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A bounded dynamic programming approach to schedule operations in a cross docking platform

Gülgün Alpan *, Rim Larbi, Bernard Penz

Laboratoire G-SCOP, Grenoble INP-UJF-CNRS, 46 avenue Félix Viallet, 38031 Grenoble, France

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A B S T R A C T

Cross docking is a logistic technique employed to reduce the inventory holding, order picking, transportation costs as well as the delivery time. Products arriving to the cross dock are unloaded from inbound trailers, possibly reconsolidated with other products arriving from different destinations and loaded into outbound trailers within less than 24 h. In this study, we consider a multiple receiving and shipping door cross dock environment. The objective is to find optimal (for reasonably small cross docks) or near optimal (for larger cross docking facilities) scheduling policies which minimizes the total costs related to the transshipment operations at the facility.

1. Introduction

A platform of cross docking is a consolidation point of inbound products and offers short cycle times. Materials arriving to the cross dock from suppliers are unloaded from the inbound trailer, sorted according to their destinations, possibly consolidated with other products to the same destination and reloaded into an outbound trailer within less than 24 h. Therefore, this technique is mainly used in the transportation industries or in the distribution of the perishable products.

In the literature on cross docking, we can find studies dealing with problems either on the strategical or the operational level. The solutions for strategical problems often require an investment and the decisions taken are not frequently modifiable. For instance cross dock network design (see Chen, Guo, Lim, & Rodrigues, 2006; Donaldson, Jonhson, Ratliff, & Zhang, 1998; Ratliff, Vate, & Zhang, 1998) or the layout of cross docking platforms (see Bartholdi & Gue, 2002; Bartholdi & Gue, 2004; Gue, 1999) make part of this category of problems.

The problems which are handled in the operational level are mainly on the real-time control of the cross docking platforms and hence the decisions are modified on a real-time basis. In this category of problems, we can cite the dock assignment problems, the objective of which is the assignment of inbound and outbound trucks on the docks in order to optimize a criterion (see Tsui & Chang, 1990; Tsui & Chang, 1992 for the minimization of the weighted distance between inbound and outbound trucks; see (Bartholdi & Gue, 2001) for the minimization of the congestion within the cross docking platform.) Scheduling of transshipment operations inside the cross docking platforms are also in this group of problems (see Alpan, Bauchau, Larbi, & Penz, 2008; Baptiste & Maknoon, 2007; Baptiste, Penz, & Larbi, 2007; Boysen, 2009; Boysen, Fliedner, & Scholl, 2008; Chen & Lee, 2009; Chen & Song, 2009; Larbi, Alpan, Baptiste, & Penz, 2007; Larbi, Alpan, & Penz, 2009; McWilliams, Stanfield, & Geiger, 2005; Sadykov, 2009; Song & Chen, 2007; Yu & Egbelu, 2008). These recent studies seek to find the best schedule of trucks so that either the time or the cost related performance measures of the cross dock is optimized. Among these studies, (Baptiste & Maknoon, 2007; Baptiste et al., 2007; Boysen et al., 2008; Chen & Lee, 2009; Larbi et al., 2007; Sadykov, 2009; Yu & Egbelu, 2008) consider the case where there is a single receiving and a single shipping dock. These studies give interesting insights on the solution structure for scheduling problems at the cross docking facilities, however no practical application is possible. In practice a cross docking facility has several receiving and shipping docks. The largest facilities can have several hundreds of docks. Therefore, for implementation purposes, it is important to study the multi door cross docking settings.

To the best of our knowledge, the scheduling problems in multi door cross docks are studied in Alpan et al. (2008), Boysen (2009), Chen and Song (2009), Larbi et al. (2009), McWilliams et al. (2005), Song and Chen (2007). Chen and Song (2009) presents the cross docking scheduling problem as a two-stage flow shop problem with parallel machines. Each stage corresponds to either inbound or outbound side of a cross dock, the machines and the set of jobs are analogous to inbound or outbound docks and the trucks to unload or load, respectively. Indeed, this analogy was first established by Chen and Lee (2009) where each stage of the problem contained only a

* Corresponding author. Tel.: +33 476574333.
E-mail addresses: gulgun.alpan@grenoble-inp.fr (G. Alpan), rim.larbi@grenoble-inp.fr (R. Larbi), Bernard.Penz@grenoble-inp.fr (B. Penz).

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single machine (i.e. single inbound and outbound dock). They show that the problem is NP-hard in the strong sense. An extended version is proposed by Chen and Song (2009). In this later study, at least one of the stages is allowed to have more than one machine. In these studies, the objective is to find the best schedule of inbound and outbound trucks so that the makespan of operations is minimized. The same authors have studied a similar, yet simplified version of the same scheduling problem in Song and Chen (2007).

The industrial context may impose specific constraints on the cross docking operations. McWilliams et al. (2005) and Boysen (2009) hence consider some specific industrial settings. McWilliams et al. (2005) present the parcel hub scheduling problem common in parcel delivery industries such as the postal services. The objective of this study is very similar to the scheduling problems in multi door cross docking facilities, i.e. finding the best schedule of inbound trucks so that the makespan of the parcel transfer operations is minimized. However, the environmental setting has some specificities. One of the characteristics of a parcel hub compared to a classical cross docking platform is the type of materials handling system utilized. In a parcel hub, the flow of the materials is supported by a network of fixed conveyor belts. Temporary storage of pallets are not considered. The main focus is on the congestion of the fixed conveyor belts by the untimely unloading of the incoming parcels. Therefore, we consider the parcel hub scheduling as a special case of cross docking. Another special case is studied in Boysen (2009) for a food industry cross docking facility. In this case, the inventory holding is strictly forbidden. The author presents a dynamic programming approach as well as heuristics based on simulated annealing to schedule the inbound and outbound trucks. Three time-related objective functions are considered: minimization of total processing time, total flow time and the total tardiness.

The current article is an extended version of a previous study presented at the 38th International Conference on Computers and Industrial Engineering (Alpan et al., 2008). The cross docking environment under study is a multi receiving and shipping dock setting. In this paper, similar to the above presented literature, we would like to determine the best schedule of outbound trucks which should be present at the shipping doors at any given time, given a known sequence of inbound truck arrivals. Our problem differs from the previous work in two aspects: (i) In all of the previous work, the objective function is a time-related one, such as the minimization of makespan, or total tardiness. This is rather classical in scheduling and is an indirect way of considering operational costs. In this paper, we will directly focus on operational costs related to temporary storage of merchandize inside the cross dock and the costs related to pre-emption of loading operations at the docks. (ii) The second difference comes from the problem structure. Here we allow, pre-emption of loading operations which is not allowed in previous work. Furthermore, we explicitly model the temporary storage, which is either forbidden or not modeled explicitly in the existing literature on multi dock cross-dock scheduling problems. We note that in practice, temporary storage or pre-emption are solutions to increase the flexibility of cross docking operations.

The rest of the article is organized as follows. In Section 2 we will give a detailed description of the problem with the basic assumptions and the related input data to the problem. In Section 3, we will briefly present the dynamic program used for the resolution as well as some properties taken into consideration during the resolution phase (Alpan et al., 2008). This section will also include the performance limits of the DP model illustrated by numerical results. Section 4 is dedicated to the presentation of some bounds on the DP model in order to reduce its complexity. Performance of the resultant bounded dynamic programs are illustrated by numerical experiments in Section 5. And finally concluding remarks are given in Section 6.

2. Problem description

In this section we will introduce the basic operations that are realized in the cross docking platform under study. Basic notations used and the assumptions considered will also be given.

We consider a cross docking platform with $I \geqslant 1$ receiving and $O > 1$ shipping doors. The products which transit the facility are sent to one of the D different destinations. Each outbound truck serves a single destination, d, $d = \{1, \ldots, D\}$. Each inbound truck arriving to the platform may contain products for several destinations. If an outbound truck in destination to d is present at a shipping door, the products in destination to d are directly loaded from the inbound truck into the outbound truck. Otherwise, (i) the incoming products are either temporarily stored and a holding cost, h, is paid per unit product (ii) or one of the trucks occupying a shipping door is moved to a parking zone, liberating thus the door for loading another trailer (for example the one to destination d). In this latter case, a truck replacement cost, r, is paid. Naturally, the outbound trucks which are full and are leaving the platform are excluded from this penalty.

The major assumptions of the study are enumerated below.

- A_1: The products are identically conditioned in unit size pallets. Hence, all transshipment operations on every pallet are done in an identical unit time, τ. That is, a pallet can be unloaded, then either be directly loaded into an outbound truck or transfered to the storage area in τ time units. Similarly, a pallet which is temporarily stored will take τ time units to load into an outbound truck. Without loss of generality, we assume $\tau = 1$.
- A_2: The arrival sequence of inbound trucks, as well as their contents and the position of the merchandize in the truck are known. Without loss of generality, we assume that all departing inbound trucks are immediately replaced by a new one. We note that this assumption can be relaxed technically, by inserting empty inbound trucks in the arrival sequence to fill the time gap between inbound trucks.
- A_3: The inbound trucks are assigned to receiving doors based on a FIFO policy.
- A_4: There is sufficient workforce to load/unload all docked trailers at the same time. Hence, a trailer assigned to a dock does not wait for the availability of a material handler.
- A_5: The pallets in the inbound trucks have priority on the pallets already stored in the cross dock. This assumption is a logical consequence of the cost structure and assumption A_1. Since the holding cost h is per unit stored and the time of the storage is ignored, a pallet staying in the cross dock for the whole day will cost the same as the pallet stored for a few minutes. Furthermore, any pallet transferred directly from an inbound to an outbound truck will take only τ time units compared to 2τ time units for the stored items.
- A_6: The outbound truck fleet is well dimensioned with interchangeable standard trucks so that no time is lost waiting for the arrival of an outbound truck.
- A_7: All products arriving to the cross dock during the day should leave the cross dock the same day.

We note that by assumption A_1, we discretize time into intervals of length 1. Each time interval will be denoted by t, $t = 1, 2, \ldots, T$. By assumptions A_1 and A_4 we allow I arriving pallets to be handled at the same time at the inbound docks at a given time interval t. Furthermore, if several pallets to destination d are available at distinct receiving docks and an outbound truck to destination d is also available at the shipping dock at time interval t, these pallets can directly be loaded on the outbound truck at the