transport services in the cross-docking network are often determined in advance of the scheduling decisions. Network scheduling decisions are then concerned with dispatching shipments, i.e., specifying if and how many shipments are dispatched onto a given transport service. In the local region of a cross-dock, network scheduling may include vehicle routing to collect and deliver shipments from and to the cross-dock. In this specific variant of the vehicle routing problem, there is an emphasis on aligning the resulting inbound and outbound freight flows at the cross-dock.

*Table 1: Clustering of the individual cross-docking decision problems*

INSERT TABLE 1 ABOUT HERE

4. **Literature review and classification**

Despite the separate introduction of the problem classes in the previous section, practical cross-docking design and coordination issues often consist of multiple individual decision problems from different problem classes. If a particular cross-docking problem is concerned with multiple strategic, tactical, and/or operational problem aspects, one should bear in mind the *hierarchical* interdependencies between the decision-making levels. In addition to these hierarchical interdependencies, this paper emphasizes the existence of *lateral* interdependencies (i.e., between local and network-wide problem aspects). We argue that the lateral interdependencies are particularly important in the design and coordination of cross-docking operations due to the absence of a storage buffer inside a cross-dock.

The literature review and classification approach are geared towards identifying and understanding the strong hierarchical and lateral interdependencies among the cross-docking problem classes. To that end, we analyze for each problem class which input parameters and constraints are addressed and how they are related to the outputs of individual decision problems in other problem classes. Moreover, we study the characteristics of the decision model outputs from each cross-docking problem class.
4.1 Sample selection and classification procedure

We conducted a search to identify all international journal papers on cross-docking published before 2014 and limited our selection to papers that address decision problems for at least one cross-docking design or coordination aspect. Accordingly, descriptive and normative cross-docking studies (e.g., Apte and Viswanathan, 2000; Vogt 2010) as well as papers providing analytical models to evaluate the benefits of employing a cross-docking strategy or compare different types of cross-docking operations (e.g., Alptekinoğlu and Tang, 2005; Yan and Tang, 2009) were left outside the scope of our classification. We also excluded papers proposing models that consider the deployment of some cross-docking principles inside a manufacturing plant (e.g., Hauser and Chung, 2006) or traditional warehouse (e.g., Choy et al., 2012). The search and selection procedure resulted in 76 journal papers from a wide-range of operation research journals.

Upon classification, we specify for each of the selected papers which of the individual decision problems are considered – and whether they are considered as an input or output. Papers are clustered based on the outputs of the proposed decision models. If the model includes one or multiple individual decision problems from a single problem class as output, we consider the paper to address an isolated cross-docking problem. If the model includes outputs from multiple cross-docking problem classes, we consider the paper to address an interrelated problem area. The precise classification procedure is outlined in the Appendix and the resulting classification is presented in Table A.1. The following sub-sections concisely describe the reviewed papers.

4.2 Local cross-dock management

This sub-section discusses papers solving cross-docking problems originating locally at the cross-dock.

4.2.1 Cross-dock design

Three papers were identified that focus on the design of cross-docks. Bartholdi and Gue (2004) determine the optimal shape for a cross-dock under different operating conditions. The different conditions are generated by varying the values of four characteristics: the number of dock doors, the freight flow pattern, the proportion of strip-to-stack doors, and the dock door assignment. The cross-dock shapes considered are I, L, T, H and X. Each shape is evaluated according to its associated labor costs, which is estimated using a metric for the average travel distance of material handling equipment. The authors conclude that as the number of dock doors increase,
the most labor-efficient shapes for a cross-dock are I, T, and X, successively. One practical implication from this study is that an I-shaped cross-dock can best be expanded into a T-shape when approaching 150 dock doors, and should be further expanded into an X-shape at approximately 200 dock doors or more. In a similar design study, Carlo and Bozer (2011) focus on I-shaped (i.e., rectangular) cross-docks. The authors analytically show that a narrow-shaped cross-dock minimizes the expected travel distance of material handling equipment if the perimeter of the cross-dock is fixed; whereas a square shape is best if the area of the cross-dock is fixed. Considering a cross-dock with an equal number of strip and stack doors, the authors obtain the optimal dock door assignment for different freight flow patterns.

Vis and Roodbergen (2011) study a different cross-dock design problem, which is aimed at designing the staging areas inside a cross-dock. The authors propose a dynamic design procedure which is constraint by a number of physical restrictions imposed by the shape of the cross-dock. The proposed procedure emphasizes the interplay between the design of the staging area and the policies by which employees temporarily place and pick shipments to or from that staging area.

Several potential research avenues for cross-dock design still exist – particularly with regard to internal cross-dock design. The internal design of a cross-dock greatly affects the ability to efficiently sort shipments and move them from inbound to outbound trailers; yet it remains a fundamental challenge for many cross-dock managers. Determining the optimal location for value adding logistics activities (e.g., labeling, pricing and re-packaging) inside the cross-dock further adds to the complexity of this design problem, and hence would form a significant research contribution. Furthermore, most cross-dock design studies assume that manually operated forklift trucks move the freight from inbound to outbound trailers. However, highly automated material handling systems for cross-docks recently became available. Future cross-docking research could be aimed at quantifying the benefits of using automated cross-dock systems in order to weigh those benefits against the loss of flexibility associated with using such automated systems.

4.2.2 Cross-dock planning
All identified cross-docking planning papers focus on the dock door assignment problem. Tsui and Chang (1990; 1992) consider a variant of this problem in which the aim is to assign each stack door to a destination and each strip door to an origin over a mid-term planning horizon. Cohen and Keren (2009) argue that high volume destinations often require multiple trailers to be
loaded simultaneously. Accordingly, the authors extend the approach of Tsui and Chang (1990; 1992) by allowing multiple stack doors to be assigned to each high volume destination.

The authors of the above papers considerably limit the search space of the dock door assignment problem by assuming stack and strip doors are readily specified on opposite sides of the cross-dock. Stephan and Boysen (2011b) study the impact of this pre-determined dock door specification on the dock door assignment problem by comparing it to the situation where strip and stack doors can be specified freely around the perimeter of the facility. The study shows that the two policies differ in their levels of dock door assignment flexibility, complexity of the freight flows, and potential for congestion inside the cross-dock. It is concluded that a pre-determined specification of dock doors on opposite sides of the cross-dock leads to inferior operational performance in most cases, except when information about inbound loads is lacking.

Oh et al. (2006) propose a dock door assignment technique that clusters destinations and assigns multiple adjacent dock doors to each of these clusters. The clustering of destinations promises reduced internal travel distance by enabling additional grouping of inbound freight for movement inside the cross-dock. However, Oh et al. (2006) make the strong assumptions that all inbound freight enters the cross-dock through one strip dock door and that the material handling equipment can transfer groups of inbound shipments.

Many cross-docks receive inbound freight from a large and constantly changing set of origins, which makes the assignment of strip doors on a medium term planning horizon infeasible – and often undesirable. Accordingly, Bartholdi and Gue (2000) formulate a dock door assignment problem assuming a first-come-first-serve (FCFS) policy for allocating inbound trailers to strip doors. The proposed approach first specifies any dock door as either a strip or stack door and then assigns the stack doors to destinations. The aim is to minimize the workforce required to move all inbound shipments to their corresponding outbound trailers. Rather than using rectilinear distances alone, queuing theory is applied to calculate the weighted moving time, which delicately balances travel distance with congestion imposed by floor space constraints, forklift interference and dragline congestion.

Bartholdi and Gue (2000) assume that, over time, a FCFS policy for the allocation of inbound trailers yields a freight flow through each individual strip door that tends to resemble the aggregate flow of freight through the cross-dock. Accordingly, the authors model all inbound trailers as average trailers. Due to daily variations in freight flows, however, assuming such
average inbound trailers may result in dock door assignments that are optimal over the selected planning horizon, but yield very poor results for individual days within that horizon. Gue (1999) argues that the use of look-ahead scheduling enables the ability of cross-dock operators to allocate inbound trailers to strip doors based on the information about the destinations of their shipments. The author proposes a model to specify dock doors and assign destinations to stack doors based on inbound freight flows that are modeled as biased trailers. The model constructs biased trailers based on the premise that cross-dock operators use information about the content of inbound trailers to allocate those trailers to a strip door as closely as possible to the stack door to which most of its content has to be moved.

Bozer and Carlo (2008) extend the work of Bartholdi and Gue (2000) and Gue (1999) by taking into account the performance effects of daily variations in freight flows. The authors first propose a static stack door assignment model. A second, dynamic, dock door assignment model uses detailed freight flow information to daily assign strip and stack doors. Since this paper presents two distinct models, it appears twice in Table A.1. Yu et al. (2008) study a dock door assignment problem very similar to Bozer and Carlo (2008), but propose a sequential solution approach that first assumes a fixed stack door assignment to develop a scheduling policy for inbound trailers and then optimizes the stack door assignment based on that policy. The scheduling policy emulates the inbound scheduling decisions made by the cross-dock operators.

The above cross-dock planning procedures provide ample methodologies for solving the dock door assignment problem. The procedures that consider the effects of freight flow variations are particularly valuable for cross-docking practice. All dock door assignment studies assume the equipment and workforce required to move shipments through the cross-dock either to be always available when needed or to be constraint by a given capacity. In practice, cross-dock managers often face considerable difficulty in determining the appropriate equipment and workforce capacity over a mid-term planning horizon. Accordingly, future cross-dock planning research could develop methodologies that simultaneously address the assignment of dock doors with the planning of equipment and workforce.

4.2.3 Cross-dock coordination
We identified two recently published papers that add cross-dock scheduling aspects to the dock door assignment problem. Chmielewski et al. (2009) propose a model assigning stack doors to destinations and determining a schedule for the inbound trailers while considering multiple
internal cross-dock capacity limits. The aim is to minimize the internal travel distance of material handling equipment and the waiting time of inbound trailers. Luo and Noble (2012) propose a model that assigns strip doors to origins and stack doors to destinations. Moreover, inbound shipments are positioned in the staging area when staging is required, shipments are assigned to outbound trailers, and the departure times for outbound trailers are determined. The authors assume the arrival time distribution for inbound trailers to be known and inbound trailers to be served directly upon arrival at the strip door which is assigned to their origin.

We identify a promising research trend with regard to recent studies integrating cross-dock planning aspects (i.e., dock door assignment) with cross-dock scheduling aspects, such as trailer scheduling and positioning of shipments inside the staging area. Nonetheless, there is ample opportunity to continue this line of research. Firstly, this type of research is still in its infancy. Hence, the current problem descriptions and solution approaches are formulated only for a limited number of (rather specific) cross-dock application domains. Secondly, other cross-dock scheduling aspects could be integrated with cross-dock planning, as will become clear in the subsequent discussion on cross-dock scheduling literature.

4.2.4 Cross-dock scheduling
The vast majority of cross-dock scheduling studies are aimed at solving trailer scheduling problems. Fourteen of those studies consider variants of a highly simplified scheduling problem aimed at deriving fundamental insights that might also apply to more realistic problem settings. Most of these studies consider a cross-dock with one strip door, one stack door and infinite staging area capacity (Arabani et al., 2010; 2011a; 2011b; 2012; Boysen et al., 2010; Forouharfard and Zandieh, 2010; Larbi et al., 2011; Liao et al., 2012; Vahdani and Zandieh, 2010; Yu and Egbelu, 2008). Vahdani et al. (2010) and Soltani and Sadjadi (2010) consider a cross-dock that does not allow staging. The proposed solution approaches determine the sequence in which the inbound and outbound trailers are served and, simultaneously, assign shipments to outbound trailers. In an otherwise similar cross-dock setting, Chen and Lee (2009) assume inbound shipments to be associated with an outbound trailer already upon arrival. Briskorn et al. (2010) study a rather different variant of the simplified trailer scheduling problem, where the cross-dock handles homogeneous products through a single dock door that can be utilized both as strip and stack door.
While the above studies provide interesting insights, direct practical applicability is low as most real-world cross-docks comprise multiple strip and stack doors. In response, several studies have considered cross-docks with multiple dock doors, while focusing on the scheduling of either inbound or outbound trailers. Alpan et al. (2011a; 2011b) determine a schedule for serving outbound trailers at multiple stack doors, making the assumption that the arrival sequence of inbound trailers is fixed and that they are served at the strip doors according to a FCFS policy.

Boysen and Fliedner (2010) and Boysen et al. (2013) determine a schedule for inbound trailers in a cross-dock setting with a given outbound trailer schedule. Inbound shipments are assumed to be associated with outbound trailers upon arrival. Variants of this trailer scheduling problem include internal workforce capacity constraints (Rosales et al., 2009), cope with inbound trailer arrival times that are not exactly known (Acar et al., 2012; Konur and Golias, 2013a; 2013b), or consider the assignment of shipments to outbound trailers (Liao et al., 2013). McWilliams (2009b; 2010), McWilliams et al. (2005; 2008) and McWilliams and McBride (2012) address the scheduling of inbound trailers in a setting where inbound shipments are transferred to readily available outbound trailers by means of a network of conveyors connecting all docks doors. Accordingly, the specification of dock doors as either strip or stack door and the assignment of stack doors to destinations are known in advance. Moreover, it is assumed that outbound trailers depart when fully loaded and are immediately replaced with an empty one. These problem particularities allow the outbound trailer schedule to be ignored. An online scheduling solution for the same problem context is proposed in McWilliams (2009a). Wang and Regan (2008) propose two online procedures for the scheduling of inbound trailers in a more typical cross-dock setting. The authors assume the dock door specification and the assignment of stack doors to destinations to be known and the internal cross-dock workforce to be always available when needed.

Miao et al. (2009) were the first to consider the scheduling of both inbound and outbound trailers in a setting with multiple dock doors. The authors assume that dock doors can be used both as strip and stack door upon availability and consider predetermined arrival and departure times for all trailers. Accordingly, the aim is to allocate trailers to dock doors while minimizing the number of unfulfilled or ‘lost’ shipments.

Other studies determining schedules for inbound and outbound trailers at cross-docks with multiple dock doors assume that the doors are specified as either strip or stack door prior to the
trailer scheduling. Chen and Song (2009) extend the single strip door and single stack door proposed in Chen and Lee (2009) into a multiple door problem. The proposed approach first determines a good inbound trailer schedule and then identifies an optimal outbound trailer schedule for that particular inbound schedule. Variants of this problem consider shipments that cannot be temporarily staged inside the cross-dock (Boysen, 2010) or shipments that are not yet assigned to particular outbound trailers upon arrival (Joo and Kim, 2013). Van Belle et al. (2013) simultaneously schedule inbound and outbound trailers. Their approach considers the time needed to move shipments between dock doors and the tardiness of trailers – based on pre-defined arrival and departure times. Shakeri et al. (2012) propose a cross-dock scheduling approach that considers a capacity constraint internal workforce, and hence takes internal cross-dock scheduling into account when determining the inbound and outbound trailer schedules. In the current solution approach, the authors adopt highly simplified policy for positioning shipments in the staging area and dedicate one forklift operator to each stack door for moving shipments from the inbound staging area to its corresponding outbound staging area. The proposed solution approach is explicitly designed to include more complex internal cross-dock schedules in the future.

A different, much smaller group of cross-dock scheduling research considers the resource scarcity associated with activities inside the cross-dock. Li et al. (2004) and Álvarez-Pérez et al. (2008) propose very similar procedures to schedule a resource-constraint workforce performing jobs related to breaking down inbound truckloads and assembling loads for outbound shipment. Vis and Roodbergen (2008) propose a procedure to find the best position for temporarily placing shipments in the staging area. In order to find that position, the authors consider the additional travel distance incurred when the material handling equipment has to deviate from the shortest path associated with directly reloading a shipment onto its outbound trailer. The strip and stack door assignments are assumed to be known, as is the destination for each inbound shipment.

There is a large and fast-growing body of research on cross-dock scheduling in general, and on trailer scheduling in particular. Most of these studies are focused on minimizing the length of the planning horizon (i.e., the makespan), but often neglect workforce and material handling equipment required to move shipments from the inbound to the outbound trailers. Nonetheless, cross-dock planning studies indicate that the total distance traveled and the congestions that appear on-route between dock doors are important factors with regard to the
operational performance of a cross-dock. Therefore, future cross-dock scheduling research could consider staging policies and congestion measures to more accurately translate the distance among dock doors into the travel and waiting time of shipments inside the cross-dock. The recent study of Shakeri et al. (2012) is promising in that regard – as it considers workforce scheduling and staging policies when determining trailer schedules. Future cross-dock scheduling research is encouraged to extend the work of Shakeri et al. (2012) by including more complex internal scheduling policies.

4.3 Cross-docking network management

This sub-section is analogous to Sub-Section 4.2, except it discusses papers addressing problems originating elsewhere in the cross-docking network. We note that most cross-docking network design and coordination methodologies fall within the remit of general transportation network research (see e.g., Crainic, 2000; Eksioglu et al., 2009; Melo et al., 2009). Whereas the authors of cross-docking network papers make the explicit or implicit assumption that the absence of long-term storage inside cross-docks distinguishes their problems from general network problems, they generally remain silent on which problem aspects actually differ – and how.

We expect the most fundamental differences to be prevalent in research areas where local and network-wide cross-docking problems are considered simultaneously. Accordingly, in our discussion of the papers below, we refrain ourselves from formulating detailed suggestions for future research considering cross-docking network aspects alone. Rather, we encourage scholars to differentiate cross-docking network research from general transportation network design and coordination literature by adopting a synchronization focus, i.e., specifically aimed at simultaneously solving local cross-dock and network-wide decision problems.

4.3.1 Network design
We identified seven papers with a focus on cross-docking network design, which are primarily aimed at determining the best cross-dock locations. Determining the optimal location of cross-docks and other facilities in a cross-docking network strongly depends on how freight flows are distributed over those facilities. Therefore, the locations of the cross-docks are often determined simultaneously with the allocation of freight flows. In general facility location literature, this combined problem is referred to as the location-allocation problem (Alumur and Kara, 2008). Bhaskaran (1992) was among the first to study this problem in a cross-docking network context and focuses on determining the optimal number and location of multiple cross-docks. The
proposed approach solves a continuous facility location problem for different numbers of cross-docks and includes practical considerations, such as minimum-size requirements for cross-docks.

Besides Bhaskaran (1992), cross-docking network design literature proposes discrete network models, which determine the optimal number and locations of cross-docks from a set of pre-identified candidate locations. Each location is associated with a fixed cost for establishing or operating a cross-dock. The main decisions for these models are concerned with whether or not to establish a cross-dock at each of the candidate locations and how the freight flows are allocated to the cross-docks in the network. In addition to these decisions, the discrete network design models proposed by Sung and Song (2003) and Sung and Yang (2008) determine on-route capacity by allocating a number of vehicles to each of the network routes. Freight flows are allocated such that all shipments are handled by exactly one cross-dock and the capacity of each cross-dock is constrained by a given maximum number of transshipments. Gümüş and Bookbinder (2004) study a similar discrete cross-docking network design problem, but allow the identification of opportunities for direct shipment before solving the location-allocation problem based on the remaining shipments. Mousavi and Moghaddam (2013) not only consider the location-allocation problem, but also determine the collection and delivery vehicle routes.

The aforementioned network design problems address one particular cross-docking network configuration consisting of a set of origins, a set of destinations, and a single layer of cross-docks. Another set of papers that focus on cross-docking network design take a broader supply chain perspective. Jayaraman and Ross (2003) and Ross and Jayaraman (2008) propose a network design approach determining not only the number and locations of cross-docks in the network, but also that of the warehouses supplying the inbound shipments to the cross-docks. Bachlaus et al. (2008) study a very similar network design problem and include various aspects associated with the manufacturing plants and suppliers of raw materials, e.g., their production capacity and volume flexibility. The broader supply chain network design approaches consider the capacity of a cross-dock in terms of the number of product families they can handle.

4.3.2 Network planning
We identified only one paper that addresses cross-docking network planning aspects alone. Musa et al. (2010) propose a model that assigns capacity to the available network routes (in terms of a number of vehicles) and allocates freight flows to those routes. Freight flow constraints and costs for operating network routes are assumed to be known. The proposed model allows freight to be
routed either directly from origin to destination or intermediate pass through one of the cross-
docks in the network. Cross-dock capacity constraints are not considered.

4.3.3 Network coordination

Network planning approaches do not take temporal constraints into account, and hence assume
that individual shipments can always be consolidated as long as they are transported within the
same planning interval. We identified six papers that present more realistic network coordination
approaches by incorporating network scheduling aspects, i.e., consider also detailed resource and
temporal constraints in identifying opportunities for consolidation. More specifically, these
papers simultaneously address shipment dispatching and network planning decisions. Lim et al.
(2005) present problem formulations for several variants of this problem, assuming that the
capacity and time window constraints for each transport service are known a priori. Chen et al.
(2006) address one particular problem variant for which the network consists of multiple cross-
docks and each shipment should be handled at exactly one cross-dock. Transportation demand is
characterized by supply and demand figures for multiple product types. Besides solving the
shipment dispatching and freight flow allocation problem, the proposed approach assigns a
destination to the products upon arrival at the cross-dock. Ma et al. (2011) consider a very
similar problem, but now only one product type is considered. In addition, the shipments may
also be routed directly to the customer, i.e., bypassing the cross-docks in the network.

The above network coordination studies model all time windows as hard constraints. As a
result, there may remain unfulfilled shipments in the case that one or more transportation
services cannot be accomplished within the given time window constraints. Due to the penalties
associated with these unfulfilled shipments, solutions are likely to provide a less efficient
schedule in order to meet the hard time constraints. In response to this issue, Miao et al. (2012)
and Marjani et al. (2012) extend the above problems by considering also soft time constraints. In
Miao et al. (2012), collections are forced to be always performed within the given time windows
while customer demand may be served with a delay – albeit additional penalty costs are incurred.
Reversely, Marjani et al. (2012) allow the collection time window constraints to be violated.

Erera et al. (2013) propose a different model to include temporal constraints to a cross-
docking network planning problem. Assuming fixed and known freight flows, Erera et al. (2013)
propose a three-phase procedure to find an optimized route for each shipment. In the first phase,
the model constructs time-space feasible bundles of consolidated shipments, and hence assigns
capacity to each network route. In the second phase, a dispatch window is assigned to the consolidated bundles of shipments created in the first phase. The third phase assigns truck drivers to the routes determined in the second phase.

4.3.4 Network scheduling

We identified four papers that address network scheduling problem aspects. Hernández et al. (2011) address a network scheduling problem in a setting with centralized network coordination, i.e., a central network coordinator makes the network planning decisions. The authors address a problem where an individual freight carrier can acquire capacity from a collaborative partner when its own fleet has insufficient capacity to meet transport demand. The authors assume that network planning outcomes are known in advance and can be represented by the time-dependent availability of the collaborative transport service capacities in the network. The proposed model dynamically determines how the cross-dock operator could best dispatch shipments onto the collaborative network routes when aiming for timely deliveries.

The other cross-docking network scheduling problems consider a decentralized network coordination setting, i.e., the cross-docking network consists of multiple subsystems and each cross-dock operator coordinates the transport services in his own subsystem. In a typical decentralized setting, a cross dock operator performs network scheduling by determining the collection and delivery vehicle routes for the shipments in his particular subsystem. This variant of the vehicle routing problem distinguishes from the vast body of knowledge on classical vehicle routing problems by its emphasis on aligning inbound and outbound freight flows at the cross-dock. We refer the reader to Eksioglu et al. (2009) for a taxonomy of vehicle routing problem variants. Lee et al. (2006), Liao et al. (2010), and Vahdani et al. (2012) address a cross-docking variant of the vehicle routing problem assuming that the alignment of freight flows at the cross-dock necessitates a simultaneous arrival and departure of all inbound and outbound vehicles. Santos et al. (2013) model a very similar problem as a pickup and delivery problem with a single cross-dock. As opposed to the aforementioned vehicle routing approaches, the decision model proposed by Santos et al. (2013) allows vehicle routes to either visit the cross-dock or not. We refer the reader to Berbeglia et al. (2007) for a classification of pickup and delivery problem variants.
4.4 Synchronization
Effective cross-docking requires local and network-wide operations to be synchronized. The corresponding interdependencies between cross-docking problem classes may occur at the strategic, tactical, and operational level.

We could identify only three papers considering lateral interdependencies. Hu et al. (2013) and Wen et al. (2009) focus on determining the collection and delivery vehicle routes, while acknowledging the interdependencies that emerge between those routes when vehicles have to unload or reload shipments at the cross-dock. Accordingly, the authors consider the local cross-dock decision concerned with assigning shipments to particular outbound trailers at the cross-dock. The assignment of shipments to outbound trailers is interdependent with the vehicle routing as delivery routes can only depart the cross-dock when all its loads have arrived by means of collection routes. Tarantilis (2013) studies a similar problem in which all shipments have to unloaded and reloaded at the cross-dock.

No papers considering strategic or tactical interdependencies were identified. We refer the reader to Section 6 for suggestions for future cross-docking synchronization research at different levels of decision-making.

4.5 Research classification
The classification of the above discussed papers is summarized in Figure 4 and detailed in Table A.1 (in the Appendix). The numbers in Figure 4 represent the accounted publications in each isolated cross-docking problem class or interrelated problem area. One can observe that the overwhelming majority of papers address an isolated cross-docking problem, i.e., proposing a decision model that yields an output supporting one or more individual decision problems within the same cross-docking problem class. The papers that do address an interrelated problem area mostly aim to hierarchically integrate strategic, tactical, and operational problem aspects, considering either a local cross-dock or a network problem setting. While valuably in itself, such integrative research efforts do not consider the strong lateral interdependencies between local and network-wide operations inherent the cross-docking strategy.
Besides summarizing the classification of cross-docking papers, Figure 4 highlights potential interdependent cross-docking problem areas. Regarding the hierarchical interdependencies, \textit{cross-dock coordination} problems consist of planning and scheduling aspects of decision problems that originate locally at the cross-dock. Similarly, \textit{network coordination} problems consist of network planning and scheduling aspects. Existing cross-dock and network design models generally consider hierarchical interdependencies with cross-dock and network coordination aspects, respectively. Regarding the lateral interdependencies, Figure 4 shows two potential areas for synchronization. At the strategic decision-making level, problems in the area of \textit{design for synchronized cross-docking} include both local cross-dock design aspects and cross-docking network design aspects. At the tactical and operational level, problems aimed \textit{synchronized cross-docking operations} include a combination of coordination problem aspects with the aim to synchronize network-wide and local cross-dock operations.

The practical relevance of synchronization in cross-docking networks, combined with a general lack thereof in existing literature, justifies future research in that regard. Details about the interdependencies between the cross-docking problem classes and insights required to identify and formulate cross-docking synchronization problems will be detailed in the subsequent sections.

5. The framework
Following from the results of Section 4, and based on our observations in practice, this section proposes the framework for synchronization in cross-docking networks. The framework is shown
in Figure 5 and the interdependencies between the cross-docking problem classes are specified in Table 2. The interdependencies are identified by analyzing the decision models proposed in cross-docking literature, focusing specifically on the inputs and outputs of the existing models in each problem class. More specifically, Table 2 lists the information needs for each cross-docking problem class considering the input parameters and constraints used in existing decision models.

**Figure 5: Framework for synchronization in cross-docking networks**

**Table 2: Interdependencies between cross-docking problem classes**

The purpose of the framework and research classification is to support future cross-docking research in acknowledging the strong interdependencies between different problem classes and carefully considering those interdependencies when developing decision models and solution approaches. In the case of solving an isolated cross-docking problem, the framework can be used to identify which interdependencies should be considered. When the relevant interdependencies are identified, the classification table points to related research, i.e., either addressing a similar decision problem or a problem that is related by means of a particular interdependency. Accordingly, values can be assigned to input parameters and constraints that realistically reflect the considered cross-dock and cross-docking network problem context. Furthermore, the framework shows how future outputs of isolated cross-docking decision models can be characterized to be of value for solving decision problems from other cross-docking
problem classes. Lastly, the outputs of a particular decision model can be validated against interdependent cross-docking decision problems.

Section 6 will demonstrate how the proposed framework can be used to identify and formulate problems where multiple individual decision problems from network and local problem classes are considered simultaneously.

6. **Illustrative cross-docking synchronization problems**

This section presents two cross-docking synchronization problems, which are based on the distribution network re-design of an international grocery retailer. We do not claim that these two synchronization problems are the most important problems for future cross-docking research. Rather, the aim is to illustrate how the framework and research classification can be used to identify practical cross-docking synchronization issues and translate them into scientifically relevant problems. Both illustrative problems are classified in Table A.1.

Figure 6 schematically represents the retailer’s supply chain, which is recognized as a *few-to-many* cross-docking network with a *single layer of cross-docks*. The cross-docking network consists of 2 national distribution centers (NDCs), 4 regional distribution centers (RDCs), 4 cross-docks, and 940 retailers. The majority of stock keeping units (SKUs) is kept at the NDCs. There is no overlap in SKUs between the two NDCs. The remaining SKUs are kept at each of the RDCs. Hence, shipments to each retailer are assembled at both NDCs and one RDC and are consolidated at the cross-dock.

![Schematic representation of the cross-docking network under study](image)
The distribution network re-design entails shifting a large part of the SKUs from each RDC to the NDCs. As a result, the cross-docking flow through the network will increase considerably. Therefore, the current transportation planning and scheduling procedures are reconsidered and potential changes to the cross-dock design and coordination are investigated. The prevalent interdependencies between the local cross-dock and cross-docking network decision problems in this context are described below, where we introduce two synchronization problems.

6.1 **Tactical-strategic cross-docking synchronization problem**

The first problem considers the design and layout of the cross-docks in synchronization with the interdependent network planning decisions. The inputs to this problem stem from the network design problem class (see Figure 7 for details).

**Network planning:** Network planning in this context is concerned with assigning capacity to the network routes and allocating freight flows to those routes. At the tactical level, the freight flow allocation decisions determine which retailers are replenished from which RDC. Solution approaches to this cross-docking network planning problem can be found in literature, see, e.g., Musa et al., (2010) in Table A.1.

**Cross-dock design and planning:** Determining which, and how many, of the dock doors at the RDC should be dedicated to serving the cross-docking freight flows is an important decision towards a potential re-design of the cross-docks. The related cross-dock planning decisions are concerned with specifying the dock doors as either strip or stack door and allocating them to inbound and outbound trailers. In solving this hierarchical cross-dock design and planning problem, one can draw upon cross-dock design and dynamic dock door assignment approaches, see, e.g., Bartholdi and Gue (2004) and the dynamic model in Bozer and Carlo (2008) in Table A.1.

**Synchronization:** Network planning decisions dictate the inbound and outbound freight flow patterns through the cross-docks – and hence strongly influence the optimal design and layout of those cross-docks. Similarly, optimal network planning is dependent on the design and layout of the cross-docks, which determine the throughput rate and actual costs associated with allocating shipments to a particular cross-dock. The corresponding synchronization problem is detailed in Figure 7. In this figure we specify the individual decision problems from multiple isolated problem classes and pinpoint the interdependencies between each class according to the framework.
6.2 Operational cross-docking synchronization problem

The second problem considers a cross-docking synchronization problem at the operational level. The inputs to this problem stem from the network and local cross-dock design and planning problem classes (see Figure 8 for details).

**Network scheduling:** At the inbound side of the cross-docks, i.e., the network routes connecting the NDCs to the cross-docks, network scheduling decisions are concerned with dispatching shipments to each trailer departing the NDC. The departure times of the trailers are assumed known. Hence, network scheduling in this context specifies which consolidated loads are assembled at the NDC and indicates the arrival times of these loads at the cross-dock. At the outbound side of the cross-docks, i.e., connecting each cross-dock to its retailers, network scheduling is concerned with determining the vehicle routes replenishing the retailers. These vehicle routes specify the loading lists and departure times of trailers leaving the cross-dock. For the first aspect of the network scheduling problem, one can draw upon approaches proposed in cross-docking literature, see, e.g., Erera et al. (2013) in Tabel A.1; for the latter we refer to classic vehicle routing approaches (Eksioglu et al., 2009).

**Cross-dock scheduling:** Cross-dock scheduling can address many internal operations. In this synchronization problem, we consider trailer scheduling alone – in order to avoid excessive problem complexity. At the retailer’s cross-docks, the outbound trailer departure times are known. The outbound trailer schedule thus boils down to the decision at which dock door each outbound trailer is served. We note that this problem is not equivalent to the dock door assignment problem as the number of outbound trailer far exceeds the number of stack doors.
Solution approaches for the remaining inbound trailer schedule can be found in Boysen and Fliedner (2010) and Rosales et al. (2009) – as identified from Table A.1. The solution approach most closely related to the overall trailer scheduling problem described above is found in Van Belle et al. (2013).

**Synchronization:** Whether the network and cross-dock schedules are appropriate, or even feasible, depends greatly on the outputs from one another. Differently consolidated inbound trailer loads affect the best possible trailer schedules in terms of material handling costs and waiting times. Moreover, trailer schedules are constrained by the deadlines and loading lists for outbound trailers – as imposed by the delivery vehicle routes. Network scheduling decisions benefit from information about the actual cross-dock processing times and operational costs associated with different shipment dispatching and vehicle routing policies. The corresponding synchronization problem is detailed in Figure 8.

![Figure 8: Operational cross-docking synchronization problem](image)

### 6.3 Solution design methodologies

The two illustrative cross-docking synchronization problems pinpoint the interdependencies between individual decision problems from different problem classes. Several promising research opportunities reside in addressing these interdependencies. At a strategic or tactical
decision-making level, it may suffice to focus on local or network-wide decision problems. Nevertheless, studies with a local cross-dock focus should carefully consider cross-docking network characteristics. Similarly, network oriented cross-docking studies should consider local cross-dock characteristics in detail. This can be achieved through the identification of realistic input parameters from related problem classes, preferably followed by a sensitivity analysis of the most strongly interdependent decision problems. The framework presented in Section 5 can be used to identify relevant interdependencies.

As the research focus shifts towards the operational decision-making level, it becomes increasingly important to simultaneously consider local cross-dock and network wide logistics decision problems. To that end, future studies should aim to develop iterative solution approaches or consider multiple local and network-wide decision problems in integration. We acknowledge that many challenging complexities may arise in such developments. For example, the integration of network-level shipment dispatching and local trailer scheduling decisions is hindered by frequent deviations from scheduled arrival times of inbound trailers due to uncertain traffic. Despite the potential complexities, solution approaches to isolated local cross-dock problems will at best result in local optima, which is paradoxical with the inherent network orientation of the cross-docking distribution strategy.

7. Conclusions
This paper presents a research classification and framework for synchronization in cross-docking networks. The paper asserts that the absence of a storage buffer inside a cross-dock translates into tightly coupled local and network-wide cross-docking operations. Nonetheless, the research classification shows that the overwhelming majority of papers address isolated cross-docking problems. Accordingly, a framework is presented to support future research in developing decision models for cross-docking synchronization problems with practical and scientific relevance.

Existing cross-docking research is classified by means of a new general research classification scheme. The classification scheme is developed by identifying all individual cross-docking decision problems and structurally clustering them into six problem classes. The problem classes are distinguished based on their decision-making level (i.e., strategic, tactical, operational) and whether they address decision problems originating locally at the cross-dock or elsewhere in the cross-docking network. Our research classification resulted in an understanding
about the information needs for each problem class. The framework, specifying the interdependencies between the six cross-docking problem classes, is developed based on this understanding.

Lastly, this paper shows how the proposed research classification and framework can be used to identify cross-docking synchronization problems, i.e., appreciating the interdependencies between local and network-wide cross-docking operations. In that regard, the classification table (Table A.1) can be used to find solution approaches to related problem aspects. Moreover, the classification table supports the identification of promising research opportunities by showing combinations of cross-docking problem aspects that are not yet addressed in literature. The framework shows which interdependencies should be considered in order to take cross-docking synchronization aspects into account.

References


Joo, C., Kim, B., 2013. Scheduling compound trucks in multi-door cross-docking terminals. The


Napolitano, M., 2000. Making the Move to Cross Docking – A practical guide to planning, designing, and implementing a cross dock operation. Warehousing Education and Research Council (WERC), Oak Brook, IL.


Appendix. Classification table and detailed classification procedure

This appendix details the classification procedure and presents the resulting classification table. The columns of Table A.1 represent the individual decision problems, which are clustered according to the six cross-docking problem classes. The rows of Table A.1 represent the selected papers, which are described in Section 4.

We classified each of the selected papers based on the individual decision problems considered. The decision problems that are part of the output of a proposed model are classified in the table with the character $O$. The character $I$ indicates that the model assumes that particular decision problem to be known in advance, i.e., either as input parameter or as constraint. The character $Z$ denotes the case when an decision problem is assumed zero. Decision problems that are not considered in the proposed model are classified with the character *.

The classification of the papers is represented by the clustering of multiple rows in Table A.1 and is based on the outputs of the proposed decision model. If the model includes one or multiple individual decision problems from a single problem class as output, we consider the paper to address an isolated cross-docking problem. If the model includes outputs from multiple cross-docking problem classes, we consider the paper to address an interrelated problem area.

Table A.1: Classification of cross-docking research

INSERT TABLE A.1 ABOUT HERE