Dynamic vs. Static Optimization of Crossdocking Operations

Monique Guignard, Peter Hahn and Heng Zhang

Keywords crossdock; dynamic optimization; simulation; matheuristic; door assignment; turnaround

Introduction

Crossdocking is a practice in logistics that aims at reducing transportation and inventory holding costs in the supply chain. It involves receiving goods from suppliers or manufacturers for several destinations and consolidating these shipments with those of other suppliers for common delivery destinations, then loading them for shipment to their respective destinations at the earliest opportunity. Goods from an incoming trailer are unloaded, sorted and then loaded to outbound trailers, with little or no storage in between. Besides reducing total transportation costs, crossdocking also focuses on reducing the level of inventory held in the supply chain, and therefore inventory holding costs, and order cycle time.

This paper concentrates on the operations that take place inside a crossdock. It assumes that the decisions about trailer contents, as well as their movements from the origins to the crossdock, and the goods' final destinations, are already made. Inbound doors, also called strip doors, are the dock-doors of the building, where incoming full trailers are parked and unloaded. Outbound doors, also called stack doors, are those where outgoing empty trailers are sent to collect freight according to specific destinations. Consolidation (or staging) areas are locations within the crossdock, where goods wait to be loaded into outbound trailers. Figure 1 depicts a typical crossdock configuration and operations.

To improve operations commonly found in today's crossdocks, we offer a door assignment optimization tool that will reduce the distance travelled by goods across the crossdock, as well as workload and labor cost. The cross dock door assignment problem (CDAP) minimizes total distance travelled by the goods inside the crossdock where door capacities are limited by the time they can be used in a work day. Experience shows that following the "beginning of the day" CDAP optimization results for the entire day (the static approach) could negatively impact delivering goods efficiently. We therefore propose a dynamic assignment scheme in which door assignment is reconsidered whenever a new trailer arrives. Repeatedly updating and re-solving for door assignments within a simulation experiment is made feasible through the use of our fast matheuristic solver, CHH, and this permits us to compare the static and the dynamic assignments. Using simulation data based on data from an actual crossdock, we demonstrate the superiority of the dynamic approach in terms of operations efficiency and make managerial recommendations.

1. Problem description

We have worked closely for several years with two firms managing crossdocks in the Eastern US. The first of these firms handles goods coming from US manufacturers and from nearby seaports and destined for a number of retail outlets. This firm's crossdock is of medium size. The second firm manages a larger crossdock, dedicated to goods from a single supplier, which are then shipped to several distribution centers. Our experience shows that optimizing the distance travelled by goods in the crossdock needs to be dynamic, as its solution depends not just on incoming trailer contents, but also on the order in which incoming trailers arrive or are handled.

The major objective is often to optimize the use of the workforce, and its cost. Travel inside the crossdock represents typically 20-30% of total dock labor costs, which is not insignificant. At the beginning of the day, with the information available on the day's workload, we produce the assignments of all the inbound and outbound doors that minimize total distance by solving the crossdock door assignment problem (CDAP). We refer to this scheme as the 'static assignment strategy'.

We then dynamically update the information and optimize the crossdocking assignments accordingly. To guarantee that we meet the time requirements is our primary concern. Even if minimizing the cost of carrying the goods across the crossdock is not the main objective, it is desirable to assign doors so that the total distance travelled by goods in the crossdock is kept to a reasonable minimum. We are trying to keep a balance between meeting the time requirement and keeping the total goods travel distance reasonable, by minimizing the latter and imposing a limit on how much each door can handle within a shift, this is what we call door capacity. This capacity will naturally decrease during the day.

In summary, on the one hand, we optimize the distance travelled by products within the cross-docking facility. On the other hand, we dynamically reformulate and re-solve the distance minimization problem as needed in real-time. By integrating the CDAP model inside a dynamic scheduling of the crossdock, we overcome the CDAP's static limitations, guaranteeing timely operations without having to know ahead of time when trailers will arrive.

2. Assumptions

We consider crossdocks where a few trailers may already be in the yard at the beginning of the day, and others arrive at irregular intervals during the day. Doors are not a priori assigned to origins or destinations, and the destination of arriving goods is however known at the start of the day.

The arriving goods may be packed in boxes of varying size, and we use volume as the standard unit, thus in fact ignoring, as a first approximation, the problem of fitting boxes in outgoing trailers. We hypothesize that all unloading work is done in an identical unit of time, per unit of volume. Similarly, goods that are held in the staging area will take a number of time units proportional to their volume to load into an outbound trailer.

Note that with this assumption we will be able to properly define the capacity of each inbound or outbound door. Obviously, given the time required for fully unloading or loading a trailer, as well as the time constraints that must be imposed on each working day, one can schedule only a limited number of trailers at a door. Following this we introduce capacity in the problem to represent this time limitation.

Our prior information on arrival times of inbound trailers is limited in the sense that we only know in advance which trailers will be arriving that day, but not their actual arriving times. The contents of each trailer are known in advance, but individual item positions in the trailer are not known.

The unloading of the trailers is done using a FIFO policy, i.e., the first inbound trailer arriving in the crossdock yard will be considered for assignment to one of the free inbound doors, if any. Otherwise it will wait in the yard.

The workforce at the crossdock is sized such that it can unload all the inbound trailers and load them in the same work shift even if all the doors are occupied. At this point, we do not try to directly minimize the cost of labor, even though this is of great concern to management. This will be part of our ongoing research.

Goods are loaded into outbound trailers only after having been placed in one of possibly many staging areas. The use of staging (consolidation) areas is a common practice in cross-docking operations. The specific position of staging areas can vary in practice. They may be in the middle of the cross-dock or closer to the stack door side. They may be divided into slots corresponding to the destinations but not always. We do not make specific assumptions on their positions organization. Instead, we only assume two things that should be easily satisfied in practice. First, the amount of materials accumulated in the staging areas is known to us. Second, the door-to-door distances we use already assume that the goods make a stop-over at a staging area.

We further assume that once the materials accumulated *for one destination* exceed a certain threshold, which we assume to be 90% of a Full Truck load (FTL), we consider the accumulation adequate and one outbound trailer assignment should be called in for this particular destination.

The outbound trailer fleet is well supplied with interchangeable standard trailers, so that no time is lost waiting for the arrival of an outbound trailer.

Note that most of the time, the load will consist of goods coming from several incoming trailers, and one has to wait until the last of these trailers is fully unloaded, as the loading patterns inside incoming trailers are usually not known in advance. Thus for simplicity, the staging areas will not be updated unless an inbound trailer has just finished unloading.

3. Problem to be solved

In terms of distance optimization, we shall consider the CDAP problem. The objective of the CDAP is to minimize the total distance travelled by all goods across the floor of the crossdock for the entire processing period, subject to assignment and capacity constraints. It is a pure 0-1 bilinear generalized assignment-type model. We look at a realistic simulation problem to compare the dynamic and static schemes, where the trailer loads are taken from volumes processed by the first company mentioned above on a typical busy day. In our dynamic algorithm, the CDAP problem is re-solved and its data updated, after each new trailer arrival, while in the static model one waits until the infeasibility resolves itself.

The constraints of the CDAP make sure that the capacity S_i of strip door i is not exceeded, that each arriving trailer gets assigned to only one receiving (strip) door, that the capacity R_j of outbound (stack) door j is not exceeded, and that each destination is assigned only one stack door.

With this model we are able to assign multiple origins to a single strip door, as long as its capacity could accommodate them. It is also possible to assign multiple destinations to one stack door, as long as its capacity could accommodate them.

4. The simulation study of static and dynamic assignments

Several critical things happen in the course of crossdocking operations and require management actions:

B1. The arrival of an inbound truck.

B2. The finish of unloading of a particular inbound trailer

B3. The finish of loading of a particular outbound trailer.

These three things are formally defined as **Events** in the simulation. Regardless of the nature of these events, we need two actions: inbound or outbound assignment. In static and dynamic assignment schemes, we handle inbound and outbound assignment differently.

To compare the dynamic and static optimization of cross-docking operations, we have developed a discrete event simulation, using MatLab. We follow the general principles of standard discrete event simulation. Our purpose is to mimic the real operations of cross-docking facilities to demonstrate the efficacy of the dynamic optimization compared with the static optimization, relative to several performance aspects.

Corresponding to the three types of **Events**, there are three types of **Activities** in this simulation system. **Activity 1** is the interarrival of inbound trailers. **Activity 2** is the unloading of an inbound trailer. **Activity 3** is the loading of an outbound trailer.

5. Simulation experiment protocols and results

We compare the impact of our dynamic model and static CDAP model through controlled experiments and the resultant operations statistics. The data used in the experiment are taken and modified from the one-day operational data of the first cross-docking firm with which we were working. The original data set specifies the 25 inbound and 16 outbound doors available, as well as the size 25x16 distance matrix. Also, the flow matrix of size 56x16 as given in the original data represents the typical operation of the cross-docking facility of the first firm. We now present the main findings from these experiments.

Both strategies are helpful in achieving our secondary goal -- saving the distance travelled by products. The dynamic CHH CDAP solver better utilizes the doors, as the flows are more evenly distributed to both inbound and outbound doors. This allows us to better use door capacity to work efficiently. Also, towards the end of the planning period, no new inbound assignments are produced in the dynamic assignment strategy, since all trailers have already been assigned to the strip doors, as opposed to what happens in the static strategy. The dynamic flow pattern not only helps us to better utilize the doors so that work can be finished in a timely manner, it also avoids the over-crowded operations in one small area of the crossdock. Finally, three more inbound trailers are handled this day in the dynamic assignment.

We now move on to other aspects of the comparison of the static and dynamic strategies. Recall that our primary goal is to finish the work in a timely manner. The superiority of the dynamic assignment strategy is clear in terms of our primary objective. Flows move faster inside the cross-dock. More materials and inbound trucks are left unhandled in the static assignment strategy. The door capacity of the cross-dock in the dynamic assignment strategy is better utilized.

With more doors being utilized in the dynamic assignment strategy, naturally more workers are needed in the operations. Efficiently employing the human resources is important. In the typical cross-docking operations of the two companies we are working with, about 80% of the workers are temporary and reserved from agencies. Once workers are called in for crossdocking work, the crossdock managers hope these workers could be better scheduled, so they could be better utilized in their shift, since they still need to be paid even when idle. Our dynamic assignment helps us to better achieve these goals. The workers worked longer on average and were less idle. The worker utilization rate in the dynamic situation is better than the one in the static situation.

The above results correspond only to uniformly distributed arrival times. We performed two additional sets of experiments with different arrival time distributions of inbound trucks. The more concentrated the arrival times, the more difficult the operations would be. Congestion resulting from the large number of arrivals in a short time interval has a negative impact on various aspects of operations. For both static and dynamic assignment schemes, more trailers and materials are left unhandled at the end of the day when more concentrated arrivals take place. Operations get slower, as the inbound truck turn-around time and material turn-around time increase. This effect is more prevalent in the static situation.

The dynamic assignment strategy, through flexibly using the capacity of the crossdock, handles this congestion better. But this comes at a certain price: we can observe the salient increment in the number of workers needed in the dynamic assignment strategy in the last two experiments. But the number of workers required and working for the static assignment scheme remains steady. When we are facing operations where the arrival times tend to be concentrated at certain hours of a day, and the efficient run of cross-dock is the most important concern, a dynamic assignment strategy becomes even more valuable.

6. Conclusions

To improve the experience-based operations commonly found in today's crossdocks, we offer a door assignment optimization tool for crossdock managers that will reduce the distance travelled by goods across the crossdock as well as the workload and even the labor cost. While CDAP is a useful guide, our close cooperation with two firms managing crossdocks indicates that to blindly follow CDAP optimization by itself could negatively impact delivering goods efficiently.

Some key guiding principles regarding this are the following rules-of-thumb from crossdock managers. First of all, materials need to be sent out from the facility efficiently. Sometimes crossdock managers will have to pay fines for goods not shipped out within 48 hours. When the customers evaluate the services provided by the crossdock, they sometimes consider the efficiency of processing the materials as the most important factor. In either case, our communications with the two firms with which we have worked indicates that this is always the most important performance measure in their operations. The inbound trailers should also be returned efficiently. Delay in doing this may result in fines. In view of this, and considering that the situation changes constantly in the course of cross-docking operations, maybe to the extent that it becomes very different from our original planning, we introduce a dynamic assignment scheme to efficiently utilize the solutions from CDAP as a guide of the door assignment.

In summary, we do as follows in the dynamic assignment scheme. Whenever a strip door assignment is needed, we look at our cross-dock and check for available strip doors by removing all the doors that cannot be of immediate use, calculate their remaining capacities, and solve the CDAP problem in real-time. On the stack door side, however, when an assignment is required, since all the origin doors of the flows that need to go across the cross-dock are already assigned, we only search the best stack door in terms of distances. Note that this scheme is made possible by the Convex Hull Heuristic (CHH) to solve the CDAP problem, which is a nonlinear integer problem and is NP-complete. Our dynamic scheme requires solving the problem for a dozen times in practice and no delay of assignment should happen due to the long time of solving CDAP, thus to implement this scheme we need a good heuristic such as CHH to find a satisfactory door assignment in a very short time. The reassignment rules are simple to implement and the CH heuristic takes only one or two minutes on a PC. This dynamic scheme thus gives us a holistic solution to the trailer-to-door assignment problem in the cross-dock.

Within the framework of our current distance-based dynamic CDAP model, we are considering developing a more complete solution. Workers in our simulation are called in on an ex-post basis. We produce the number of workers needed in the course of the simulation. But in reality, practitioners will have to plan ahead. Based on the results of simulation, we will try to control the worker numbers and move our research to a more direct approach -- a labor cost based approach, -- while the time related constraints are still satisfied and the distance is still being optimized.

The CDAP problem could also be modified in other directions. Instead of assuming one destination could only be handled at one stack door, we may relax the problem and allow fractional numbers. In this fashion, the CDAP problem will better mimic the real operations. Inside congestion is also an important problem to be considered. Directly modeling the congestion based on empirical methods and having the CDAP problem modified accordingly are also possible. We should mention to the reader that these changes should cause no difficulty for solving. CHH is designed to tackle general non-linear objectives . We could modify the algorithms accordingly to suit these formulations.

Future research might also involve an extended CDAP model with time-indexed variables. Such a model may be impossible to solve exactly, but the CH heuristic can likely be extended to handle this enlarged model, albeit requiring longer solution time. However it will need to be executed only if there is an unexpected change in the arrival schedule.