A systematic literature review on uncertainties in cross-docking operations

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Abstract

Purpose – The technique of cross-docking is attractive to organisations because of the lower warehousing and transportation (consolidated shipments) costs. This concept is based on the fast movement of products. Accordingly, cross-docking operations should be monitored carefully and accurately. Several factors in cross-docking operations can be impacted by uncertain sources that can lead to inaccuracy and inefficiency of this process. Although many papers have been published on different aspects of cross-docking, there is a need for a comprehensive review to investigate the sources of uncertainties in cross-docking. Therefore, the purpose of this paper is to analyse and categorise sources of uncertainty in cross-docking operations. A systematic review has been undertaken to analyse methods and techniques used in cross-docking research.
Design/methodology/approach – A systematic review has been undertaken to analyse methods and techniques used in cross-docking research.
Findings – The findings show that existing research has limitations on the applicability of the models developed to solve problems due to unrealistic or impractical assumption. Further research directions have been discussed to fill the gaps identified in the literature review.
Originality/value – There has been an increasing number of papers about cross-docking since 2010, among which three are literature reviews on cross-docking from 2013 to 2016. There is an absence of study in the current literature to critically review and identify the sources of uncertainty related to cross-docking operations. Without the proper identification and discussion of these uncertainties, the optimisation models developed to improve cross-docking operations may be inherently impractical and unrealistic.

Keywords Warehousing, Supply chain management, Uncertainties, Cross-docking, Distribution centres, Systematic literature review
Paper type Literature review

1. Introduction

Over recent years, competition between companies forced them to cut costs to remain in the market. Cross-docking, which refers to direct shipment of receiving products from inbound trucks to the outbound trucks, is a just-in-time and lean system of distribution, which makes an essential contribution to the rapid movements of goods (Nassief *et al.*, 2016). This approach of distributing products helps reduce costs and leads to better service to the customers. Distribution of products in an efficient way along supply chain is a complex task that needs a careful attention to address a large number of challenges such as uncertainties, just-in-time and cost-effective distribution (Dulebenets, 2019). Consequently, many businesses try to address these challenges by using cross-docking, but cross-docking operations are influenced by the dynamic nature of the business.

Cross-docking operations consist of receiving of inbound trucks and assigning them to the doors of cross-docking centre and the same for shipping trucks and doors.

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The operations include the process of unloading receiving trucks, consolidating products inside of the cross-docking centre and according to the available resources and available shipping trucks, transferring the products to the temporary storage, and loading the products to the shipping trucks according to their destination. Variations in the volume of work, available resources and possible disruptions in the process are uncertainties that can impact the cross-docking operations. Cross-docking centres have to be flexible to overcome challenges, such as short lead times, real-time responses and the supply of a wide variety of products (Ardakani *et al.*, 2020). As a result, distribution centres need a system that can minimise the negative impact of uncertainties in the whole process.

Uncertainties in the supply chain can be from environmental or systemic sources (Ho, 1989). The performance of different members of a supply chain, such as suppliers and manufacturers, can bring environmental uncertainties, and some activities in a supply chain, such as production and distribution, may bring systemic uncertainties (Ho, 1989). Gong and de Koster (2011), however, classified uncertainties according to their locations of occurrence, for example, uncertainties inside or outside the supply chain, inside or outside the warehouse, and uncertainties between warehouse control system.

Over recent years, distribution centre managers have used various innovative approaches to develop robust operations and plans against uncertainties. These attempts although solved part of problems, many issues still remain causing disruptions in the process of cross-docking (Gong and de Koster, 2011). On the other hand, researchers have tried advanced optimisation methods to reduce the negative impact of uncertainties on supply chain and cross-docking operations (Kenne *et al.*, 2012; Lee *et al.*, 2010). During the last decades, many papers focussed on deterministic models to address problems in a stable environment considering various factors influencing cross-docking operations. In addition to supply uncertainties resulted from the suppliers or manufacturers or demand uncertainties from end users and retailers, there are other sources of uncertainty that can affect cross-docking operations. Delay in arrival time of trucks, changes in the contents of a truck, truck breakdown, unloading incoming trucks, a breakdown in handling facilities, the absence of workers, loading, shipping, and delay in the departure time of vehicles can all be considered operations that are prone to uncertainty.

Several literature reviews on cross-docking have been published. Van Belle *et al.* (2012) carried out a review on cross-docking which considered all aspects of cross-docking problems from operational to physical characteristics. They covered a broader range of definitions and categories to complement the studies of Boysen and Fliedner (2010) and Agustina *et al.* (2010). There has been an increasing number of papers about cross-docking since 2010, among which three are literature reviews on cross-docking from 2013 to 2016 (Buijs *et al.*, 2014; Ladier and Alpan, 2016a; Walha *et al.*, 2014). However, there is an absence of study in the current literature to critically review and identify the sources of uncertainty related to cross-docking operations. Without the proper identification and discussion of these uncertainties, the optimisation models developed to improve cross-docking operations may be inherently impractical and unrealistic.

The remainder of this paper is organised as follows. Section 2 describes the research method used to explore the relevant literature. In Section 3, the identified studies are analysed using thematic statistics to identify and classify the uncertainty components. The limitations of existing literature are discussed in Section 4 with future research directions being proposed.

2. Method for literature review

The objectives of this literature review are to examine the studies in cross-docking under uncertainty so that all possible sources of uncertainty can be identified and the limitations of existing studies can be discussed. To achieve this objective, a systematic literature review (SLR) was conducted. To carry out a literature review, a wide range of research should be studied. However, it is impossible to consider all studies unless it is a new field (Seuring and Müller, 2008). To define the area of research, selection criteria and research steps to produce a better review of literature, SLR guidelines are adopted. A SLR can be divided into four stages (Denyer and Tranfield, 2009; Tranfield *et al.*, 2003) including planning, conducting a review, analysis and presenting the findings.

2.1 The planning process in SLR

To develop a coherent flow, the gaps in the literature need to be identified and discussed. To present a comprehensive literature review of cross-docking under uncertainty, the following questions are framed to guide the literature review:

- Which decision levels are considered?
- What uncertainties are considered?
- What performance measures are discussed?
- What methodology is used?
- What are the limitations?

2.1.1 The searching and screening process in SLR. Boolean logic was used to define the keywords for the search. The following keywords were selected: "cross-dock*" AND "uncertainty" AND "supply chain". After determining the keywords, eight databases were identified and selected including Scopus, web of science sciencedirect, Emerald, Wiley Online, Springer Online, Taylor & Francis and ProQuest. Google Scholar was used as a separate database. The period for the data search was set from 1980. According to Krajewski *et al.* (1999) and Apte and Viswanathan (2000), the cross-docking approach started from the 1930s. However, it only became popular from the 1980s after the successful experience of Walmart. In addition, we excluded the strategic level because these studies tend to focus on infrastructure and facilities development prior to the construction of cross-docking centres. Other inclusion criteria were that the research was written in English and the document was either a published paper, a thesis, a book or a chapter. After applying these rules, 1,351 items were found. The list was then checked for duplication which resulted in 234 items being excluded. In the screening process, the authors read the title, abstract and conclusion of the remaining studies and excluded studies that did not have uncertainty in abstract and conclusion. This process resulted in 1,079 being removed and 38 remained. In addition to the database search, a snowball approach was used to avoid the possibility of missing relevant papers. The searching and screening process resulted in 46 papers which have been included in this literature review.

2.1.2 The analysing process in SLR. In evaluating the selected studies, the approach suggested by Tranfield *et al.* (2003) was used. Each study was evaluated using descriptive and thematic analysis (Table I).

	Category	Information
Descriptive analysis	Year	Year of publication
	Country	Authors affiliation
	Type of document	Journal, conference, thesis
Thematic analysis	Solution method	Review, simulation, exact method, heuristics, meta-heuristics
	Research area	Research is related to which area in cross-docking problems?
	Uncertainty component	Which uncertainty factor is considered?
	Decision level	The problem belongs to which decision level?
	Performance measurement	Which performance measure(s) was considered?

Table I.
Classifications used in categorising and analysing data in SLR

2.1.3 Presenting the findings in SLR. Descriptive statistics findings through SLR. While the search criteria were set from 1980, a majority of studies on uncertainties in cross-docking started from 2008 with the first one appeared in 2004 (Figure 1). There has been an increase number of studies from 2012. In terms of the research context of these studies, a majority of studies were from developed economies with the USA having the greatest number (Figure 2). Among these published studies, a third were published in journals, about a quarter were thesis and over 40 per cent were conference papers (Figure 3).

3. Thematic findings: uncertainty components in cross-docking centres operations

In this step, all research items were reviewed according to the components of uncertainties. Following the discussion below, tables are presented to summarise the essential features of each study. The papers were categorised based on the sources of uncertainty as shown in

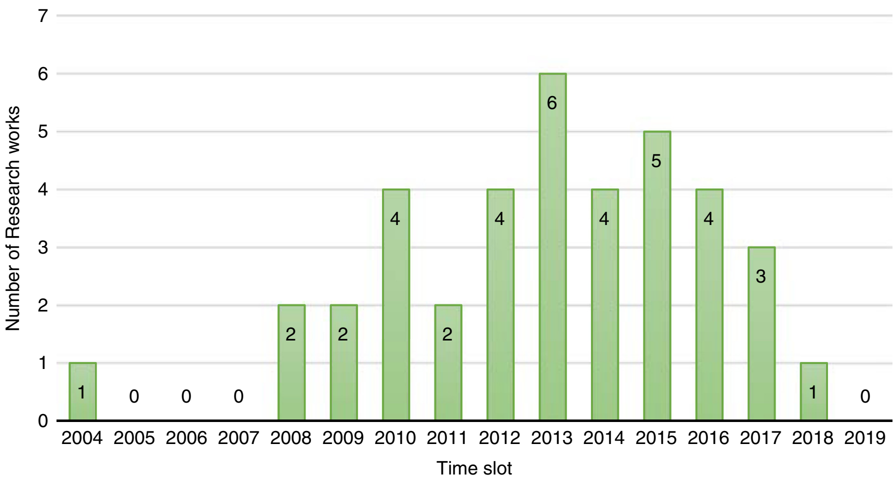

Figure 1.
Distribution of documents between time slots

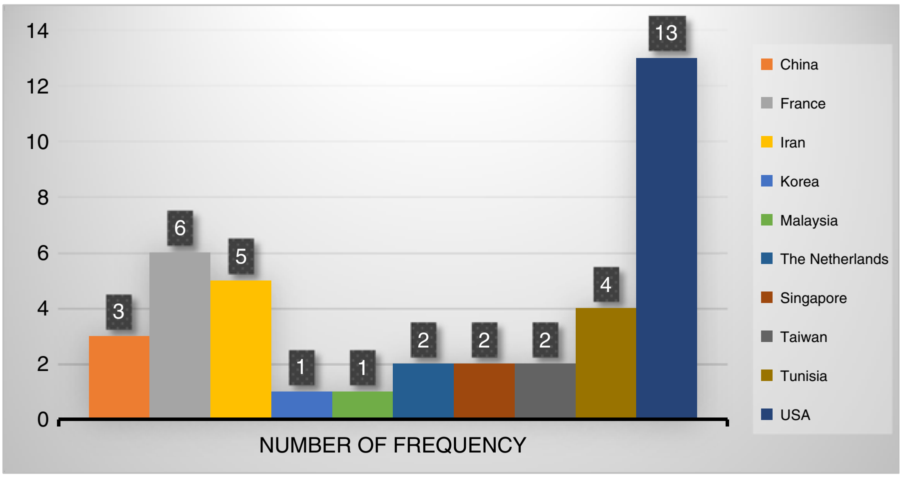

Figure 2.
Countries of published papers

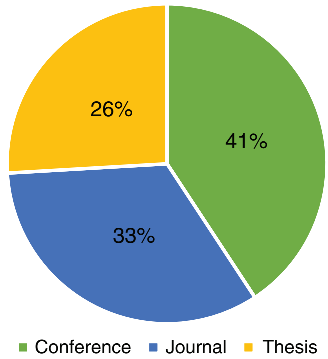

Figure 3.
Type of published research works

Table II, and information on the performance measures used in these studies is provided in Table III. Table IV summarises the solution methods. Table IV is presented. Based on an analysis of the reviewed studies, a framework is developed to illustrate the composition of uncertainty components in cross-docking operations (Figure 4).

3.1 External uncertainty components

In this part, each component of research is analysed in detail according to the external uncertainty component.

3.1.1 Demand. Demand is one of the main factors of uncertainty in supply chain environment. Most businesses are faced with the challenge of accurately predicting customer needs in terms of product type, quantity and timing of delivery. The inability or inaccuracy in predicting demand has a flow-on effect on cross-docking operations. Existing literature on cross-docking only considered the impact of demand uncertainty on network leaving the effect of cross-docking operations unaddressed.

According to Yan and Tang (2009), demand uncertainty can have a negative impact on system performance in terms of total expected cost. The impact can be decreased by employing pre- or post-distribution strategies. According to the results, pre-distribution is preferred when demand is stable. However, in a situation where the demand is uncertain, post-distribution is preferred. Pre-distribution has less impact on cross-docking operations because suppliers have done all necessary preparation, while in post-distribution the process of preparing happens inside the cross-docking centre leading to high operation costs. A weakness of Yan and Tang (2009) is that the pre- and post-distribution strategies were evaluated in isolation from other problems such as scheduling and dock-door assignment in DC which may affect the outcomes of the distribution strategies. Using a robust optimisation model, Spangler (2013) addressed the demand uncertainty from a strategic level through location selection for the cross-docking centre to ensure that the centre can handle changes in demand caused by seasonal fluctuation and adverse weather conditions. The outcomes of Spangler's (2013) research may be helpful for the initial planning of a cross-docking centre but less relevant to the operation of the centre.

Inability in prediction of demand can lead to a delay of trucks at cross-docking centres and more gas and carbon emissions (Arnaout *et al.*, 2010; Rodriguez-Velasquez *et al.*, 2010). Arnaout *et al.* (2010) considered demand, lead-time and service time as stochastic parameters, which improved the results by reducing the use of unrealistic constraints in their models. The results indicate that truck utilisation can be decreased by using cross-docking centres and larger trucks when demand is uncertain. However,

Table II. Uncertainty components and types of cross-docking problems

Name of authors	Type of uncertainties: External	Type of uncertainties: Internal	Component of uncertainties: Truck arrival time	Availability of trucks	Truck departure time	Processing time	Demand	Available resources	Supply	Type of cross-dock problem
M.K. Acar (2004)	✓	✓	✓		✓					Truck-to-door scheduling
Wang and Regan (2008)		✓				✓				Truck-to-door scheduling
Yu *et al.* (2008)	✓	✓	✓			✓			✓	Truck-to-door assignment
McWilliams (2009)		✓				✓				Truck-to-door sequencing
Yan and Tang (2009)	✓						✓			Distribution strategy
Alpan (2010)	✓		✓						✓	Truck sequencing
Arnaout *et al.* (2010)	✓						✓			Cross-docking operation
Rodriguez-Velasquez *et al.* (2010)	✓						✓			Cross-docking operation
Tang and Yan (2010)	✓						✓			Distribution strategy
Larbi *et al.* (2011)	✓		✓						✓	Truck sequencing
Sathasivan (2011)		✓				✓				Truck scheduling problem
K. Acar *et al.* (2012)	✓	✓	✓		✓					Truck-to-door scheduling
Li *et al.* (2012)	✓	✓	✓			✓		✓		Truck scheduling
Shakeri *et al.* (2012)		✓						✓		Truck-to-door scheduling
Soanpet (2012)	✓							✓		Location and routing
Guignard, Hahn, and Zhang (2013)	✓		✓							Truck-to-door scheduling
Konur and Golias (2013a)	✓		✓							Truck-to-door scheduling
Konur and Golias (2013b)	✓		✓							Truck-to-door scheduling
Shi *et al.* (2013)	✓	✓	✓			✓		✓	✓	Scheduling
Spangler (2013)	✓						✓			Location of cross-dock
Zaerpour (2013)	✓		✓							Cross-dock storage operation
Cattani *et al.* (2014)	✓								✓	Flow of network
Ladier (2014)	✓	✓	✓		✓	✓		✓		Truck scheduling
Ladier *et al.* (2014)	✓	✓	✓		✓	✓				Truck scheduling
Walha *et al.* (2014)	✓	✓	✓	✓	✓	✓		✓		Dock-door assignment

(*continued*)

Table II.

Name of authors	Type of uncertainties		Component of uncertainties							Type of cross-dock problem
	External	Internal	Truck arrival time	Availability of trucks	Truck departure time	Processing time	Demand	Available resources	Supply	
Heidari *et al.* (2018)	✓		✓							Truck scheduling and truck allocation
Ladier *et al.* (2015)	✓	✓	✓			✓				Truck scheduling
Suh (2015)	✓						✓			Cross-docking operation
Yin *et al.* (2015)	✓		✓	✓			✓			Collaborative planning and scheduling
Zaerpour *et al.* (2015)	✓		✓							Cross-docking storage operation
Amini and Tavakkoli-Moghaddam (2016)	✓							✓		Truck scheduling
Fatthi *et al.* (2016)	✓	✓	✓		✓				✓	Truck-to-door assignment and scheduling
Ladier and Alpan (2016b)		✓	✓		✓					Truck scheduling
H. Zouhaier and Ben Said (2016)	✓		✓							Dynamic scheduling
Motaghedi-Larijani and Aminnayeri (2017)	✓		✓							Scheduling
Houda Zouhaier and Ben Said (2017a)	✓		✓					✓		Dynamic truck scheduling
Houda Zouhaier and Ben Said (2017b)	✓		✓					✓		Dynamic truck scheduling
Motaghedi-Larijani and Aminnayeri (2018)	✓		✓							Scheduling

Table III. Performance measures

Name of authors	Performance measures: Inventory level/cost	Working hours	Balanced workload	Travel distance	Congestion	Total product stay time	Total loading time	Total unloading time	Truck processing time or deviation to the deadline
M.K. Acar (2004)									
Wang and Regan (2008)				✓				✓	
Yu *et al.* (2008)		✓		✓					
McWilliams (2009)									
Yan and Tang (2009)	✓					✓			✓
Alpan (2010)		✓							
									✓
Rodriguez-Velasquez *et al.* (2010)									✓
Tang and Yan (2010)	✓					✓			✓
Larbi *et al.* (2011)		✓							
Sathasivan (2011)								✓	
K. Acar *et al.* (2012)									
Li *et al.* (2012)	✓								
Shakeri *et al.* (2012)									
Soanpet (2012)				✓					
Guignard *et al.* (2013)				✓	✓				
Konur and Golias (2013a)								✓	✓
Konur and Golias (2013b)								✓	✓
Shi *et al.* (2013)									
Spangler (2013)									
Zaerpour (2013)	✓								
Cattani *et al.* (2014)	✓					✓			✓
Ladier (2014)	✓								✓
Ladier *et al.* (2014)	✓								✓
Walha *et al.* (2014)	–	–	–	–	–	–	–	–	–
Heidari *et al.* (2018)									
Ladier *et al.* (2015)	✓								✓
Suh (2015)							✓	✓	✓
Yin *et al.* (2015)									
Zaerpour *et al.* (2015)	✓								
Amini and Tavakkoli-Moghaddam (2016)									✓

(continued)

Table III.

Fatthi *et al.* (2016)									
Ladier and Alpan (2016b)	✓								✓
H. Zouhaier and Ben Said (2016)									✓
Motaghedi-Larijani and Aminnayeri (2017)									✓
Houda Zouhaier and Ben Said (2017a)									✓
Houda Zouhaier and Ben Said (2017b)									✓
Motaghedi-Larijani and Aminnayeri (2018)									✓
	Performance measures								
Name of authors	Door utilisation	Product not loaded	Schedule length / makespan	Preemption costs	Travel time	Truck utilisation	Number of touches	Transportation cost	Operation cost
M.K. Acar (2004)	✓								
Wang and Regan (2008)	✓				✓				
Yu *et al.* (2008)									
McWilliams (2009)			✓						
Yan and Tang (2009)									
Alpan (2010)					✓				
Rodriguez-Velasquez *et al.* (2010)						✓			
Tang and Yan (2010)									
Larbi *et al.* (2011)					✓				
Sathasivan (2011)			✓						
K. Acar *et al.* (2012)	✓								
Li *et al.* (2012)			✓						
Shakeri *et al.* (2012)			✓						
Soanpet (2012)									✓
Guignard *et al.* (2013)			✓						
Konur and Golias (2013a)									
Konur and Golias (2013b)									
Shi *et al.* (2013)									✓
Spangler (2013)								✓	
Zaerpour (2013)									✓
Cattani *et al.* (2014)		✓							✓
Ladier (2014)									
Ladier *et al.* (2014)									

(*continued*)

Walha *et al.* (2014)	–	–	–	–	–	–	–	–	–
Heidari *et al.* (2018)									✓
Ladier *et al.* (2015)									
Suh (2015)			✓			✓			
Yin *et al.* (2015)			✓						
Zaerpour *et al.* (2015)									✓
Amini and Tavakkoli-Moghaddam (2016)									
Fatthi *et al.* (2016)			✓						
Ladier and Alpan (2016b)									
H. Zouhaier and Ben Said (2016)									✓
Motaghedi-Larijani and Aminnayeri (2017)									
Houda Zouhaier and Ben Said (2017a)									
Houda Zouhaier and Ben Said (2017b)									
Motaghedi-Larijani and Aminnayeri (2018)									

Table IV.
Solution methods

		Solution methods			
Name of authors	Type of mathematical model	Exact method	Heuristics	Meta-heuristics	Simulation
M.K. Acar (2004)	MIQP	Mathematical programming	Other dedicated heuristics	–	–
Wang and Regan (2008)	–	–	Scheduling heuristics		✓
Yu *et al.* (2008)	–	–	Other dedicated heuristics	Genetic algorithm/local search	–
McWilliams (2009)	–	–	Other dedicated heuristics	–	–
Yan and Tang (2009)	Analytical models	Mathematical programming		–	–
Alpan (2010)	Polynomial algorithm	–	Other dedicated heuristics	–	–
Arnaout *et al.* (2010)	–	–	Other dedicated heuristics	–	✓
Rodriguez-Velasquez *et al.* (2010)	–	–	Other dedicated heuristics	–	✓
Tang and Yan (2010)	Analytical models	Mathematical programming	–	–	–
Larbi *et al.* (2011)	Polynomial algorithm	–	Other dedicated heuristics	–	–
Sathasivan (2011)	IP	Mathematical programming	–	Genetic algorithm	–
K. Acar *et al.* (2012)	Mixed integer quadratic programming (MIQP)	Mathematical programming	Other dedicated heuristics	–	–
Li *et al.* (2012)	–	–	Other dedicated heuristics	–	–
Shakeri *et al.* (2012)	MIP	Mathematical programming	Other dedicated heuristics	–	–
Soanpet (2012)	IP	Mathematical programming			
Guignard *et al.* (2013)	–	–	–	Other meta-heuristic	–
Konur and Golias (2013a)	Bi-level optimisation	Mathematical programming	–	Genetic algorithm	–
Konur and Golias (2013b)	Bi-objective and bi-level optimisation	Mathematical programming	Other dedicated heuristics	Genetic algorithm	
Shi *et al.* (2013)	RSM Latin hypercube sampling	–	–	–	✓
Spangler (2013)	MIP	Mathematical programming	–	–	–
Zaerpour (2013)	MIP	Mathematical programming	Other dedicated heuristics	–	–
Cattani *et al.* (2014)	Markov decision process		Other dedicated heuristics	–	–
Ladier (2014)	IP	Mathematical programming	–	–	✓
Ladier *et al.* (2014)	IP	Mathematical programming	–	–	✓
Walha *et al.* (2014)	–	–	–	–	–
Heidari *et al.* (2018)	Bi-objective bi-level optimisation	Mathematical programming	–	Mode, NSGA-II, GASH	

(*continued*)

Name of authors	Type of mathematical model	Exact method	Solution methods Heuristics	Meta-heuristics	Simulation
Ladier *et al.* (2015)	IP	Mathematical programming	–	–	✓
Suh (2015)	–	–	–	–	✓
Yin *et al.* (2015)	MIP	Mathematical programming	Other dedicated heuristics	–	–
Zaerpour *et al.* (2015)	MIP	Mathematical programming	Other dedicated heuristics	–	–
Amini and Tavakkoli-Moghaddam (2016)	Bi-objective linear programming	Mathematical programming	–	NSGA-II, MOSA, MODE	–
Fatthi *et al.* (2016)	MIP	Mathematical programming	–	–	–
Ladier and Alpan (2016b)	Minmax	Mathematical programming	–	–	✓
H. Zouhaier and Ben Said (2016)	MIP	Mathematical programming	Other dedicated heuristics	–	–
Motaghedi-Larijani and Aminnayeri (2017)	Queuing model	–	Other dedicated heuristics	–	–
Houda Zouhaier and Ben Said (2017a)	Queuing Model	–	Other dedicated heuristics	ANI	–
Houda Zouhaier and Ben Said (2017b)	IP	Mathematical programming	–	–	✓
Motaghedi-Larijani and Aminnayeri (2018)	Queuing model	–	Other dedicated heuristics	–	–

Table IV.

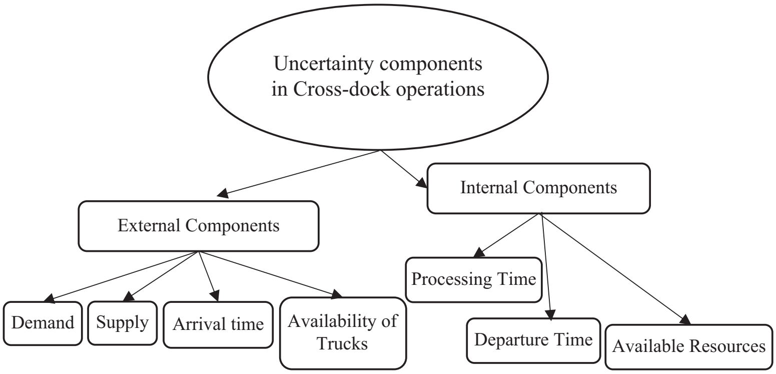

Figure 4.
Uncertainty components in cross-docking operations

Arnaout *et al.* (2010) assumed that cross-docking centres have infinite space, and loading and unloading delays are negligible, which is unrealistic.

3.1.2 Supply. Uncertainty in supply is one of the disruption factors in operation of distribution centres. In order for a distribution centre to deal with the negative impact of supply uncertainty, large amount of inventory is required. This contradicts with the aim of DCs and cross-dock centres. The other reason for uncertainty in supply is because retailers tend to request for shorter delivery times increasing the pressure on both manufacturers and distributors. The inability of cross-docking centres in distributing the products to manufacturers or retailers on time is caused by the high volume of transactions along the supply chain (Cattani *et al.*, 2014; Shi *et al.*, 2013). It is vital for distributors to have proper access to accurate information derived from suppliers. This can help distribution centres to develop proper plans to manage their resources. The literature in cross-docking often assumes that the supply is always stable leaving the impact of supply uncertainty on sequencing and scheduling in cross-dock centres unaddressed.

According to Cattani *et al.* (2014), different customers request different products at various times. Some of these are supplied by distribution centres and cross-docking centres, and others are provided through direct shipments. Resupply of these orders is sometimes delayed. Also, uncertainty in supply is one of the reasons for an increase in supply cost. Cattani *et al.* (2014) aimed to help the online retailers to reduce the expenses of resupplying and short delivery. The results show that a cross-docking strategy can help reduce the penalties for delays in resupplying. This study only considered cross-docking from the demand and supply viewpoint without considering scheduling and assignment of trucks.

Shi *et al.* (2013) indicate that in order to control disruptive events such as supply shortage, three factors should be optimised. In storage space, dwelling time (staying time) of parts together with the number of pieces stays exceeding the threshold time should be minimised. In addition, along with the two previous factors, throughput should be maximised. A main weakness of this study was they considered temporary storage as infinite (Shi *et al.*, 2013).

3.1.3 Arrival time. The literature about uncertainty in cross-docking shows that managers consider arrival time uncertainty as one of the most critical factors that can have a negative impact on the planning and scheduling of cross-dock centres (Boysen and Fliedner, 2010; Ladier and Alpan, 2016a). In cross-docking literature, most of the researchers assumed that arrival time is constant and that all trucks are available at the time of zero, which is not realistic. Receiving and shipping trucks in the real environment have a release and due time which should be monitored carefully to reduce the overall cost associated with earliness and tardiness. Boysen and Fliedner (2010) identified several factors such as traffic and engine failures that can delay the arrival time of trucks.

Monitoring the arrival time of trucks and scheduling both receiving and shipping trucks can improve the efficiency of transhipment. The operation of cross-docking centres should be dynamic and practical. Although static environment can be a starting point to explore a research area, in order to improve the cross-docking operation in functional form, dynamic situations should be considered in research. One of the first studies in the cross-docking dynamic was presented by Konur and Golias (2013a). The authors pointed out that arrival time of trucks needs careful observation and using the prediction method is not a proper way to reduce these uncertainties. Online scheduling or scheduling on a rolling planning horizon can help practitioners obtain better information on the arrival time of trucks. However, a large amount of data and uncertainty in cross-docking operations can make the scheduling process more complicated (Boysen and Fliedner, 2010; Konur and Golias, 2013a; Van Belle *et al.*, 2012).

Konur and Golias (2013a) considered only the inbound side of a cross-dock centre to minimise the total waiting time for trucks with consideration of risk averse. The model provided four perspectives. The deterministic perspective disrespects the possible earliness and tardiness while pessimistic perspective is a risk averse method and uses the worst probability distribution function on arrival time. The optimistic perspective works on the best possible distribution for arrival time and hybrid cases. Konur and Golias (2013b) also conducted a study to minimise costs associated with the arrival time of trucks on the inbound side of cross-docking centres. This method was compared with a first-come-first-served policy. In this study, the probability distribution of the arrival time of trucks was not considered, and temporary storage space was zero.

In continue of research provided by Konur and Golias (2013a), Heidari *et al.* (2018) performed a bi-objective bi-level optimisation to schedule and allocate trucks. Different from Konur and Golias's (2013a) study, Heidari *et al.* (2018) considered the outbound side as well. The arrival time of trucks was uncertain, but a time window was defined for truck arrival. To improve usability, Ladier and Alpan (2016b) developed a model to address the frequent disruptions in the scheduling of trucks in cross-docking centres. However, a weakness of their study is that the limits of the temporary storage are not considered.

In order to reduce the long waiting times at the gates and yards, management of arrival time is vital. H. Zouhaier and Ben Said (2016) explained that reducing the waiting times caused by delays in arrival time of trucks can increase efficiency. To reduce the negative impact of uncertainties, one of the practical measures is a truck appointment system. This method can monitor the planning of arrival times by assigning an appointed slot to each truck, which, in turn, minimise truck deviation time. Although H. Zouhaier and Ben Said (2016) considered the limitation of resources and doors, the limitations of temporary storage and yard space were not considered.

The above-discussed studies considered the uncertainties in arrival time of receiving trucks. The arrival time of shipping trucks is equally important can impact cross-docking operations. The first study about uncertainties in the arrival time of shipping trucks was presented by Zaerpour (2013) and Zaerpour *et al.* (2015). The authors argued that when trucks arrive outside the time window, the risk of reshuffling with shared storage will increase. Reshuffling time in this system can be increased because of improper assignment. First come, first serve (FCFS) can increase the possibility of reshuffling. Accordingly, uncertainties in truck arrival times can decrease the accuracy of defined time windows which leads to reshuffling and increase in cross-docking operations costs. Reducing the cost associated with reshuffling, arrival time of trucks needs a proper time window for the arrival time of shipping trucks. It is also interesting to consider the probability of facilities breakdown.

Queuing systems can help manage the waiting time of trucks in cross-docking centres. To improve the system, Motaghedi-Larijani and Aminnayeri (2017) proposed a model to examine the arrival time of single outbound trucks as random with uniform distribution. A queuing model was developed based on a situation where the expected waiting time of customers is considered. The aim of this paper was minimising the total admission and waiting time cost. However, the research only used one door and one side of the arrival time, which limited the applicability of the model.

By considering the arrival time of truck as a deterministic factor and a certain parameter, literature about cross-docking is far from the reality in the industry. Arrival time of trucks can be the starting source of uncertainty in cross-docking operations. Accordingly, Motaghedi-Larijani and Aminnayeri (2018) considered arrival time of trucks following beta probability distribution and applied queuing model in this problem. They calculated the waiting times of customers based on the delay that happened in arrival time.

3.1.4 Availability of trucks. The availability of trucks which is related to the external suppliers can impact planning and scheduling of resources. When proper resources are not available it impacts all products scheduled for delivery to customers. This factor includes both the inbound and outbound sides of the cross-docking centre operations. In addition, trucks can fail during the delivery of products to cross-docking centres or retailers. If the availability of trucks is disrupted, there is a need for reallocation of all orders and resources to fulfil the scheduled delivery.

Amini and Tavakkoli-Moghaddam (2016) developed a model that considered truck breakdown during service time. The breakdown of trucks followed a Poisson distribution. The objective of this paper was minimising the total weighted completion time or tardiness of outbound trucks. This paper only considered the outbound process. All of the trucks were available at the time of zero, which is impractical, and the temporary storage capacity is infinite.

3.2 Internal uncertainty components

3.2.1 Processing time. Processing of inbound and outbound trucks is prone to uncertainty. Delay in fright handling can prolong the distribution process in the whole system. There are several factors that can impact the processing time of cross-dock centres. For instance, loading and unloading of trucks can be impacted by skills of the workforce in terms of the time that people need for doing the same job. This process can disrupt the flow of products in cross-dock centres. The loading and unloading and transferring time for different types of products is also different that can influence on planning. Accordingly, Wang and Regan (2008) suggested that using real-time information to schedule the unloading of receiving trucks can decrease the total freight transfer time. Therefore, they focussed on the effect of new receiving trucks on overall transhipment time. One weakness of this study is that it did not consider both inbound and outbound sides. It is important for cross-dock operations from a practical viewpoint to focus on unloading, loading and waiting time of trucks. McWilliams (2009) conducted a study into the processing time inside cross-docking centres to minimise total transfer time. A dynamic load-balancing algorithm was designed. The process of unloading trucks and assignment of trucks to doors was updated after unloading each truck. The study assumed that all shipping and receiving trucks were available at the time of zero, which is not realistic. In addition, the priority of each truck was not considered.

According to Sathasivan (2011), unloading and loading of trucks can be overestimated or underestimated. Both can impact the optimal solution. Therefore, it is pivotal to consider the uncertainty in unloading time of trucks. As a result, stochastic and robust optimisation approaches were implemented. Sathasivan (2011) minimised weighted completion time to determine the optimal schedule for unloading receiving trucks. The study assumed that trucks were available at the time of zero and that the cross-docking centre had only one receiving and one shipping truck, which was far from a real environment.

3.2.2 Available resources. Material handling is the core of operations and includes the most expensive operations in cross-docking. Unloading, transferring, consolidating, splitting of orders and loading during the operation of cross-docking rely on labours and available resources. Therefore, this costly operation needs to be carefully monitored to reduce cost and increase utilisation. Shakeri *et al.* (2012) developed a model to address the delays caused by forklift breakdown inside the cross-dock centre. The model may be improved through assessing the probability of forklift breakdowns. From a different perspective, Soanpet (2012) studied the effects of capacity uncertainty on the location of cross-dock centres to minimise the total routing cost. Capacity can impact on the number of products that can be handled in the centre. However, their study did not consider limited temporary storage and truck arrival time. Zouhaier and Ben Said (2017a) argued that increasing the available resources can increase the performance of cross-dock centre and decrease the completion time at the same time. They presented a multi-agent-based truck scheduling model to coordinate the arrival and gate process and the availability of human resources inside the cross-docking centre. They considered available human resources with different abilities, but did not consider temporary storage inside the cross-docking centre.

3.2.3 Departure time. The departure time of trucks is one of the uncertainty components that can be resulted from internal and external sources. It can absorb other uncertainties such as arrival time and service time. This situation becomes more challenging when the trucks on the inbound and outbound sides have a deadline. Assignment of trucks to doors is one of the critical decisions in cross-docking operations. With restricted truck departure time, M.K. Acar (2004) studied dock-door assignment to minimise the distance travelled inside the cross-docking centre to deliver products to shipping doors. The authors assumed that shipping trucks were always available at shipping docks and temporary storage was not considered, which is not realistic (Acar *et al.*, 2012). Literature about departure uncertainty is limited and requires further attention. Studies in the area of flight routing and scheduling with departure uncertainties in air traffic management may be a good starting point for developing solutions in cross-docking operations.

3.3 Multiple uncertainty components

Multiple uncertainties can exist during cross-docking operations. For the purpose of discussion, research that considered more than one uncertainty components is grouped into this category. Inaccuracy in arrival time and content in trucks can lead to uncertainty in processing time. Yu *et al.* (2008) presented an online method to solve dock-door assignment problems. The authors considered uncertainties in arrival time and the content of trucks and supply to minimise processing time using the FCFS policy. According to the results, this method can improve resource planning by 20 per cent. Temporary storage and unavailability of resources were not considered in this study.

Following the same concept, Alpan (2010) presented a problem for the scheduling of cross-docking operations under uncertainties of inbound truck arrival time. The model aimed to minimise the total cost by using the best sequence of shipping trucks. They assigned the products to the shipping trucks following the first-in-first-out policy, which is the same as FCFS. The model, however, only considered one receiving door and one shipping door with infinite temporary storage space. The results illustrated that when no information was available on the arrival time of trucks, the total cost exhibited a significant increase (Larbi *et al.*, 2011).

Manual rules used to manage cross-dock operations give sub-optimal result, which according to Li *et al.* (2012) is inappropriate. Consequently, they developed an online scheduling and planning tool which reached optimal solutions for planning inbound trucks, the allocation of trucks to docks and the priority of jobs for forklifts to maximise the output. Research attempts to optimise cross-docking operations in three layers: planning, scheduling and coordination. The aim of the planning layer is minimising processing time, which consists of sequencing and allocation of containers. Processing time is the first uncertainty component, the late arrival time of trucks is the second uncertainty and the third one is resource management in a dynamic environment. To integrate the three layers, an event-based integrated optimisation model was developed by Ladier *et al.* (2014) with discrete event simulation. They aimed to evaluate the robustness of the IP model. In their study, arrival time, unloading time and processing time were uncertain. They used FlexSim software to develop the simulation model. In order to model unloading and to transfer time, they used triangular distribution and, for arrival time, exponential distribution. Temporary storage space was infinite. Resources inside the cross-docking centre were limited. The results showed that the model had reasonable robustness against uncertainties. To improve the previous model, Ladier *et al.* (2015) conducted further research and they considered uncertainties in available resources and tasks as well.

Collaborative computing using a poll of heuristics can be used to find solution. Yin *et al.* (2015) researched collaborative vehicle routing and scheduling in cross-docking centres under uncertainties to minimise the makespan of cross-docking centres along the horizon. Three types of uncertainties were considered including vehicle failure, demand and arrival time. In order to solve the problem, a hyper-heuristic method was used which included collaborative computing and service rules. In this paper, the temporary storage and the process inside the cross-docking centre were not considered. Two-thirds of the operations in cross-dock centres are focussed on scheduling and assignment. Proper coordination of inbound and outbound activities can facilitate the smooth operation inside of the cross-dock centres. Fatthi *et al.* (2016) presented a study about the scheduling and assignment of trucks in an inbound phase to minimise the completion time on the inbound side. This model was based on real-time information with the number of receiving trucks, the content of trucks, arrival time of trucks and unloading time of trucks were dynamic.

4. Conclusions and future research directions

This literature review focusses on cross-docking operations under uncertainty. The selected studies addressed various issues in cross-docking at tactical and operational levels. Since the focus is on optimising operations with existing infrastructure and facilities, studies on strategic-level problems were excluded. The framework presented in Figure 4 illustrates the composition of uncertainties in cross-docking operations. Based on the results derived from reviewing the literature, several gaps have been identified.

First, according to Boysen and Fliedner (2010), truck arrival time is often uncertain. The causes of this uncertainty include weather condition, traffic condition and truck failure. While several authors considered truck arrival time as uncertain, all these studies are far from applicable to the practical environment. A main limitation is yard management and the effects of uncertain arrival time and limited yard storage on cross-docking operations when there are deadlines for receiving and shipping trucks.

Second, the availability of resources significantly influences cross-docking operations. Forklifts, conveyors and labour are the most common resources for unloading, transferring and loading the products. In the literature, some studies considered limited resources. However, the assumptions used in developing the model are unrealistic and cannot be used for practical solutions (Amini and Tavakkoli-Moghaddam, 2016; Fatthi *et al.*, 2016; Ladier, 2014; Li *et al.*, 2012; Shi *et al.*, 2013; Soanpet, 2012; Zouhaier and Ben Said, 2017a, b). If temporary storage has unlimited capacity, the impact of resources limitation is not visible as all the extra products have to be moved to the temporary storage. If the storage capacity is not enough, the operations of the cross-docking centre will be disrupted. Therefore, models combining the limited temporary storage with limited resources capacity may provide meaningful solutions to optimise cross-docking operations.

Finally, the departure time of trucks relies on arrival time, truck processing time and availability of resources inside the cross-docking centres. Previously, literature is limited to arrival time and due date for shipping trucks (Acar *et al.*, 2012; Acar, 2004; Fatthi *et al.*, 2016; Ladier, 2014; Ladier and Alpan, 2016b; Ladier *et al.*, 2014; Walha *et al.*, 2014). Future research can focus on developing integrated solutions through several steps. In the first phase, the process of optimising departure time and all related activities should be considered in the model. In the second phase, the impact of limited yard storage and temporary storage should be addressed. Finally, the effects of deadline on the overall performance of cross-docking centres and the capacity of trucks occupied by loaded products should be examined because in some cases, with deadlines on shipping trucks, the capacity which can be used may be less. Limited yard and temporary storage can increase the waiting time of shipping trucks and therefore increasing carbon emission. This is another gap that should be addressed in future research. The result of this review shows that the combination of uncertain factors and the effect of physical characteristics of cross-docking centres is one of the leading research areas which deserve more attention.

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