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Operational Strategies for Single-Stage Crossdocks

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Transportation Science

by

Jiana-Fu Wang

Dissertation Committee:
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2008

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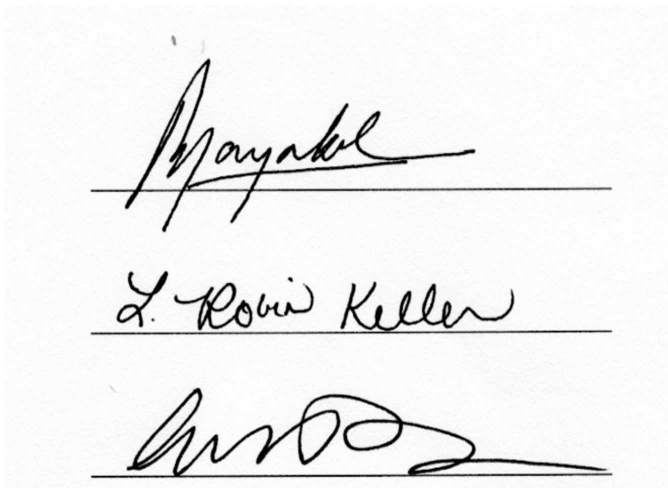

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ABSTRACT OF THE DISSERTATION

Operational Strategies for Single-Stage Crossdocks

By

Jiana-Fu Wang

Doctor of Philosophy in Transportation Science

University of California, Irvine, 2008

Professor Amelia C. Regan, Chair

Because of the growing importance of hub-and-spoke operations in the trucking industry, crossdocking has become an important and effective tool to transfer freight. Companies like Wal-Mart, Costco and Home Depot are using this kind of facility in their logistics operations. In these crossdocks, efficiently operating them, thereby reducing unnecessary waiting and staging congestion for freight and workers is an important issue for managers.

This dissertation uses real-time information about the contents of inbound and outbound trailers and the locations of pallets to schedule unloading for waiting trailers or assign destinations for unloading pallets: we choose a waiting trailer that will need the least time for its pallets and existing pallets; and we may assign an alternate destination for a pallet if its primary destination is expected to encounter

congestion. Two dynamic trailer scheduling and four alternate destination strategies are proposed and compared with baseline scenarios.

Our simulation results suggest that:

1. Our strategies are effective. The two time-based trailer scheduling algorithms can save cycle times as much as 64%, 57% and 30% in the 4-to-4, 4-to-8 and 8-to-8 crossdock scenarios, respectively; the four alternate destination strategies can save cycle times as much as 34% in the 8-to-8 staging crossdock scenarios. In addition, these strategies can raise throughputs for crossdocks. These effects should result in noticeable improvements in supply chain networks, including shorter transportation lead-times, more reliable on-time deliveries and lower inventory costs.
2. In our alternate destination strategies, even if a destination-change results in extra time for value-added services for freight, the strategies are still worth adopting.
3. The combination models of our trailer scheduling algorithms and alternate destination strategies work better than solely implementing an alternate destination strategy when trailer arrivals are dense.
4. A higher flexibility in choosing alternate destinations can bring higher performance for crossdocks.

Chapter One

Introduction

Two growing trends have been intensifying the importance of hub-and-spoke operations in the trucking industry. First, e-commerce stimulates the need for small but frequent shipments. Second, the dispersion of business and residential locations caused by urban sprawl enlarges the range of freight networks. Using hub-and-spoke trucking operations, transportation resources can be employed more efficiently and, at the same time, transportation costs can be reduced and service levels of networks can be improved. Related issues of interest have achieved attention from both the private and public sectors. Trying to improve operations from a point of view of the government, Kay and Parlikad (2002) propose a public logistics network to minimize the transport time of the entire supply chain. Because of the importance of hub operations, any delay or inefficiency in a hub can hinder the performance of the whole network. They conclude that the performance of this public logistics network depends heavily on the time required for loading/unloading. Hence minimizing both the operation time and costs at hubs has become one of the key issues in freight transportation systems and also one of the objectives for the U.S. national freight policies (DOT, 2007).

A crossdock is a kind of hub that can effectively transfer freight from inbound trailers to outbound trailers without storage. Many manufacturing and retail companies, such as Wal-Mart and Home Depot, have broadly adopted this kind of facility in their logistics operations. According to Bartholdi and Gue (2004), there are more than 10,000 crossdocks in the U.S. and Canada.

Most crossdocking papers use static models and consider only door-to-door distances to optimize freight flows in crossdocks. In reality, congestion effects occur in crossdock operations. Though Bartholdi and Gue (2000), Bartholdi, Gue and Kang (2001), Gue and Kang (2001) and Brown (2003) discuss congestion, none of them consider both internal freight movements and queueing processes. Queueing processes are an important feature in crossdocks. Formally, queueing appears in the form of staging lanes, but staging in front of shipping doors should also be considered as a kind of queueing. Without correctly taking into account the queueing effects, sub-optimal strategies may result. In this research, we consider internal freight flows with congestion effects caused by waiting and stage queueing, and then use strategies like trailer scheduling rules and alternate destination assignments to alleviate congestion. By doing this research, we hope to improve crossdocks' operational efficiency and hence enhance the competitiveness of logistics networks.

1.1 Types of Crossdocking

The crossdock is a special type of warehouse. A traditional warehouse has four basic functions: receiving, storage, order-picking and shipping. First, a bundle of freight is received in a warehouse and then placed in a storage location. Next, order-picking occurs when an item is requested by a customer. Finally, shipping is activated when orders are consolidated and moved to trailers. Among these activities, storage and order-picking together account for about 70% of warehouse operation expenses (Bartholdi and Hackman, 2007). The crossdocking system, like the just-in-time (JIT) system, is designed to reduce inventory and processing labor, and also aims to attain truckload transportation economies within shorter order cycle times. Crossdocking attains these benefits by transferring shipments directly from inbound trailers to outbound trailers with no storage in between. Usually, shipments are shipped within 24 hours, though sometimes it could be less than one hour (Gue, 2001; Bartholdi, Gue and Kang, 2001; Apte and Viswanathan, 2000).

Crossdocks can be classified by the types of freight handled, the timing of information flows or the types of staging involved. Napolitano (2000) categorizes them into five types: manufacturing, distribution, transportation, retail, and opportunistic crossdocking. Bartholdi, Gue and Kang (2001) divide them into pre-distribution and post-distribution crossdocks according to whether the destinations of the shipments have been determined before they arrive at the crossdock, and they also classify them into single-stage, two-stage and free-stage crossdocks. Here we explain the latter two classifications further.

A pre-distribution crossdock maintains an extensive information sharing system with vendors. Destinations have been determined before shipments arrive, so these can be transported directly to outbound docks. Hence, it requires less space and shorter handling time than a post-distribution crossdock. In a post-distribution crossdock, workers assign destinations to shipments, so shipments have to be staged for assigning or labeling.

In a single-stage crossdock (Figure 1.1.a), pallets are put into queues corresponding to their receiving or shipping doors. In a two-stage crossdock (Figure 1.1.b), workers put pallets on the first staging lanes corresponding to the receiving doors.

Another set of workers sort them to the second staging lanes corresponding to the shipping doors. Accordingly, more time and labor are required than in the single-stage type. Free staging areas are usually used in the less-than-truckload (LTL) trucking industry outside shipping doors. The receiving and shipping doors in a LTL crossdock could be on both sides (see Figure 1.1.c).

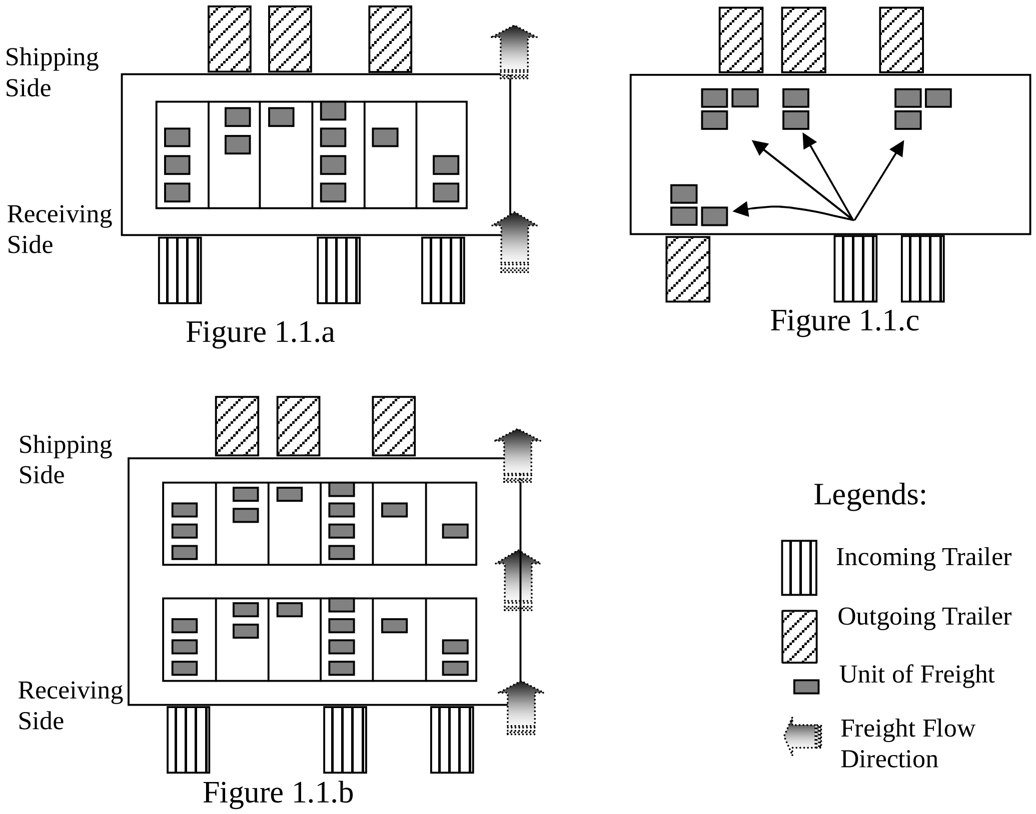

Figure 1.1 Representation of a Single-Stage Crossdock (1.1.a), a Two-Stage Crossdock (1.1.b) and a Free-stage (LTL) Crossdock (1.1.c) (adapted from Bartholdi, Gue and Kang (2001))

1.2 Problem Statement

This research focuses on the freight movements in a single-stage crossdock. We assume that the information about the destinations of pallets is known before or when trailers arrive and that this information is used to identify pallets and assign their destinations. A radio frequency identification (RFID) tag is labeled on each pallet and RFID receivers are installed on forklifts and at certain locations in a crossdock to detect the real-time locations of pallets and forklifts and to check the accuracy of deliveries.

Currently, when an inbound trailer arrives at a receiving door, a worker, called a “stripper,” is assigned to remove a pallet from the trailer to a staging lane corresponding to the receiving door or its destination door using a forklift. The stripper then returns to his original receiving door with an empty forklift to transport the next pallet until the inbound trailer is completely unloaded. On the shipping side, workers, called “stackers,” move pallets from staging lanes to outbound trailers accordingly. Outbound trailers on the shipping side wait for pallets until they are fully loaded.

Under this operation, pallets spend most of their time waiting in inbound and outbound trailers instead of traveling inside a crossdock. However, the existing first-come-first-served or the look-ahead policy (Gue, 1999) fails to consider this feature when assigning a trailer to be unloaded. Hence, the first objective of this research is to use real-time information to schedule trailer unloading to decrease total freight transfer time and, at the same time, increase the productivity of a crossdock.

On the other hand, when conducting the staging operation, congestion may occur at the entrance side of a staging lane if more than one stripper accesses the staging lane at the same time, and waiting may occur if a stacker is too slow to empty the last pallet of his or her staging lane in time. Here we note that the pallets in a staging lane cannot move forward by themselves– this makes such operations different from those typically encountered in transportation systems. Thus, a staging lane cannot be reloaded unless the last pallet in the staging lane has been removed. That is why there may be waiting in front of staging lanes.

For this operation, we assume that a stripper could have other destinations to choose from instead of waiting for a vacancy in the desired lane if the staging lane to which a stripper wishes to transport a pallet is full. This assumption is one of a crossdock's characteristics that a cargo of inbound freight with the same contents can be usually broken into several portions to deliver to different destinations. Hence, when a pallet's primary staging lane is unavailable or too congested, and the content of the pallet could also satisfy the demand for an alternate destination, it could be assigned to that alternate destination. This operation is the concept of our alternate destination strategy. These considerations need a real-time, dynamic approach to analyze their advantages and disadvantages, which constitutes the second theme of this dissertation.

1.3 Organization

The remainder of this dissertation is organized as follows. Chapter Two reviews the related literature of this research. Chapter Three describes internal freight flow features in crossdocks theoretically and empirically from the crossdocking literature, queueing theory and simulation results. Chapter Four discusses the development of our trailer scheduling algorithms and their simulation results. The results are compared to the first-come-first-served and the look-ahead policies. This chapter is mainly from our previous work that was published in the Transportation Journal (Wang and Regan, 2008). Chapter Five begins with the formulations of staging costs, a pallet's transfer cost and a stripper's transport cost. It then presents our alternate destination strategies to mitigate the congestion brought by staging queues. Simulation results of those strategies are compared to do-nothing scenarios. In Chapter Six, some extension studies are conducted related to the alternate destination strategies. Lastly, Chapter Seven summarizes main findings from this research work, highlights its contribution and suggests potential topics for future studies.

Chapter Two

Literature Review

2.1 Crossdocking

Research on crossdocking has increased during the last decade because of several successful applications in industry. Examples are Wal-Mart, Home Depot and Costco. These research efforts can be roughly classified into four categories according to their focuses: supply chain network design, inbound and outbound door assignment, trailer scheduling and internal freight movement.

These four aspects are depicted in Figure 2.1. For the network design problem, research mostly focuses on the number and locations of crossdocks, the routing and the size of vehicle fleet, and the situations with capacity or time window constraints. For the door assignment part, they explore how to arrange inbound and outbound trailers to crossdocks' receiving and shipping doors to minimize their transfer time or costs. In the trailer scheduling studies, the emphasis is on how to decide which waiting trailer should go to an available receiving door, or the effects of scheduling the arrival and departure times of inbound and outbound trailers. Finally, the internal freight movement papers discuss how freight moves in crossdocks. The interfering, congestion, queueing and sequencing of freight and the shapes of crossdocks are the topics of this area. The detailed reviews of these studies are introduced in the following sections.

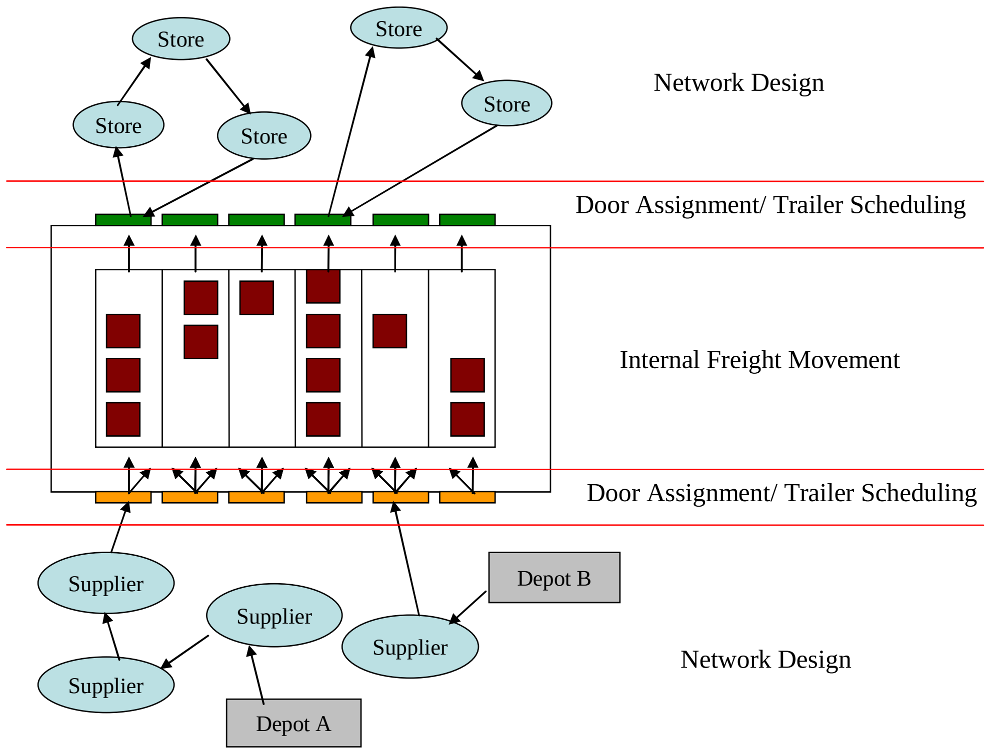

Figure 2.1 Illustrations of the Classifications of Crossdocking Research

2.1.1 Supply Chain Network Design

Donaldson et al. (1999) use the US Postal Service First Class Mail transportation system to construct a schedule-driven crossdocking network model. In their integer programming model, 148 area distribution centers are considered as origins, crossdocks and destinations to distribute mail, and their objectives are deciding how many trucks to assign to each link and how mail should be routed to minimize transportation costs. Small scale networks are tested using branch-and-bound, Bender's decomposition and relaxation methods. They claim that the relaxation heuristic can provide near optimal solutions. Ratliff, Vande Vate and Zhang (1999) examine the automobile delivery network in the US for Ford Motor Company. In their study, newly assembled cars with the same destination railroad center are loaded onto a railcar. Railcars headed in the same directions are sorted into trains at railroad centers—this is what they call a “load-driven” crossdocking system. Typically, a railcar would be switched about six times before arriving at its destination station. For this problem, they formulate a mixed-integer programming model to find the ideal number and locations of crossdocks that minimize the average delay between the time a vehicle is produced and the time it arrives at its destination railroad center. They specify several cases with different numbers of plants, crossdock centers and railroad centers and compare their outcomes. Chen et al. (2006) extend the above two papers with delivery and pickup time windows in their new research. Their objectives are choosing which crossdock to transfer and the time of delivery or pickup to minimize the sum of transportation costs and inventory-handling costs. They use the inventory-handling cost to penalize delays so that inbound shipments can be transported to outbound trailers as soon as possible. An integer programming problem is formulated. And they propose a greedy method to find an initial solution and three heuristics (simulated annealing, Tabu search and hybrid methods) to compare with the results of an exact method (using Cplex).

Sung and Song (2003) consider an integrated service network design problem which solves a combined objective of locating crossdock centers and allocating vehicles from origins to crossdocks and from crossdocks to destinations subject to vehicle capacities and service times. They develop two Tabu-search-based heuristic algorithms to solve their model and compare to the results found using Cplex. The role of transportation providers has been added in Lim et al. (2005). They regard crossdocking as a transshipment problem with constraints of times and inventories, and carriers’ transporting schedules are considered beyond suppliers' and customers' shipping or receiving time windows. Their work identifies nine classes of problems (according to the flexibility of transporting schedules and the frequency of shipping and delivery) and examines a variety of solution methods. Stickel and Furmans (2005) construct a centralized crossdocking model from a view point of a third-party logistics provider operating at minimum costs. A vehicle routing problem for picking up goods from suppliers, a dock door assignment problem for allocating trucks to receiving or shipping doors, and a resource scheduling problem for performing crossdocking inside a terminal are combined in their work. The objective function is too complex to allow for the solution of large problems but a small scale network can be solved within a reasonable time using a branch-and-bound algorithm. A 3-receiving- and 3-shipping-door crossdock, 5 suppliers and 7 customers are included in their network, and the transport cost inside the crossdock is fixed in that model.

2.1.2 Receiving and Shipping Door Assignment

The assignment of dock doors to inbound and outbound trailers is very important for an LTL crossdock. Having inbound trailers as close as possible to their main shipment destination doors could decrease the total weighted travel distance and thus improve efficiency. The basic mathematical model for the door assignment problem is developed by Tsui and Chang (1990). The objective function of their model is to minimize the weighted distance between receiving and shipping doors, and a solution algorithm is proposed in their work. In 1992, they develop an alternative solution using a branch-and-bound algorithm. After these two studies, Bermúdez and Cole (2000) apply a Genetic

Algorithm (GA) to solve the problem. They examine their method with 16-door, 43-door and 195-door LTL terminals and find that their algorithm is able to get better solutions than a popular optimization technique.

Lim, Ma and Miao (2006a) introduce time windows and capacity constraints to this door assignment problem. In their research, the number of trailers exceeds the number of doors and the handling capacity of the crossdock is limited. Hence, each inbound trailer and outbound trailer is assigned an arrival time and a departure time, and the objective is to minimize the total shipping distances for pallets from receiving doors to shipping doors. The authors use a Tabu Search (TS) heuristic and a GA to test some small and large-scale datasets and compare them with the results attained from the Cplex solver. They conclude that the two heuristics are more effective than Cplex. If the runtime is of greater concern, the TS is preferred for solving large-scale problems.

Lim, Ma and Miao (2006b), an extension from Lim, Ma and Miao (2006a), minimize both operational costs and penalty costs in their objective function. The operational costs are measured by shipping distances and the penalty costs denote the costs for the unfulfilled shipments due to time windows and capacity constraints. A GA is applied to solve this problem and the answers are compared to the results using Cplex. According to their results, the GA is better than Cplex in computation time and solution quality for all instances.

In the above door assignment problems, the shortest door-to-door distance is the gauge of measuring costs. Bartholdi and Gue (2000) argue that only paying attention to minimizing weighted distance could cause congestion in front of doors and thus increase labor costs and delays. They formulate several types of congestion that may be found in a LTL crossdock and minimize the total labor cost, which includes travel and congestion costs. Because of the complexity of their model, they construct a simulated annealing procedure to swap pairs of trailers to evaluate the total cost of the resulting layout. In their case study, they show that congestion is a significant factor and report a labor cost savings of nearly 12%. Also, by reducing processing time the crossdock's level of service improves.

2.1.3 Trailer Scheduling

Trailer scheduling is similar to the door assignment problem. Assigning a trailer from a queue of inbound trailers when a receiving door is available is a tough decision, because many factors have to be considered, such as closeness to the destination trailer having the most freight, the number of destinations of the freight in the incoming trailer, the type of freight in the trailer, the availability of transport facilities and the time windows of outbound trailers. By contrasting with the conventional first-come-first-served (FCFS) rule, Gue (1999) proposes a look-ahead scheduling rule: it searches for the trailer in queue with the lowest cost when assigned to the available receiving door. If none exists, it finds the trailer that would be its second lowest cost when assigned to the door. This continues until an assignment is made.

Gue first gets a best layout for each situation with a different number of destinations using his pair-swapping method. Then he runs simulations for these layouts. He only uses weighted travel distances as the criteria of evaluating layouts in this study. He claims a 15-20% saving in labor cost due to travel (about 3-4% of total labor costs), comparing to the FCFS rule.

Ting, Weng and Chen (2004) examine the effect of coordinating the schedules of inbound and outbound trailers in a crossdock terminal. To attain such coordination, an effective information system is needed. In their research, they use a branch-and-bound algorithm to find an optimal headway to minimize the total system cost which includes the vehicle operating cost, inventory cost and transshipment cost. They conclude that the integer ratio headway under a coordinated operation situation is the best strategy, while when the value of goods is low, an uncoordinated operation is better.

2.1.4 Internal Freight Movement

When discussing the internal freight movement in a crossdock, most studies only calculate the direct flows from the receiving side to the shipping side. Here we focus on articles other than those.

For the modeling of freight flow in a LTL crossdock, except for the travel time between doors, Bartholdi and Gue (2000) take into account the waiting time caused by interference among forklifts, congestion in a dragline when placing full carts and pulling empty carts, and floor space congestion due to temporarily putting shipments in front of a shipping door in their cost model. They prove that the performance of the terminal has improved after accounting for the congestion factors to assign doors (11.7% improvement, as mentioned in Section 2.1.2), and they also provide some guidelines for designing efficient layouts.

Li, Lim and Rodrigues (2004) minimize the breakdown and buildup time needed in the import area and the export area, respectively, of a warehouse to allow it to function as a crossdock. They view these two areas as two machines working in parallel, and each one has its own due date and processing time. The problem is to find a schedule to start breakdown and complete buildup of all freight that minimizes the total penalty (they have specified penalties for earliness and tardiness). They propose two GA-based methods to compare these with the Cplex solver and conclude that their heuristics are faster.

Bartholdi, Gue and Kang (2001) and Gue and Kang (2001) use simulation techniques to model the queuing in one-stage and two-stage crossdocks, respectively. In the first paper, they examine how the one-stage queue affects the throughput of a crossdock and how it can influence a crossdock's design. They construct the staging queue as a continuous time Markov chain and then compare their simulation results with the queuing of a flow rack, which can automatically move pallets to the front of the queue. Their experiment shows that the performance of one-stage queues and flow rack queues are nearly the same. They also observe that longer staging queues could have higher throughputs because they are not blocked so often. The second work extends the first one to investigate two-staging queues. Three different staging queues are defined, which are parallel queues, tandem queues and a closed system, according to the waiting behaviors or the activities being done in the waiting period. Their results show that (1) parallel queue systems should have more short queues than fewer long ones; (2) two-stage crossdock systems have lower throughputs than do equivalent single-stage systems; and (3) more strippers and stackers are better in two-stage queue systems. The results of these two studies are further integrated in Bartholdi, Gue and Kang (2007).

Taylor and Noble (2004) also use simulation to examine staging methods in various LTL crossdocking environments. In their study, three staging alternatives which include flow rack, single staging queue and double staging queue (two parallel queues at each dock) are studied under two crossdock layouts (block and alternating layouts) and three outbound demand scenarios (equal freight flows, some have higher flows and placing them at the best doors, and some have higher flows but placing them at disbursed locations). After the simulations, they evaluate these scenarios with four performance criteria: the average flow time per pallet, the make-span to complete processing all inbound freight, the time-based average number of pallets staged in staging areas, and the time-based average number of pallets staged in the central overflow queue. They find that the demand type is more important than either the layout or the type of staging.

Sandal (2005) studies another kind of staging problems. In his research, packages have different sizes and the space of each row in a staging lane is subdivided to hold multiple packages. He considers three staging cases (all freight are staged before being loaded, either being loaded or staged according to the scheduled loading sequence, and being loaded directly) with two staging strategies (random staging and zoned staging). The objectives of this problem are both maximizing outbound container utilization and minimizing material handling and space cost. As a result, he finds that loading outbound trailer simultaneously (the second case) while using a zoned staging strategy outperforms than others. Moreover, he also finds that the freight consisting of larger dimension sized boxes improves profit even though the container volume utilization is lower.

The design of a crossdock's internal setting or external shape could influence freight flows. We found two papers about this topic. In order to compare the workload of the workers in the old and the new settings of a just-in-time factory, Hauser and Chung (2003) use a simulation model to see the effect of the change of material in volume. They examine several cases by varying incoming quantities, levels of part mixture and degrees of crossdocking activities to see the changes in the new layout. They conclude that the proposed new design has a worse effect on the workload. Bartholdi and Gue (2004) study how the shape of crossdocks affects labor costs. They examine the average travel distances of I, L, T, H and X-shape crossdocks with different door sizes under two patterns of inbound freight flows (uniform flows and exponential flows). They find shapes do affect travel costs and suggest “when an I-shape approaches about 150 doors, it should be expanded….creating a T. Should the dock grow again (over 200 doors), the T should be made an X.”

Brown (2003) models the internal flows of a LTL crossdock as a door-assignment and freight sequencing problem. In her study, a stripper might go to another origin trailer for his or her next task after transporting a shipment to its destination trailer. The two problems are solved separately, and their objective functions are to minimize the total travel distance and minimize the bottleneck time (the time window required to transfer freight from a set of origin trailers to the correct destination trailers), respectively. The results from her static model using C++ and from her dynamic model using a simulation package are compared to find out which approach is more efficient. Six freight sequencing approaches are simulated: trailer-at-a-time, trailer-at-a-time with offloading, trailer-at-a-time with exact offloading, nearest neighbor within a group, nearest neighbor within a shared group and nearest neighbor. She concludes that (1) the nearest neighbor sequencing method offers the largest reduction of total labor time and bottleneck time

(23% and 8% of average improvement in the dynamic layout, respectively); (2) the door assignment methods (crossdock layouts) have more influence on total labor time and total distance traveled, while the freight sequencing rules have more impact on bottleneck time; and (3) from the simulation results for the dynamic layout, the blocking in front of receiving and shipping doors increases 2% to 59% of average total labor time and 2% to 93% of the average bottleneck time when compared to conditions without blocking.

2.2 Open Queueing Networks with Blocking

A queueing network is composed of multiple connected nodes; each of them consists of a queue that can accommodate a number of customers waiting for services. If the capacity of those queues is finite, the queueing network is called a queueing network with blocking. A customer gets blocked in a queueing network will be delayed for a period of time. If customers may arrive from outside of a queueing network, it is an open network, or else, it is a closed network. (Perros, 1994; Willig, 1999) The applications of an open queueing network with blocking (OQNB) can be used in different aspects, such as in manufacturing (Papadopoulos, Heavey and Browne, 1993), hospital patient flows (Koizumi, Kuno and Smith, 2005; Osorio and Bierlaire, 2007) and the evaluation of investment for a prison system (Korporaal et al., 2000).

The blocking caused by finite capacities complicates the analysis of a queueing network and hence exact methods to obtain the solution of an OQNB are limited to very small networks— mainly with two queues in tandem with a finite queue between them. The discussion of these methods can be found in Papadopoulos, Heavey and Browne

(1993).

Another way to analyze an OQNB is using approximation methods. The main approximation methods are decomposition methods, which divide a network into sub-systems and analyze them separately. Among them, single-node and two-node decomposition methods are most commonly used. The main differences among these decomposition methods are the ways to estimate the parameters of their sub-systems. For example, in Perros' (1994) exponential effective service time model, he augments the capacities of downstream nodes by the number of upstream nodes to accommodate the blocked customers and assumes that the effective arrival rate of the last node in a network equals to the throughput of the queueing network because there is no blocking for the last node. In Perros' (1994) phase-type effective service time model, he further assumes a customer upon completion a service at a node may find the next node blocked or non-blocked, each with a probability. When there are multiple nodes in a sequence downstream and thus form sequential exponential phases, a Coxian or phase-type distribution is used to estimate customers' effective service times.

Koizumi, Kuno and Smith (2005) assume that the "effective service time" includes the "treatment time" and the "blocked time", and effective service times follow an exponential distribution. Hence, by using an iterative algorithm, they can find the expected blocked time and the effective service time for each node. Alternatively, Osorio and Bierlaire (2007) obtain their "blocked time" by considering the average probability of being blocked and the average value of blocked time.

Though analytic models are simple and less data intensive, they can only be used to obtain performance under steady states and do not directly handle blocking (Cochran and Bharti, 2006). In addition, one problem raised by Curry, Peters and Lee (2003) is that the transportation between nodes has not been considered as an important factor of the performance of a queueing network. Therefore, discrete event simulation has been the most popular approach for queueing network studies (Cochran and Bharti, 2006).

2.3 Other Related Literature

2.3.1 Simulation

Simulation is "the imitation of a real-world process or system over time" (Banks, 1999). It is an excellent tool to analyze operational alternatives for complex systems, especially when the implementing cost is large. The advantages of simulation and the processes of doing it have been introduced by Shannon (1998) and Banks (1999). Now it is broadly applied in many fields, such as manufacturing systems, logistics, designing and operating transportation systems and inventory systems (Law, 2007). Many commercial simulation packages are available and some of them (Arena, AutoMod and ProModel, for example) have been used to study crossdocking.

Several studies for crossdock operations have been evaluated using this technique. First Rohrer (1995) proposes some guidelines for implementing simulation models: (1) retain input data as much of the detail as possible; (2) take into account the actual truck movements in yards; (3) dock doors are a finite resource and should be modeled; (4) automated material handling equipments should be modeled precisely because they are sensitive to system performances; and (5) a few performance metrics must be provided in the output. Magableh and Rossetti (2005) establish a generic simulation model for a crossdocking network. In order to evaluate the throughput of the crossdock, factors like demand arrivals, the door assignment, the availability of resources, shipment characteristics, origin and destination mixes, and processing times are all important. They use their model to test and verify with a large crossdock and examine the effects of increasing demand on the facility. Similarly, Zhou, Setavoraphan and Chen (2005) also propose a conceptual warehousing model, hoping to provide patterns for people to create simulation models more efficiently and effectively.

Aickelin and Adewunmi (2006) suggest a simulation optimization way for the crossdock door assignment problem. In that method, they want to find the best door using Memetic Algorithms after conducting different possible door assignment simulations. However, they hope to do some empirical studies in the near future.

2.3.2 Dynamic Assignment

Selecting destination staging lanes for pallets at receiving doors can be viewed as a dynamic assignment problem. In our study, whenever a pallet needs to be transported, the costs to feasible staging lanes are evaluated dynamically and then a best staging lane is chosen. The dynamic assignment problem "arises when a set of workers must be assigned to a set of tasks over time, responding to new demands as they are called in. The distinguishing characteristic of the dynamic assignment problem over other routing problem is that a worker is never handling more than one task at a time." (Powell, Jaillet and Odoni, 1993) The applications of dynamic assignment have been used in machine scheduling, vehicle routing, full truckload, and fleet management problems (Spivey and Powell, 2004).

The application of dynamic vehicle assignment in warehouses is close to the subject of our study. In Le-Anh and De Koster (2004), they evaluate the performance of static dispatching rules and dynamic scheduling approaches. They propose two dynamic assignment algorithms to solve real-time vehicle scheduling problems: the first algorithm uses the objective of minimizing the average load waiting time to assign tasks to vehicles, and the second algorithm further considers the arriving tasks during a look-ahead period. The results from the above two methods are compared with the static vehicle dispatching rules in De Koster, Le-Anh and Van der Meer (2004). They find that their dynamic scheduling strategies outperform the static vehicle dispatching rules, and the look-ahead dynamic algorithm performs better than a simple dynamic assignment algorithm.

2.3.3 Postponement

The concept of postponement is about delaying activities as late as possible. For example, Hewlett-Packard's build-to-order approach postponed its PCs' final assembly at its distribution centers which close to customers to have quick response to orders and save transportation and duty costs. Benetton dyed uncolored sweaters either when it got an order or when it had certain confidence about customers' color tastes instead of dyeing and finishing them at one time. (See Feitzinger and Lee (1997) for details.)

This idea was first applied in the marketing area and now it has been expanded to logistics, manufacturing, purchasing, distribution and promotion processes (Yang, Burns and Backhouse, 2004). Zinn and Bowersox (1988) classify postponement into five types:

a. Labeling postponement: products are shipped in unlabeled cans to warehouses and labeled after customer orders are received.

b. Packaging postponement: products are bulk shipped to warehouses and packaged based on orders if they are marketed in different package sizes.

c. Assembly postponement: it applies to a base product having a number of common parts that are used in several similar products.

d. Manufacturing postponement: parts are shipped to warehouses and manufacturing is finished there according to customer orders.

e. Time postponement: products are shipped to customers from a centralized inventory instead of storing products in different locations of warehouses.

A detailed review and many successful cases can be found in Yang, Burns and Backhouse (2004), Feitzinger and Lee (1997) and Twede, Clarke and Tait (2000). From Yang, Burns and Backhouse's (2004) review, we found that the postponement strategies applied in logistics focus on (1) postponing shipment; (2) reducing inventory locations; (3) repositioning manufacturing activities to local distributors; (4) delaying raw material inventories; and (5) delaying a product's variety, volume and weight increase.

As for our second research topic—delaying the assignment of products' destinations in crossdocking, it is still an extremely new idea. This strategy is similar to the "rolling warehouse" (Lee and Whang, 2001), the quantity of products unloading to a destination is determined by a truck driver according to the customer's real-time demand information instead of predetermining it when the truck leaves its origin, except that this process happens outside a warehouse.

Chapter Three

Freight Flow Features in Single-Stage Crossdocks

3.1 Flow Features Learned from Crossdocking Literature

From the crossdocking literature reviewed in Chapter Two, we can summarize the following freight flow features:

1. Five major factors affecting freight flows are door assignment, geometry, material handling systems, freight mix and trailer scheduling. Among them, door assignment and trailer scheduling are less expensive to change (Bartholdi and Gue, 2000). Studies related to these two factors were discussed in Sections 2.1.2 and 2.1.3, respectively.
2. Travel distance is the basic consideration. As discussed in Section 2.1, most crossdocking studies consider the travel distance of freight between receiving and shipping doors, which constitutes part of labor and inventory costs. Those studies also indicate that the weighted travel distance for all pallets in a trailer can be changed by applying different door assignment or trailer scheduling methods. Travel distance minimization has been a basic element in the optimization problems for crossdocking operations. However, this is a factor that is usually ignored when conducting queueing studies.
3. Congestion exists and it consumes workers' time. Studies show that congestion is a significant factor when designing freight flow. Bartholdi and Gue (2000) estimate that about 21% of a worker's time is spent in queues in front of shipping doors due to congestion. Brown (2003) argues that congestion

increases total labor time and bottleneck time.

4. Longer staging lengths can provide higher throughput. Bartholdi, Gue and Kang (2007) experiment with several types of staging queues and find that longer staging queues could have higher throughputs because they are not blocked as often, but that the magnitude of incremental throughput improvement decreases as the number of staging spaces increases. They point out that most crossdocks adopt staging areas of about 10 to 15 pallets.
5. A single-stage queue is economically better than a double-stage queue or move-to-front queue (flow rack). Bartholdi, Gue and Kang (2007) show that a double-stage queue yields lower throughput than a single-stage queue, and a move-to-front queue is only 11% greater than a single-stage queue in throughput. If installation costs and flexibility are considered, they suggest that single-stage system could be better. Taylor and Noble (2004) also reach a similar conclusion.
6. The variability of demands among outbound destinations is one of the key factors that affect crossdocking performance. Taylor and Noble (2004) find that the unbalance of outbound demands is a more important factor than door assignment and staging methods. According to their results, the unbalanced-demand scenarios have higher cycle times and staging congestion levels than the balanced scenarios.

3.2 Features Interpreted from Queueing Theories

Stage queueing is different from normal queueing. As discussed by Bartholdi, Gue and Kang (2007), pallets in a staging lane do not move forward by themselves, and a staging lane is blocked once its last space is occupied. Nevertheless, since staging behavior is a type of queueing, we can examine its features via queueing theories.

Waiting occupies most of the time freight spends during crossdocking. The processes of crossdocking are similar to the production processes in a factory if we consider the transporting of workers in a crossdock as the manufacturing of machines in a factory. During manufacturing, Bradt (1982) points out that actual process time typically represents only 5 to 10 percent of the total cycle time in a plant and the majority of the extra time is spent waiting for various resources. Hopp and Spearman (2008) further explain that the main causes of long waiting times are high level of variability and high utilization. These can be interpreted using queueing theories.

Let us regard a crossdock as a single station. Trailers with pallets inside arrive at the receiving area waiting to be transferred. Workers in a crossdock serve the trailers and then the pallets leave the crossdocking system. The basic queueing relationship can be established using Kingman's VUT equation (Kingman 1961). The cycle time for a pallet from arriving at a crossdock to leaving the crossdock, CT, can be approximated under the G/G/1 model as:

$$CT(G/G/1) \approx T_p[(\frac{C_a^2 + C_p^2}{2}) \cdot (\frac{u}{1-u}) + 1] \tag{3-1}$$

where C_a: the coefficient of variation of pallet arrivals. Note that the coefficient of variation is the standard deviation divided by the mean;

C_p: the coefficient of variation of process times;

u: average utilization of the crossdock, the percent of time that the crossdock is busy;

T_p: average process time of the crossdock. That is, the average time to move one pallet from a receiving door to a shipping door.

Equation (3-1) indicates the factors that effect cycle times. First, the process time, which depends on which receiving door a trailer is assigned to be unloaded, is a key factor. This value could be improved via door assignment or trailer scheduling methods. Second, the higher the variations of pallet arrivals and process times are, the higher the cycle time will be. Third, the $(\frac{u}{1-u})$ term represents utilization effects. Because u is smaller than one under steady states, the value of the term will be sharply enlarged when u approaches one. Finally, when cycle time increases, the expected number of pallets that are in progress (work-in-process; WIP) will also increase[1].

3.3 Observation via Simulation

To further examine the applicability of the relationships we obtained from queueing theory and also to examine their relevance to staging queues, a series of crossdocking simulations were conducted. In order to obtain steady-state performance, each simulation is executed over a long period of time and its initial unstable condition is excluded from simulation results. Hence, our simulation tests run 10 replications for each scenario, and each replication operates 5000 minutes with the first 500 minutes excluded as a warm-up period. The crossdock in the simulation models is equipped with four receiving doors, four shipping doors and staging spaces ranging from one to four. The travel distances between different places (receiving doors, shipping doors, staging spaces) are considered. Test results are shown below.

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[1] According to Little's law, $WIP_q=r_a \cdot (CT-T_p)$, where WIP_q is the expected number of pallets that are waiting in queue and r_a is the average arrival rate of trailers (pallets). Next, using the relationship that $WIP=WIP_q+u$, we can find that WIP increases with CT.

3.3.1 Arrival variability- pooling and arrival distribution

According to Equation (3-1), the variation of pallet arrivals can affect the performance of crossdocking. In this section, we examine two kinds of arrival variabilities: queueing method and arriving schedule.

For the queueing methods, individual and pooled trailer assignment methods are compared. In the first method, each receiving door has its own queueing line, while in the second method, arriving trailers are waiting in a common waiting line and assigned to receiving doors accordingly. The pooled trailer assignment is supposed to reduce the trailer arrival uncertainty at individual receiving doors.

For the arriving schedules, the distributions of trailer headways are tested with exponential and constant distributions. The constant distribution means no variation in trailer headways. In both schedules, the headways of every 75, 100 or 150 minutes (indicated as Expo(75), Expo(100), Expo(150), Constant(75), Constant(100) and Constant(150) for the two types of schedules, respectively) are considered.

In the simulation models, each trailer contains 28 pallets and a pallet must go through the following steps before leaving a crossdock: waiting in an inbound trailer, being unloaded by a stripper and moved to a staging lane, being conducted with value-added work and waiting for a stacker, and finally being transported by a sttacker to a shipping door. When a pallet is leaving a receiving door, one of the four staging lanes is assigned with equal probabilities (25% each). The aim of this section is simply to discuss the factors affecting crossdocking performance. Hence the details of our simulation models are not emphasized here. A more detailed single-stage crossdocking introduction can be found in Chapter Five.

Let us first compare the results between individual and pooled trailer assignments. According to the simulation results in Table 3.1, generally, the values of cycle times and work-in-processes under exponential headway scenarios are significantly improved under the pooled trailer assignment method. However, this situation does not occur in the constant headway scenarios because these scenarios have no arrival variabilities. In addition, the throughputs under the pooled assignment scenarios only increase a little bit compared to the individual assignment scenarios. The effect on throughput from reducing variability can not be evaluated here and this can be explained in the following:

1. *WIP= Throughput • CT*, according to Little's law (Hopp and Spearman, 2008).
2. The reduction of arrival variability makes both WIP and CT decrease and hence the impact to throughput is unclear.

As for the effects of arriving schedules, the constant headway scenarios which have almost zero variability[2] show shorter cycle times and lower work-in-process values in most of the scenarios when compared to the exponential headway scenarios.

From the above analysis, we find that these simulation results coincide with our analysis of Equation (3-1) about arrival variability.

[2] The variability of trailer arrivals is zero. However, since the assignment of staging lane is by probability, there could exist a small amount of variability even though the average chance to be assigned to each staging lane is equal.

Table 3.1 Performance under Different Trailer Queueing Methods and Arrival Schedules

	Performance	Throughput (pallets/ per minute)				Work-In-Process (pallets)				Cycle Time (minutes)			
	Staging Size	4	3	2	1	4	3	2	1	4	3	2	1
Individual Trailer Assignment	Expo(75)	1.37	1.31	1.16	0.82	537	694	1091	1964	352	455	717	1267
	Expo(100)	**1.13**	**1.13**	1.07	0.81	154	195	340	996	131	165	282	823
	Expo(150)	**0.76**	**0.75**	**0.75**	0.71	47	52	66	196	60	67	84	243
	Constant(75)	1.44	1.35	1.17	0.82	217	459	942	1893	142	303	627	1265
	Constant(100)	**1.12**	**1.12**	**1.12**	0.82	49	52	62	869	43	46	55	776
	Constant(150)	**0.75**	**0.75**	**0.75**	**0.75**	32	35	39	54	43	46	52	72
Pooled Trailer Assignment	Expo(75)	1.43	1.35	1.17	0.83	472	729	938	2136	305	474	617	1367
	Expo(100)	**1.14**	**1.14**	**1.14**	0.83	74	96	308	937	64	85	260	845
	Expo(150)	**0.74**	**0.76**	**0.77**	**0.75**	31	35	51	128	41	45	64	161
	Constant(75)	1.45	1.35	1.17	0.82	187	444	942	1896	125	296	630	1269
	Constant(100)	**1.12**	**1.12**	**1.12**	0.82	49	52	61	870	43	46	54	776
	Constant(150)	**0.75**	**0.75**	**0.75**	**0.75**	32	35	39	55	43	46	52	73

P.s.: 1. The scenarios are performed under balanced destination distributions (distribution A).
2. The average pallet arrivals for the headway of 75 minutes are about 1.49 pallets/minute; 1.12 pallets/minute for the headway of 100 minutes; 0.77 pallet/minute for the headway of 150 minutes.

Other important features can also be extracted from Table 3.1. First, throughput increases and work-in-process and cycle time decrease with staging sizes, but the increment and decrement diminish with staging sizes, as mentioned by Bartholdi, Gue and Kang (2007). Therefore, there will be an upper-bound on the degree of improvements possible by adding staging sizes. In fact, we already have the upper bounds for throughputs in Table 3.1 which shown in bold fonts. This indicates a chance to use less staging spaces and attain a same level of throughput. Furthermore, the upper bound of throughput and the number of staging size are related to the quantity of pallet arrivals: a higher volume of pallet arrivals needs a larger number of staging spaces. Second, under heavy traffic densities (such as arriving headways at 75 and 100 minutes), increasing staging size can greatly reduce work-in-process and cycle time. Finally, under very high traffic densities, such as the arriving headway of 75 minutes with one, two or three staging space(s), the cumulated queue has exceeded the processing capability of the crossdock. Under this circumstance, the queue(s) of the receiving doors and the crossdock are always saturated and therefore the pooled trailer assignment method can not improve the performance of work-in-process and cycle time.

3.3.2 Processing time variability

The three different destination distributions in Table 3.2 indicate different processing times in the crossdock. In distribution A, a pallet has equal chance (25%) to be assigned to one of the four shipping doors and this makes pallets under this distribution have similar travel and staging times (that is, the crossdock's process times). On the contrary, the skewed distributions, distributions B and C, have pallets more concentrated on certain destinations and this should generate higher congestion at those destinations and longer average staging times.

The simulation results in Tables 3.2 and 3.3 show that the scenarios under distribution A, which have the lowest processing time variability, have shorter cycle times and higher throughputs than the scenarios under distributions B and C. This outcome also agrees with our analysis of Equation (3-1) about process time variability and Taylor and Noble's (2004) conclusion about the effect of demand variability on crossdocking performance.

Table 3.2 Cycle Times under Different Trailer Assignment Methods and Destination Distributions (Unit: Minutes)

	Destination Distribution	Under distribution A (0.25/0.25/0.25/0.25)*				Under distribution B (0.15/0.33/0.33/0.19)*				Under distribution C (0.33/0.15/0.19/0.33)*			
	Staging Size	4	3	2	1	4	3	2	1	4	3	2	1
Individual Trailer Assignment	Expo(75)	352	455	717	1267	489	607	859	1406	503	624	870	1395
	Expo(100)	131	165	282	823	169	221	387	980	177	228	391	968
	Expo(150)	60	67	84	243	64	72	97	339	67	75	99	339
Pooled Trailer Assignment	Expo(75)	305	474	617	1367	416	541	886	1492	521	632	901	1458
	Expo(100)	64	85	260	845	89	146	336	1106	81	119	297	1163
	Expo(150)	41	45	64	161	44	51	72	323	46	50	73	436

*: The numbers in the parentheses denote the probabilities of assigning pallets to shipping doors one, two, three and four, respectively.

Table 3.3 Throughputs under Different Trailer Assignment Methods and Destination Distributions (Unit: Pallet/Per Minute)

	Destination Distribution	Under distribution A (0.25/0.25/0.25/0.25)				Under distribution B (0.15/0.33/0.33/0.19)				Under distribution C (0.33/0.15/0.19/0.33)			
	Staging Size	4	3	2	1	4	3	2	1	4	3	2	1
Individual Trailer Assignment	Expo(75)	1.37	1.31	1.16	0.82	1.29	1.22	1.07	0.75	1.28	1.21	1.06	0.74
	Expo(100)	1.13	1.13	1.07	0.81	1.12	1.1	1.02	0.74	1.12	1.1	1.02	0.74
	Expo(150)	0.76	0.75	0.75	0.71	0.75	0.75	0.75	0.69	0.75	0.75	0.75	0.69
Pooled Trailer Assignment	Expo(75)	1.43	1.35	1.17	0.83	1.31	1.24	1.07	0.75	1.31	1.24	1.07	0.74
	Expo(100)	1.14	1.14	1.14	0.83	1.17	1.15	1.06	0.75	1.13	1.11	1.05	0.74
	Expo(150)	0.74	0.76	0.77	0.75	0.76	0.76	0.75	0.72	0.76	0.74	0.75	0.74

3.3.3 Utilization

A stripper is a worker who transports pallets from a receiving door to staging lanes. Since a stripper is the first server for a pallet when entering a crossdock, observing the utilization of strippers can help us to get the whole picture of the utilization of the crossdock. From the simulation results in Table 3.4, cycle times increase rapidly when the utilization of strippers approaches 100%. This finding also coincides with the analysis in Section 3.2. In addition, the results also indicate that the expansion of staging spaces can help decrease the values of cycle time and utilization.

Table 3.4 The Relationship between Stripper Utilization and Cycle Time

	Stripper Utilization				Cycle Time (minutes)			
Staging Size	4	3	2	1	4	3	2	1
Expo(75)	0.984	0.996	0.999	1.000	305	474	617	1367
Expo(100)	0.731	0.797	0.961	1.000	64	85	260	845
Expo(150)	0.441	0.486	0.568	0.856	41	45	64	161

1. These results are gotten under the pooled trailer assignment method and destination distribution A.

3.4 Factors Affecting Crossdocking Performance

The factors affecting crossdocking performance are summarized in Table 3.5. These factors are obtained from the crossdocking literature and queueing theory, and some of them are verified by our simulation models. The factors that can only be changed or adjusted in a medium to long term time period, such as a few weeks to a few years, are classified into the strategic or tactical decisions; others that can be changed or adjusted during several hours or days are categorized into the operational decisions. Among them, because the material handling/workforce factor can be changed by hiring more workers in a medium term or adjusting worker allocation temporarily, the arrival variability factor can be altered by arranging trailer arrival times previously or controlled by scheduling trailers' orders of unloading instantly, and the processing time factor can be impacted both by long and short term factors (for example, staging size and congestion both can affect the value of processing time), these three factors are concurrently classified into the two groups.

Table 3.5 Factors that Affect Corssdocking Performance

Factors	Strategic or Tactical Decision	Operational Decision	Impact on Performance
Geometry	√		∆
Freight Mix	√		-
Staging Size	√		+(With upper bounds)
Door Assignment (Layout Design)	√		∆
Material Handling System/ Workforce	√	√	+
Arrival Variability	√	√	-
Processing Time	√	√	-
Processing Time Variability		√	-
Worker Utilization		√	-
Trailer Scheduling		√	∆
Congestion/Blocking		√	-

1. ∆ means that the impact could be positive or negative.
2. + means that the impact will be positive with the increase of the factor.
3. - means that the impact will be negative with the increase of the factor.

3.5 Operational Strategies to Improve the Performance of Crossdocking

In this research, we focus on the last six operational factors in Table 3.5. In Chapter Four, trailer scheduling techniques are developed to assign waiting trailers to available receiving doors considering wait time, processing time or cycle time. The arrival variability, processing time, processing time variability, and trailer scheduling factors are examined in that chapter. In Chapter Five, alternate destination strategies are discussed to alleviate staging lane blocking, reduce pallet’s processing time and stripper’s waiting time and hence to increase transfer efficiency. The processing time, worker utilization and congestion/blocking factors are considered in that chapter. Further, models combining trailer scheduling and alternate destination strategies are analyzed in Chapter Six.

Chapter Four

Time-Based Trailer Scheduling Strategies

A crossdock is the hub of its distribution network. Any delay in its freight handling can hinder the performance of the whole network. Hence, minimizing the time and/or costs occurred when transporting freight from inbound trailers to outbound trailers in the hub is the main challenge of crossdock operations.

In the past, because of the lack of real-time information about incoming and outgoing shipments, a crossdock supervisor could only draw on his or her past experience to assign waiting trailers to receiving doors. Therefore, the efficiency of typical crossdock operations was, by definition, sub-optimal. For example, case studies like Gue (1999), Bartholdi and Gue (2000) and Brown (2003), report improvements from 7% to 23% when applying more efficient scheduling methods. Due to advances in technologies, real-time information about the contents, locations and destinations of shipments in a crossdock is readily available. For example, with advance shipping notices (ASN), the information about the contents of incoming trailers is known before they arrive; with radio-frequency identification (RFID) tags attached on freight and RFID readers installed at receiving and shipping doors, information about the movement of freight within the crossdock is available anytime. In collaboration with a warehouse management system, this real-time information should allow for the development of more efficient operations.

In this chapter, real-time information is employed to schedule trailer unloading to decrease total freight transfer time. Trailer scheduling policies directly impact freight wait time and travel time and thus affect the performance of crossdock operations. Even though trailer scheduling is important, few studies about this topic have been published. To date those studies focus mainly on minimizing travel distance for workers. From a practical viewpoint, the travel time from a receiving door to a shipping door might take less than five minutes, but the wait time for one unit of freight in an inbound trailer to be unloaded and for the outbound trailer to be fully loaded and ready to leave might exceed an hour. Therefore, instead of only measuring travel time/distance to assign waiting trailers, taking into account the wait time that a waiting trailer will impose on itself and other freight should have the potential to increase the efficiency of crossdocking.

This chapter discusses our two time-based trailer scheduling algorithms and their effectiveness. In Section 4.1, we introduce the first-come-first-served (FCFS) policy and the look-ahead algorithm, the only other policy that can be found in the literature. The two time-based algorithms are proposed in Section 4.2. They aim at considering processing time or cycle time to assign waiting inbound trailers. To evaluate the above four policies, we built detailed simulation models to imitate the transfer of freight under our algorithms and the other two scheduling policies. The simulation models and their results are presented in Section 4.3 and 4.4 respectively. Finally, in Section 4.5, the time-saving effects that our algorithms can achieve for crossdock and supply chain operations are discussed.

4.1 The First-Come-First-Served Policy and the Look-Ahead Algorithm

The FCFS policy is a natural way to assign waiting inbound trailers to available receiving doors. Whenever there is a vacant receiving door, the first waiting trailer in line is assigned to the door. This rule is fair with respect to the wait times of the trailers, but may not be beneficial to the overall operation of crossdocks. This policy is used as a baseline scenario in this chapter.

The look-ahead scheduling algorithm is proposed by Gue (1999). This algorithm turns static criteria into rules that are applicable in a dynamic environment: Each inbound trailer is assigned ranks for each shipping door according to the weighted distances of its contents before or when it is in the trailer waiting line. When a receiving door is available, the algorithm searches for the trailer in the trailer waiting line with its first choice for that receiving door. If none exists, it finds the waiting trailer that would have the second lowest weighted distance when assigned to that receiving door. This process continues until an assignment is made. For example, waiting trailers one, two and three have their first three priorities as (A, D, E), (B, A, C) and (A, C, B), respectively. When receiving door A is available, waiting trailer one will be chosen because receiving door A can give waiting trailer one the lowest weighted travel distance and also it arrives at the trailer waiting line prior to waiting trailer three. On the other hand, if receiving door C is available, since no waiting trailers have receiving door C as their first priority, the waiting trailer with its second priority for receiving door C (waiting trailer three) will be chosen.

4.2 The Time-Based Strategies

From the point of view of crossdock operations, minimizing workers' travel costs is important, and hence this is the main objective of the look-ahead algorithm. However, from the perspective of a whole supply chain, minimizing transfer time could be the most critical issue for a crossdock, especially for time-oriented logistics strategies and high-value or perishable items (Cook 2007). Time-oriented logistics strategies like just-in-time, make-to-order and merge-in-transit all require short lead-time to achieve their feature of flexibility. High-value products have high corresponding holding costs and transferring perishable products faster can maintain their freshness and quality. In addition, crossdocks work as hubs of a supply chain and hence the less time freight stays at a crossdock, the more efficient the supply chain will be.

Our time-based approaches concern about the impact of a new unloading trailer on the total processing time or the transfer time needed for existing pallets in the crossdock and the pallets from the new unloading trailer. Our trailer scheduling algorithms require dynamic information. Whenever a receiving door is available and there is more than one new trailer waiting, the algorithms calculate and compare the total processing time or the whole transfer time needed for each alternative waiting trailer. The waiting trailer with the lowest processing or transfer time will be chosen. Two time-based algorithms are introduced below. The first one considers the total processing time for all pallets in the crossdock, while the second one considers the whole transfer time.

4.2.1 Minimizing processing time algorithm—a criterion based on the processing time during the unloading of a waiting trailer

Pallets' travel time between receiving doors and shipping doors, wait time at receiving doors and wait time at shipping doors are considered here, and the total of these three times is called the “processing time”. Since the destinations of pallets in an unloading trailer are given, the total travel time of the trailer depends on which receiving door is assigned and this also affects the wait time at receiving doors. The wait time at shipping doors is another situation. A pallet arriving at an outbound trailer will stay there until the outbound trailer is fully loaded and leaves the crossdock. If more pallets are sent to an outbound trailer and the trailer becomes full, then the wait time of the pallets already in the trailer is reduced. Therefore, the mix of pallet destinations in each new waiting trailer impacts the wait time of pallets at shipping doors.

We would like to assign a waiting trailer that can minimize the processing time, taking into account the new waiting trailer and all pallets at receiving doors and shipping doors at the time of the assignment. Figure 4.1 shows a simplified example about how to make the assignment using this time-based algorithm.

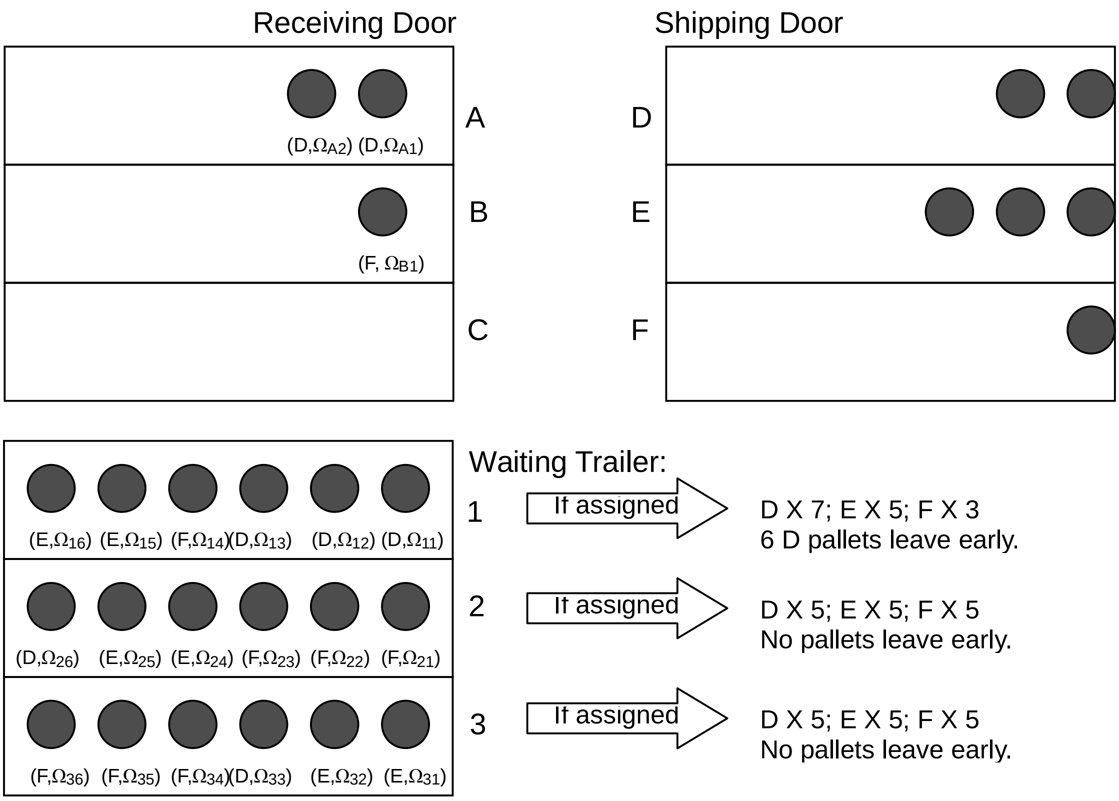


Figure 4.1 A Simplified Example to Illustrate How to Calculate the Processing Time for a Waiting Trailer

In Figure 4.1, trailers 1, 2 and 3 are waiting in the trailer waiting line. When receiving door C becomes available, receiving doors A and B still have 2 and 1 pallets, respectively, waiting to be transported. We call these pallets “existing” pallets. The first part of the symbol under an existing pallet represents its destination (shipping door) and the second part displays the cumulative time, starting when a newly assigned trailer begins its unloading and ending when the pallet arrives at its destined receiving door. For instance, for the first pallet in receiving door A, it is going to shipping door D and the time arriving at shipping door D will be Ω_{A1}. Notice that the value of Ω_{A1} changes over time, so real-time information about its value is needed for each new trailer assignment. The symbol under a pallet of a waiting trailer has the same meaning as an existing pallet’s and its cumulative time changes if the waiting trailer is assigned to a different receiving door because of different travel distances between receiving and shipping doors. For each waiting trailer assignment, if there are multiple waiting trailers, we compare the processing time that occurs due to transporting the pallets in each waiting trailer and the existing pallets as well as the wait time for all pallets at shipping doors during the time span of unloading the waiting trailer. Of course, the wait time will be shorter if some pallets can leave early from shipping doors before completion of unloading the waiting trailer. This becomes a time-saving advantage to a waiting trailer when applying this time-based approach.

Let us return to the calculation of processing time for all waiting trailers in Figure 4.1. The time span for unloading waiting trailer 1 is Ω_{16} and 6 pallets at shipping door D can leave early during the course of unloading. If we assume the second pallet of waiting trailer 1 will be the sixth pallet at shipping door D, we can know the first six pallets only take Ω_{12} time units in the crossdock and thus they save the total wait time at shipping door D of 6*(Ω_{16}-Ω_{12}) time units. Besides the 6 pallets, other 9 pallets will stay at the crossdock while waiting or being transported and thus consume a total of 9*Ω_{16} time units. Thus the processing time for waiting trailer 1 is 15*Ω_{16}-6*(Ω_{16}-Ω_{12}). On the other hand, the processing time for waiting trailers 2 and 3 are 15*Ω_{26} and 15*Ω_{36} respectively, since no pallets can leave early during their unloading. These three processing times are compared and the trailer with the lowest value is chosen.

There are two other important features about this algorithm:

First, in order to determine how much time can be saved by each alternative trailer assignment, we need to know which pallets will be able to leave early. In our example, the second pallet at receiving door A and the second and third pallets in waiting trailer 1 all have the possibility of being the one which results in the outgoing trailer at shipping door D leaving early. In order to find out the right leaving time and leaving pallets, sorting the arrival times of all pallets going to shipping door D is necessary.

Second, when there are no time saving effects for any waiting trailers during an assignment, the cumulative times to transport the pallets in each trailer are compared– similar to the criterion used in the look-ahead algorithm.

Following the assumption that the pallet enabling an outbound trailer to leave early is from a waiting trailer rather than existing pallets, if waiting trailer *x* is assigned to receiving door *n* at time *t*, the total processing time imposed on pallets (including pallets in waiting trailer *x* and the existing pallets at time *t*) can be formulated as equation (4.1).

$$C_n(t,x)_{process} = 2[a + \sum_{m=1}^{|M|} e_m(t)]\sum_{h=1}^{a} T_n^{xh} - \sum_{m=1}^{|M|}\sum_{b=1}^{B_m(t,x)}(2a \cdot y_{mx}^b \cdot \sum_{h=o_{mx}(b)+1}^{a} T_n^{xh}) \quad (4.1)$$

$$x \in X(t), n \in N, m \in M$$

where

X(t): the set of waiting trailers at time *t*.

N: the set of receiving doors.

M: the set of shipping doors; $|M|$ is the number of members in set *M*.

$C_n(t,x)_{process}$: the total processing time that waiting trailer *x* imposes on pallets if it is allocated to receiving door *n* at time *t*.

T_n^{xh} : the time needed for the *h*th pallet in waiting trailer *x* traveling to its destination when the trailer is assigned to receiving door *n*. This travel time changes if a pallet departs from a different receiving door.

y_{mx}^b equals to 1 when it is the "*b*"th time that one outgoing trailer at shipping door *m* will be fully loaded by a pallet from waiting trailer *x*; others, it equals to 0.

$B_m(t,x)$: the number of times that waiting trailer *x* can make outgoing trailers at shipping door *m* leave early when making a trailer assignment at time *t*.

a: the number of pallets in each trailer.

$e_m(t)$: the total number of existing pallets going to or in outgoing trailer *m* at time *t*.

h: the order of pallets in an incoming trailer.

$o_{mx}(b)$: the order of pallets in waiting trailer *x* that is the last pallet ("*a*"th, "*2a*"th, "*3a*"th,…)to fully fill the "*b*"th outgoing trailer at shipping door *m*. $o_{mx}(b)$ changes with waiting trailer *x* and time *t*.

Hence, the objective of this algorithm is to find waiting trailer *x* such that

$$Minimize \underset{x\in X(t)}{C_n(t,x)_{process}}$$

In equation (4.1), the first term is the product of the number of all pallets (new and existing pallets) in the crossdock and the whole round-trip time for transferring the new pallets. It is the total processing time consumed during the course of unloading the new waiting trailer if no outbound trailers can be fully loaded. The second term represents the time saved from fully loaded outbound trailers. This formulation considers both the total processing time and the total travel distance at the same time. Hence, this implies that the performance of our minimum processing time-based method is at least equal or even better than the look-ahead algorithm.

Note that as the number of existing pallets grows, the times that new pallets and existing pallets can push the number of outbound trailers at shipping door *m* might be more than once. That is why we need to find out $o_m(b)$. In addition, the pallet fully filling an outbound trailer could be one of the existing pallets. This will complicate the formulation of this algorithm. So we leave the details in Figure 4.2 and the simulation model.

The procedures for assigning a new waiting trailer to an available receiving door are illustrated in Figure 4.2.

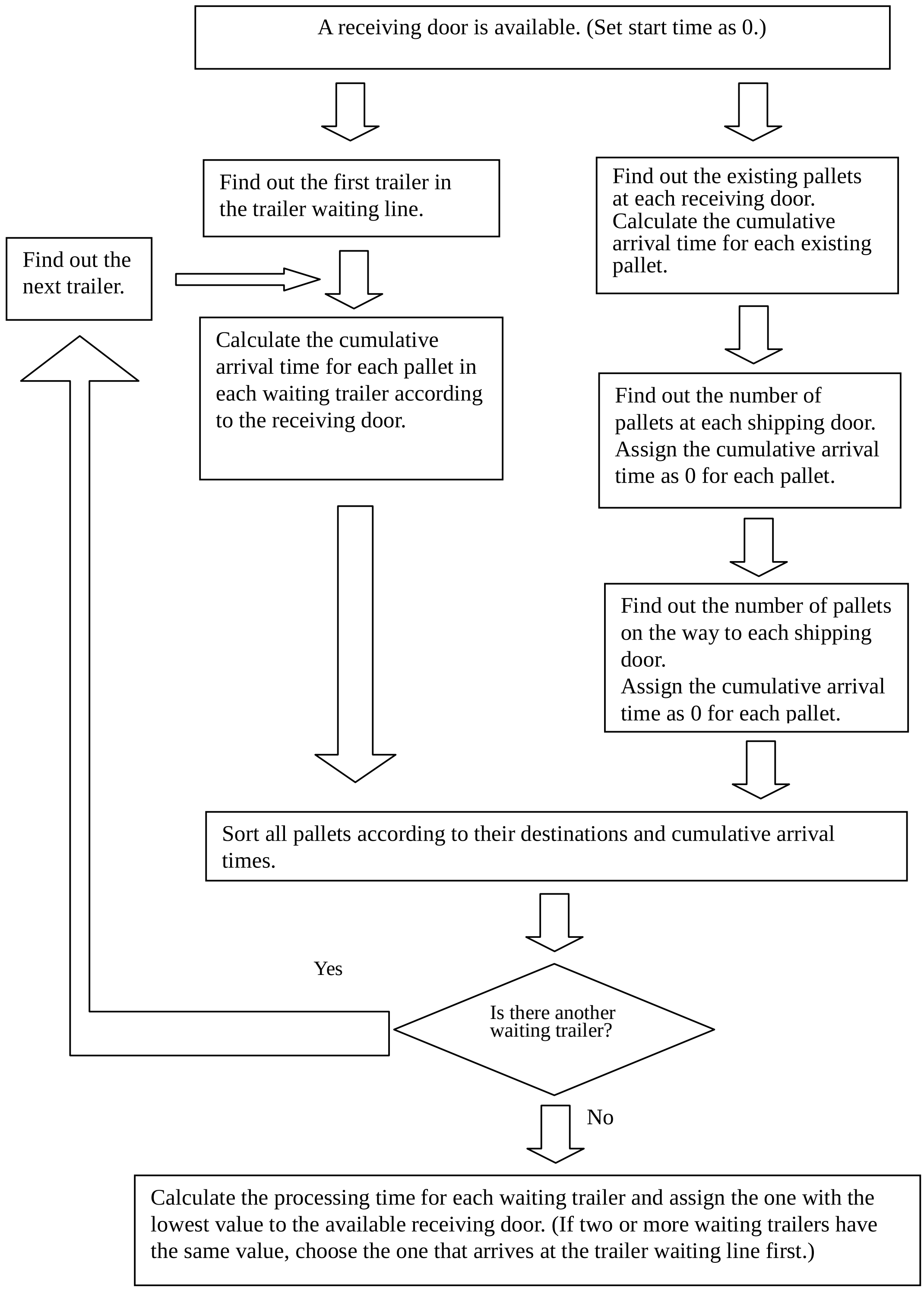


Figure 4.2 Procedures of Calculating Processing Times for Waiting Trailers

4.2.2 Minimizing cycle time strategy—a criterion based on the cycle time during the unloading of a waiting trailer

The second criterion considers not only the processing time in the above subsection, but also a trailer's wait time in the trailer waiting line. The procedures of obtaining the cycle time (i.e. the processing time plus the wait time in the trailer waiting line) are similar to the minimizing processing time (MPT) strategy's except that we calculate the cycle time instead of the processing time when comparing all waiting trailers at the last step. Consider the wait time in the waiting trailer line can avoid delaying too much time for those waiting trailers with high processing time values and ensured that trailers are assigned in the most time-saving way.

The formulation of this cycle time can be extended from equation (4.1):

$$C_n(t,x)_{cycle} = aw_x(t) + 2[a + \sum_{m=1}^{|M|} e_m(t)]\sum_{h=1}^{a} T_n^{xh} - \sum_{m=1}^{|M|}\sum_{b=1}^{B_m(t,x)}(2a \cdot y_{mx}^b \cdot \sum_{h=o_{mx}(b)+1}^{a} T_n^{xh}) \qquad (4.2)$$

$$x \in X(t), n \in N, m \in M$$

where

$C_n(t,x)_{cycle}$: the cycle time, which includes the total processing time plus the wait time that waiting trailer x spends in the trailer waiting line, if waiting trailer x is allocated to receiving door n at time t.

$w_x(t)$: the wait time at the waiting line for trailer x up to time t.

4.3 Simulation Models

4.3.1. Crossdock layouts

Three different crossdock layouts—4 receiving doors and 4 shipping doors (4-to-4 doors), 8 receiving doors and 8 shipping doors (8-to-8 doors), and 4 receiving doors and 8 shipping doors (4-to-8 doors) to represent staging crossdocks and a free-stage crossdock—are considered to test four trailer scheduling policies. These four policies are the FCFS, look-ahead, minimizing processing time (MPT) and minimizing cycle time (MCT) policies. The crossdock dimensions are based on Sandal's work (2005): all crossdocks are 75 feet wide; each door is 15 feet wide and has 8 feet of space from its neighbor doors. Staging crossdocks (4-to-4 doors and 8-to-8 doors) have their receiving doors and shipping doors on different sides, while in the free-stage setting (4-to-8 doors), these two kinds of doors are distributed on both sides and receiving doors are located near the middle of the crossdock to reduce travel distance. The details of the layouts are shown in Appendix A.

4.3.2. Transferring processes

The transferring processes in our simulation models are as follows: When an inbound trailer arrives at the crossdock, it will be immediately assigned to a receiving door if one is available and no other trailers are waiting. If none are available, the inbound trailer will be put into a trailer waiting line. Whenever a new inbound trailer arrives or a receiving door becomes empty, the simulation model checks if it needs to apply a trailer scheduling policy to assign a waiting trailer to an available receiving door, as illustrated in Figure 4.3. The waiting trailer then is moved to the receiving door. Each receiving door is allocated with one worker and one forklift. The worker unloads a pallet from the inbound trailer, moves it to its destined shipping door and uploads it to the outbound trailer waiting at the shipping door. In the operations of crossdocking, each shipping door stands for a specific destination and that destination typically does not change for several months. After uploading a pallet, the worker goes back to his original receiving door to start his or her next task. A pallet placed in an outbound trailer has to wait until the outbound trailer is fully loaded with pallets. At that time, the pallet leaves the simulation model and we stop counting its time in the crossdock.

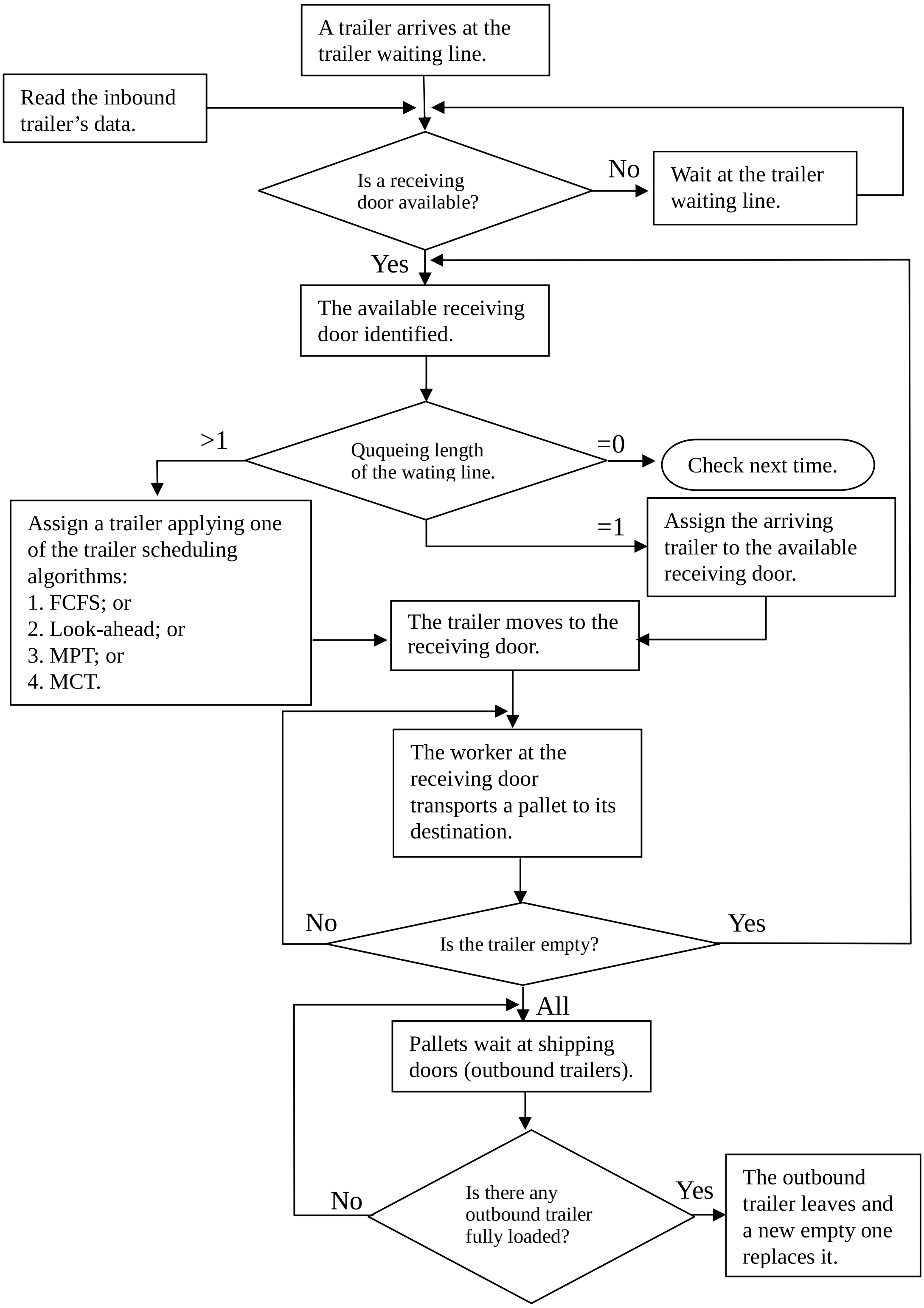


Figure 4.3 The Logic of the Simulation Models Used in the Trailer Scheduling Study

4.3.3. Model basics and assumptions

The four simulation models are built separately using the Arena simulation package (version 11). Inbound and outbound trailers are assumed to be 48 feet long, each carrying 28 pallets. We simulate the inter-arrivals of inbound trailers as exponential distributions with means ranging from five to thirty five minutes for each dataset. Once an outbound trailer is fully loaded, it leaves the simulation model and another new and empty outbound trailer replaces it immediately. Twenty replications are run for each scenario and the average performances are calculated across the twenty replications. Every replication starts with all doors empty and terminates at the 1000th minute.

Except for the stochastic characteristic of the trailer arrivals, other process times are deterministic, including travel times between doors, unloading and uploading times.

4.3.4. Datasets

Four different datasets are randomly generated from the probabilities we show up in columns three and five of Table 4.1. First, we draw the number of destinations for each inbound trailer. For example, we get 2 destinations. And then we draw the actual destinations, like destination 2 and 4. Finally, the destination of each pallet is assigned according to the relative percentages in column five of Table 4.1. For example, if we get destinations 2 and 4 for a trailer in dataset 1, there will be 16 pallets bound for destination 2 and 12 pallets bound for destination 4. The reasons we create these types of datasets are as follows:

Table 4.1 Sampling Probabilities and Results of Four Datasets

	Freight Mixture		Destination Distribution		Sampling Results	
	Number of Destinations	Probability	Destinations*	Probability	Destinations*	Amount (Pallets)
Dataset 1 (Used in the 4-to-4 Door Case)	One	0.25	S 1	0.33	S 1	703
	Two	0.45	S 2	0.15	S 2	341
	Three	0.2	S 3	0.4	S 3	890
	Four	0.1	S 4	0.12	S 4	306
Total		1.00		1.00		2240
Dataset 2 (Used in the 4-to-4 Door Case)	One	0.25	S 1	0.25	S 1	676
	Two	0.45	S 2	0.25	S 2	620
	Three	0.2	S 3	0.25	S 3	415
	Four	0.1	S 4	0.25	S 4	529
Total		1.00		1.00		2240
Dataset 3 (Used in the 4-to-8 Door Case and the 8-to-8 Door Case)	One	0.25	S 1	0.15	S 1	430
	Two	0.35	S 2	0.09	S 2	172
	Three	0.2	S 3	0.08	S 3	206
	Four	0.1	S 4	0.13	S 4	319
	Five	0.04	S 5	0.15	S 5	285
	Six	0.03	S 6	0.20	S 6	452
	Seven	0.02	S 7	0.08	S 7	136
	Eight	0.01	S 8	0.12	S 8	240
Total		1.00		1.00		2240
Dataset 4 (Used in the 4-to-8 Door Case and the 8-to-8 Door Case)	One	0.25	S 1	0.125	S 1	294
	Two	0.35	S 2	0.125	S 2	271
	Three	0.20	S 3	0.125	S 3	322
	Four	0.10	S 4	0.125	S 4	228
	Five	0.04	S 5	0.125	S 5	294
	Six	0.03	S 6	0.125	S 6	208
	Seven	0.02	S 7	0.125	S 7	233
	Eight	0.01	S 8	0.125	S 8	390
Total		1.00		1.00		2240

*: Destinations S1, S2, S3, S4, S5, S6, S7 and S8 represent shipping door 1 to shipping door 8 respectively.

- Not all inbound trailers have their pallets going to four or eight destinations every time. Hence, we assume that the number of destinations found on each trailer is determined according to a probability.
- After a period of crossdocking operation, the distribution of pallets' destinations can be found and we assume that the relative percentages among destinations

should be stable even if all four or eight destinations are not used by a particular trailer.

- Pallets in an inbound trailer going to the same destination are assumed to be grouped.

In the four datasets, datasets 1 and 2 are for the 4-to-4 door setting and datasets 3 and 4 are both for the 4-to-8 and 8-to-8 door settings. Datasets 1 and 3 have more skewed destination distributions and hence more unbalanced demands (as shown in Table 4.1), while datasets 2 and 4 are relatively balanced. These two types of datasets can help us check the sensitivity of the four policies relative to different demand distributions.

4.3.5. Performance measures

Since our algorithms are time-oriented, we mainly measure the average "cycle time" needed for a pallet starting from arriving at the trailer waiting line to leaving a crossdock at the shipping side. In addition, "travel time" and "throughput" are also measured. The travel time is the average time needed for moving a pallet from a receiving door to a shipping door, which is the same measure as travel distance, the decision criterion of the look-ahead algorithm. The throughput represents the average number of pallets leaving a crossdock in a 1000-minute operation period, not including pallets still waiting in outbound trailers. The above three measurements are all obtained after a twenty-replication run.

Because we have four or eight shipping doors in our simulations and each door has different demand density, we get four or eight different values from these shipping doors for the travel time and the cycle time measurements. Therefore, we calculate weighted average values for comparison. The average travel time of a shipping door is multiplied by the number of pallets that have left the crossdock and the sum of the above weighted values for all the shipping doors are then divided by their throughput to get a weighted average travel time. The same procedure applies to the calculation of the weighted average for the cycle time.

4.4 Simulation Results

4.4.1 4-to-4 scenarios

Hereafter mentioned values in this chapter are averages from twenty replications. Tables 4.2 and 4.3 show the travel times, cycle times and throughputs for the four trailer scheduling policies under different trailer arrival headways and under datasets 1 and 2. Because of the property of the look-ahead algorithm, when there are more choices from the trailer waiting line, it can find a better trailer to shorten the total travel distance of the assignment. Therefore, in most cases the look-ahead algorithm has advantages over the other policies with respect to travel time. However, when the trailer arrivals are sparse (headways exceeding 30 minutes), the four policies do not have obvious differences.

Table 4.2 Performance of the 4-to-4 Crossdock Layout Using Dataset 1 under Different Scheduling Methods and Trailer Arrival Headways

Travel Time (minutes)

Headway	MCT*	MPT*	Look-Ahead	FCFS
5	1.49	1.47	1.44	1.53
10	1.50	1.47	1.44	1.53
15	1.51	1.49	1.47	1.53
20	1.52	1.51	1.49	1.53
25	1.51	1.51	1.50	1.52
30	1.52	1.51	1.51	1.52
35	1.51	1.51	1.51	1.52

Cycle Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	261.89	345.96	387.83	437.96
10	122.19	225.46	268.52	341.40
15	121.67	181.37	204.29	248.71
20	128.56	150.38	162.22	176.01
25	127.02	131.43	134.57	138.15
30	123.15	124.39	124.52	126.11
35	123.58	123.87	123.88	124.98

Throughput (pallets/1000 minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1125	1145	1148	1117
10	1106	1133	1146	1110
15	1088	1099	1106	1087
20	1024	1028	1031	1020
25	907	909	901	897
30	770	772	770	766
35	667	666	667	666

*: "MCT" stands for the minimizing cycle time algorithm, and "MPT" stands for the minimizing processing time algorithm.

Table 4.3 Performance of the 4-to-4 Crossdock Layout Using Dataset 2 under Different Scheduling Methods and Trailer Arrival Headways

Travel Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1.50	1.48	1.45	1.53
10	1.50	1.48	1.46	1.53
15	1.51	1.49	1.47	1.53
20	1.51	1.51	1.49	1.52
25	1.52	1.51	1.50	1.52
30	1.52	1.52	1.52	1.53
35	1.52	1.52	1.52	1.53

Cycle Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	261.94	353.79	397.42	426.83
10	121.46	232.75	292.81	330.13
15	121.18	186.33	216.48	240.18
20	129.39	155.65	164.78	174.48
25	131.39	135.31	140.22	143.97
30	128.45	129.43	130.51	131.89
35	132.68	132.62	134.04	133.73

Throughput (pallets/1000 minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1118	1134	1163	1096
10	1107	1128	1139	1084
15	1088	1109	1118	1064
20	1019	1029	1030	1005
25	901	907	905	889
30	767	766	769	767
35	669	673	671	668

On the other hand, our two time-based algorithms perform well on the cycle time as expected, especially our MCT policy. When the headways are less than 30 minutes, the performances of the time-based methods are better than the other two on both datasets. As for the throughput, the look-ahead policy is the best in most scenarios and the two time-based methods are better than the FCFS policy.

4.4.2 4-to-8 scenarios

A little different from the results in the previous subsection, the MPT algorithm incurs the shortest average travel time in this 4-to-8 door layout and thus produces the highest throughput among these four policies in most cases under datasets 3 and 4, as shown in Table 4.4 and 4.5. Under the 4-to-8 door layout, the MPT algorithm can increase the throughput up to 29% compared to the FCFS policy. As for the cycle time, the MCT algorithm still has its advantage. Again, these four policies have similar performances when trailer arrivals are sparse.

Table 4.4 Performance of the 4-to-8 Crossdock Layout Using Dataset 3 under Different Scheduling Methods and Trailer Arrival Headways

Travel Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1.04	0.99	1.07	1.32
10	1.06	1.02	1.08	1.30
15	1.16	1.13	1.15	1.30
20	1.24	1.22	1.22	1.31
25	1.25	1.25	1.25	1.29
30	1.29	1.29	1.29	1.30
35	1.28	1.28	1.28	1.30

Cycle Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	269.21	307.03	383.22	421.79
10	138.59	186.21	261.93	314.07
15	141.34	162.70	188.59	225.01
20	143.85	148.21	150.85	168.55
25	144.13	144.36	145.63	149.83
30	147.52	147.40	147.25	149.58
35	153.81	153.68	153.49	155.09

Throughput (pallets/1000 minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1495	1553	1443	1204
10	1439	1499	1417	1210
15	1298	1333	1314	1176
20	1086	1103	1095	1047
25	896	906	906	886
30	734	736	737	732
35	640	640	642	639

Table 4.5 Performance of the 4-to-8 Crossdock Layout Using Dataset 4 under Different Scheduling Methods and Trailer Arrival Headways

Travel Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1.00	0.97	1.04	1.31
10	1.06	1.00	1.05	1.30
15	1.14	1.12	1.12	1.30
20	1.22	1.21	1.20	1.29
25	1.26	1.25	1.25	1.29
30	1.26	1.26	1.26	1.28
35	1.26	1.26	1.26	1.27

Cycle Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	262.00	288.01	363.89	424.01
10	135.39	176.38	255.22	315.28
15	138.49	158.14	186.93	224.01
20	145.57	150.67	155.11	170.76
25	148.19	148.11	149.79	154.90
30	149.11	149.16	149.72	151.40
35	154.70	154.35	153.95	154.25

Throughput (pallets/1000 minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1519	1571	1428	1235
10	1449	1529	1431	1229
15	1327	1352	1334	1188
20	1106	1115	1131	1068
25	906	910	911	887
30	738	743	741	737
35	645	645	645	640

4.4.3 8-to-8 scenarios

Because of additional receiving doors in this crossdock layout, the average queue lengths under the seven headway scenarios are smaller than those under the 4-to-4 and 4-to-8 door scenarios. When the headway is 20 minutes, the average queue length is about 0.21 to 0.24 trailers, which makes all of the scheduling policies perform similarly (see Table 4.6 and 4.7). Except for the cases in which the headways are equal to or greater than 20 minutes, we find that the two time-based algorithms still consistently perform better on the cycle time, and the throughputs of the MPT algorithm exceeds that of the look-ahead algorithm in most cases. The increase of throughput attains up to 14.4% for the MPT algorithm compared to the FCFS policy.

Table 4.6 Performance of the 8-to-8 Crossdock Layout Using Dataset 3 under Different Scheduling Methods and Trailer Arrival Headways

Travel Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1.61	1.60	1.58	1.84
10	1.67	1.64	1.63	1.84
15	1.76	1.76	1.76	1.83
20	1.81	1.81	1.81	1.82
25	1.83	1.83	1.82	1.83
30	1.83	1.83	1.83	1.84
35	1.83	1.83	1.83	1.83

Cycle Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	313.84	318.71	337.20	364.48
10	151.15	166.66	183.68	214.66
15	130.05	130.51	131.85	139.31
20	136.49	136.32	136.07	137.38
25	146.85	146.83	146.86	146.92
30	156.82	156.76	156.84	156.86
35	166.74	166.88	166.87	166.88

Throughput (pallets/1000 minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	2048	2074	2058	1813
10	1929	1963	1962	1775
15	1564	1569	1571	1525
20	1150	1150	1151	1151
25	912	912	912	912
30	739	739	739	739
35	640	640	640	640

Table 4.7 Performance of the 8-to-8 Crossdock Layout Using Dataset 4 under Different Scheduling Methods and Trailer Arrival Headways

Travel Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	1.64	1.63	1.62	1.85
10	1.69	1.66	1.65	1.84
15	1.79	1.78	1.78	1.84
20	1.83	1.83	1.83	1.84
25	1.83	1.83	1.83	1.83
30	1.82	1.82	1.82	1.82
35	1.81	1.81	1.81	1.81

Cycle Time (minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	303.31	310.34	333.72	362.12
10	149.87	165.66	183.40	216.01
15	132.51	132.03	134.49	141.74
20	139.71	139.55	139.95	140.54
25	151.49	151.47	151.64	151.65
30	159.31	159.31	159.39	159.43
35	167.31	167.32	167.29	167.32

Throughput (pallets/1000 minutes)

Headway	MCT	MPT	Look-Ahead	FCFS
5	2015	2035	2024	1808
10	1919	1951	1958	1781
15	1551	1552	1559	1528
20	1162	1161	1159	1161
25	906	906	906	906
30	738	738	738	738
35	635	635	635	635

4.5 Concluding Remarks

Two time-based trailer scheduling algorithms are proposed and compared with the look-ahead and FCFS policies under different trailer arrival headways, crossdock layouts and pallet destination distributions. The overall cycle time improvements shown in Table 4.8 provide evidence that our time-based algorithms can save more time on transferring pallets than the FCFS and look-ahead policies do when the average number of waiting trailers is greater than 0.65 (our simulation results also show that it has no meaning to use scheduling techniques when the average number of waiting trailers is below 0.65 because there are not many choices from the trailer waiting line). The time-saving effect from the two time-based trailer scheduling algorithms can be as high as 64%, 57% and 30% in the 4-to-4, 4-to-8 and 8-to-8 door scenarios, respectively, compared to the FCFS policy. All these improvements are attainable by just changing trailer scheduling methods without expanding facilities or manpower. These methods can result in noticeable influences on a supply chain:

- Reliable on-time delivery is an important criterion for rating a crossdock's operation. With shorter total transfer time, the time-based algorithms are expected to perform with higher reliability.
- In our simulations for the 4-to-8 and 8-to-8 doors, the MPT algorithm generates the highest throughputs in most cases. This means higher productivity and less transferring times for those crossdocks.
- The best travel time saving from the look-ahead algorithm compared to the MCT algorithm is about 0.06 minutes under the 4-to-4 door crossdock, dataset 1 and 10-minite headway scenario. If we compare the cycle times of these two

algorithms under the same scenario, the MCT method saves about 146 minutes. If the average inventory holding cost of pallets for the 146 minutes is higher than the labor cost of the 0.12-minute round-trip saving for a worker, it will be justified to adopt the MCT method. Under the situations in which the travel time using the look-ahead algorithm is higher than or equal to the time-based algorithms, adopting one of the time-based methods will be a better choice.

The main purpose of this chapter was to evaluate the performance of the four trailer scheduling policies on transferring freight. To avoid distraction, we do not consider staging processes in the 4-to-4 and 8-to-8 layouts. In fact, when allocating staging lanes in crossdocks, the real travel distances should be shorter than the travel distances used in our simulation models, and accordingly this should weaken the advantage of the look-ahead method.

Table 4.8 Improvements on Cycle Time for Each Scenario Compared to the FCFS Policy

4-to-4 Scenarios with Dataset 1

Headway	MCT	MPT	Look-Ahead
5	40.20%	21.01%	11.45%
10	64.21%	33.96%	21.35%
15	51.08%	27.07%	17.86%
20	26.96%	14.56%	7.83%
25	8.05%	4.87%	2.59%
30	2.34%	1.37%	1.26%
35	1.12%	0.89%	0.87%

4-to-4 Scenarios with Dataset 2

Headway	MCT	MPT	Look-Ahead
5	38.63%	17.11%	6.89%
10	63.21%	29.50%	11.30%
15	49.55%	22.42%	9.87%
20	25.84%	10.79%	5.56%
25	8.74%	6.02%	2.60%
30	2.60%	1.87%	1.04%
35	0.78%	0.83%	-0.23%

4-to-8 Scenarios with Dataset 3

Headway	MCT	MPT	Look-Ahead
5	36.18%	27.21%	9.15%
10	55.87%	40.71%	16.60%
15	37.19%	27.69%	16.19%
20	14.66%	12.07%	10.50%
25	3.80%	3.65%	2.80%
30	1.37%	1.46%	1.55%
35	0.82%	0.91%	1.03%

4-to-8 Scenarios with Dataset 4

Headway	MCT	MPT	Look-Ahead
5	38.21%	32.07%	14.18%
10	57.06%	44.06%	19.05%
15	38.18%	29.41%	16.55%
20	14.75%	11.76%	9.16%
25	4.33%	4.38%	3.30%
30	1.51%	1.48%	1.11%
35	-0.29%	-0.06%	0.20%

8-to-8 Scenarios with Dataset 3

Headway	MCT	MPT	Look-Ahead
5	13.89%	12.56%	7.48%
10	29.59%	22.36%	14.43%
15	6.65%	6.31%	5.35%
20	0.65%	0.77%	0.95%
25	0.05%	0.07%	0.04%
30	0.03%	0.06%	0.01%
35	0.09%	0.01%	0.01%

8-to-8 Scenarios with Dataset 4

Headway	MCT	MPT	Look-Ahead
5	16.24%	14.30%	7.84%
10	30.62%	23.31%	15.10%
15	6.51%	6.85%	5.12%
20	0.59%	0.71%	0.42%
25	0.10%	0.12%	0.00%
30	0.07%	0.07%	0.03%
35	0.01%	0.00%	0.02%

Chapter Five

Alternate Destination Strategies to Control Internal Freight Flows

Due to an imbalance of destination demands, it is common for certain destinations to experience more congestion than others during crossdocking. This congestion is reflected in blocking of staging lanes and strippers' waiting for spots to unload. One solution to mitigate this congestion is smoothing the concentration of deliveries to popular destinations. This solution has a similar role to the reduction of processing variability which was discussed in Chapter Three.

In this research, we assume that a pallet facing congestion while transferring could have one or more alternate destinations. This assumption is reasonable, especially in retail industries. For example, a pallet with boxes of a certain brand of beverages designated to store A may be also ordered by store B for the same delivery day. Therefore, we suggest that a pallet facing congestion to the staging lane for store A could alternatively be transported to the staging lane for store B, while the demand from store A can be satisfied later. In that case we need to delay the decision of a pallet's destination until it is to be transported by a stripper, as well as any value-added activities (such as labeling and pricing) specific to the destination.

The process of assigning a pallet to its primary or alternate destination through a staging lane is a dynamic assignment problem. The congestion cost for moving a pallet to a destination varies over time, depending on how many pallets are in the staging lane, the locations of those pallets and how many pallets (or strippers) are waiting for unloading before the staging lane. We therefore have to assign strippers dynamically according to real-time information about the states of staging lanes.

In this chapter, the basics of the staging cost are formulated in Section 5.1. Section 5.2 describes the transfer cost needed for a pallet to travel through a staging lane. A simplified example is also presented to show how transfer costs change. Sections 5.3 to 5.5 explain our four alternate destination strategies (two congestion smoothing strategies, minimizing a pallet's transfer cost strategy and minimizing a stripper's transport cost strategy) to control internal freight flows to avoid congestion. Simulation models are introduced in Section 5.6 to test the effectiveness of our strategies and their results are presented in Section 5.7. Finally, concluding remarks are presented in Section 5.8.

5.1 Staging Cost

Ideally, directly transferring pallets from receiving doors to shipping doors is the most cost-effective way of crossdocking, as discussed in Chapter Four. However, in practice, pallets are staged in most crossdock operations because of one or some of the following needs (Bartholdi, Gue and Kang, 2007):

"1. To perform value-added processes (labeling, pricing, etc.),

2. To wait for other items of an order to arrive,

3. To facilitate building tightly-packed loads in the outbound trailers, or

4. To load in reverse order of delivery if there will be multiple stops."

We define the staging cost as the time needed for a newly arriving pallet to be removed from a space of a staging lane until it arrives at a shipping door if the satging lane is not blocked; or the time needed for a newly arriving pallet waiting in front of a staging lane to arrive at a shipping door (not including the within-lane travel cost before arriving at a staging space and its unloading cost) if the staging lane is blocked. Because a pallet needs to wait for its preceding pallets to be removed, it could face different staging costs at different times even if it is going to a same shipping door from a same staging lane. The staging costs depend on how many pallets are in a staging lane, which staging space is available, and how many pallets are blocked in front of the staging lane.

In this section, we describe the notation used in this chapter and the simplest form of staging cost that has no congestion. Having set up this background, we extend the formulations of staging costs to all possible conditions in Section 5.2 from the point of view of a pallet. In this study we consider only the inventory (pallet) and labor (stripper) time costs.

The following notation is used throughout this chapter.

N: the index for receiving doors;

M' : the index for shipping doors;

M: the index for staging lanes in front of shipping door M';

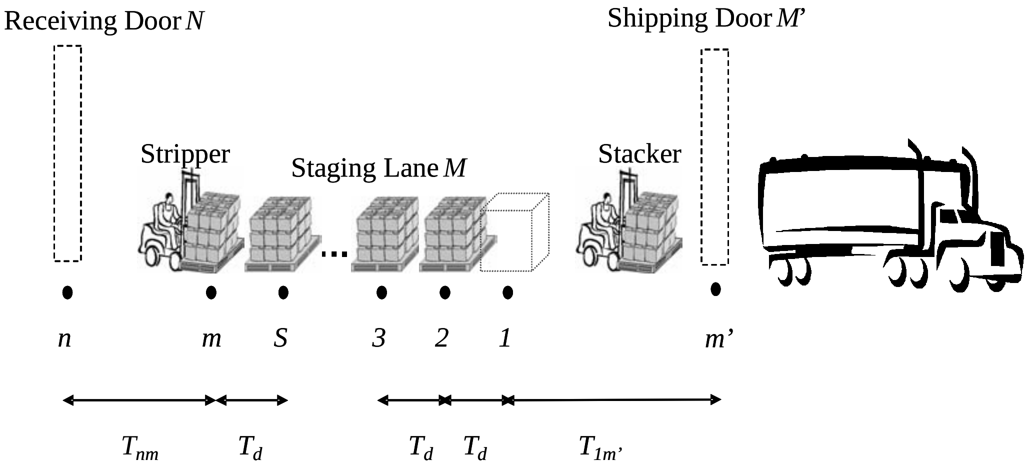
$R(p)$: is the set of possible destinations for pallet p;

t : the index for time periods;

$C_{NM'}(t,p)$: the expected transfer cost for pallet p at time t; it represents the expected time needed at time t to move pallet p from receiving door N, through staging lane M and finally to shipping door M';

$C_{NM}(t,s)$: the expected transport cost for stripper s at time t; it represents the expected time needed at time t to move a pallet from receiving door N to a space in staging lane M and then return back to receiving door N;

T_{nm}: the expected travel cost (time) needed from spot n (see Figure 5.1) at receiving door N to spot m in front of staging lane M;



Parameter Setting in Cost Functions				(Unit: Minute)		
Layout	T_{nm}	T_d	$T_{1m'}$	T_{va}	K	S
Example in 5.2.3	0.5	0.2	0.4	0.4	0.5	4
4-to-4 Crossdock	Depends	0.08	0.25	0.5	0.5	4
8-to-8 Crossdock	Depends	0.07	0.2	0.5	0.5	12

Figure 5.1 Travel Times inside a Single-Staging Crossdock

$T_{1m'}$: the expected travel cost (time) from staging space *1* to spot *m'* at shipping door *M'*.

L_{mj}: the within-lane travel cost (time) from spot *m* at staging lane *M* to the *j*th staging space of the staging lane;

K: the sum of cost (time) needed for loading and unloading a pallet; *K* is a constant;

S: the capacity of a staging lane; *S* is a constant.

$T(i_M(t), j_M(t))$: the expected total cost (time) needed for a stacker to clear the queue of staging lane *M* where staging pallets start from the *i*th space and end at the *j*th space of the staging lane at time *t*;

T_d: the expected travel cost (time) between two adjacent staging spaces; T_d is a constant;

$w_M(t)$: the number of pallets waiting before staging lane M at time t because of blocking;

T_{va}: the expected value-added activity cost (time) needed when remaining at a staging lane (for example, labeling);

$T_{lag}^{M}(t)$: the expected cost (time lag) between the time of assignment (time t) and the time the stacker for staging lane M really finishes his/her current transporting and is ready for his/her next task;

$D_M(t)$ *or* $D_{M'}(t)$: the remaining demand for staging lane M or shipping door M' at time t. Because the pallets in staging lane M will be moved to shipping door M', the remaining demands for staging lane M and shipping door M' are exactly the same.

We make the following assumptions when formulating costs:

1. Each stripper starts tasks from his or her respective receiving door, whose location is labeled as "*n*" in Figure 5.1; each stacker starts tasks from the first space of his or her respective staging lane, whose location is labeled as "*1*" in Figure 5.1.
2. The travel cost (time) inside an inbound or outbound trailer is considered to be zero, while the travel cost (time) between two staging spaces is measured. The travel cost between two adjacent staging spaces is T_d.
3. When a stripper finds a staging space for his or her pallet, he or she can put down the pallet and return to his or her original receiving door for his/her next task. However, if the last space of the staging lane is occupied, the staging lane is

blocked and the stripper must wait in front of the staging lane (see the label "*m*" in Figure 5.1) until the lane is cleared. We also assume that the spot, *m*, is large enough for all strippers to wait there (to facilitate the computation of travel cost).

4. The cost for a stripper or a stacker to unload or load a pallet is assumed equal. Each incurs $\frac{K}{2}$ time units.

5. Each pallet needs value-added activities (such as labeling or pricing) at a staging lane, which incurs T_{va} units. It is assumed that T_{va} is smaller than the round-trip cost between spots "*1*" and "*m*" for a stacker and hence only the T_{va} of the first pallet will be counted into the waiting time in a staging lane because the value-added activities for other pallets can be done when they are waiting.

6. The number of spaces in a staging lane is enough to provide rooms for all pallets waiting in spot "*m*" once a lane is cleared. This assumption is reasonable in practice: if a destination is so popular that it could accumulate a long line of waiting pallets during transferring, it would be better to open another staging lane for the destination.

$T(i_M(t), j_M(t))$ is the expected total cost to transport all the pallets in staging lane M with the first pallet at the ith space and the last pallet at the jth space. Hence, the total number of pallets in the staging lane is $j_M(t)-i_M(t)+1$. As shown in Figure 5.1, all pallets in the staging lane need to travel through the path $1m'$ (from space 1 to m') and thus incur travel cost $[j_M(t)-i_M(t)+1]*(2T_{1m'})$ for a stacker since we assume a stacker starts his or her movement from the first space of a staging lane. As for the travel cost inside a staging lane, since there is no blocking downstream, a pallet can get service once the stacker for the lane is available. Hence, the pallet at the first space incurs zero cost, the pallet at the second space incurs $2T_d$, …, and the pallet at the jth space incurs $2(j_M(t)-1)T_d$ for the within-lane travel for a stacker. Therefore,

$$T(i_M(t), j_M(t)) = [j_M(t) - i_M(t) + 1] * (2T_{1m'} + K) + \sum_{x=i_M(t)}^{j_M(t)} 2(x-1)T_d. \tag{5.1}$$

When the last space of a staging lane is occupied, the staging lane blocks the pallets coming from receiving doors. The stripper and the pallet waiting for a staging space thus bear extra blocking cost. The blocking time will be $T(i_M(t),S)$ and the first pallet waiting in front of the staging lane will occupy the first space of the staging lane once the staging lane is unblocked.

Hence, the expected staging costs can be formulated as:

$T(i_M(t), j_M(t)+1) - T_{1m'}$ for a new arriving pallet that will occupy staging space $j_M(t)+1$ to be removed to spot *m'* at shipping door *M'* under a non-blocking situation; or

$T(i_M(t), S) + T_{va} + T(1, w_M(t)+1) - T_{1m'}$ for a new arriving pallet that will wait as the $[w_M(t)+1]$th queuer in front of staging lane *M* to arrive at spot *m'* at shipping door *M'* under a lane-blocking situation. Note that the within-lane travel cost before arriving at staging space $w_M(t)+1$ and its unloading cost are excluded here.

5.2 Transfer Cost for a Pallet to Be Transported to a Shipping Door

In the previous section, we formulated the simple forms of staging costs. In this section, we explore more details related to the staging costs when facing blocking. In addition, the transfer cost of the whole process for a pallet starting from being picked up by a stripper, being moved to a staging lane, waiting in front of a blocked staging lane, waiting at a staging space to be picked up by a stacker and finally being moved to a shipping door is analyzed and formulated. These formulations will be used later for our alternate destination strategies.

5.2.1 When there is no new assignment to *M*

First we define state (i_M, j_M) as the situation in which the first pallet is at the *i*th space of staging lane *M* and the last pallet is at the *j*th space. For staging lane *M*, if there is no new assignment of pallets to it at time *t*, the transfer cost (time) needed to clear state (i_M, j_M) is $T^M_{lag}(t)+T(i_M(t), j_M(t))$. This is the remaining time needed for the stacker for staging lane *M* to finish his or her current task plus the cost (time) needed to transport the (j_M+i_M-1) pallets in the staging lane.

5.2.2 When a new pallet is assigned to staging lane *M*

When a new pallet is assigned to staging lane *M* at time *t*, the transfer cost (time) needed for the new pallet to be moved to its shipping door is:

1. Under the situation that staging lane *M* is not blocked ($j_M(t)<S$) at time *t*:

$$C_{NM'}(t,p)=T^M_{lag}(t)+T(i_M(t), j_M(t)+1)-T_{1m'}, \quad (5.2)$$

if $\frac{K}{2}+T_{nm}+L_{m[j_M(t)+1]} < T^M_{lag}(t)+T(i_M(t), j_M(t))$, which means that the staging lane is not cleared when the pallet arrives. Note that we only consider the time the pallet arrives at the shipping door, so the time needed for the stacker's return trip is excluded in the transfer cost.

$$C_{NM'}(t,p)=T_{nm}+L_{m1}+K+T_{va}+T(1,1)-T_{1m'}, \quad (5.3)$$

if $\frac{K}{2}+T_{nm}+L_{m[j_M(t)+1]} \geq T^M_{lag}(t)+T(i_M(t), j_M(t))$, which means that the staging lane is cleared when the pallet arrives. Note that because the pallet will be the first pallet in the staging lane, it needs to wait for the time to process the value-added activities before being transported by a stacker.

2. Under the situation that staging lane M is blocked ($j_M(t)=S$), and the number of the waiting pallets in front of staging lane M is $w_M(t)$ at time t:

$$C_{NM'}(t,p)=T^M_{lag}(t)+T(i_M(t),S)+L_{m1}+0.5\mathrm{K}+T_{va}+T(1,w_M(t)+1)-T_{1m'}, \quad (5.4)$$

if $\frac{K}{2}+T_{nm} < T^M_{lag}(t)+ T(i_M(t),S)$, which means that the pallet will join the waiting line in front of staging lane M.

$$C_{NM'}(t,p)= T_{nm}+K+T_{va} -T_{1m'}+0.5\cdot[L_{m1}+ T(1,w_M(t)+1) +L_{m[w_M(t)+1]}$$
$$+T(w_M(t)+1,w_M(t)+1)], \quad (5.5)$$

if $T^M_{lag}(t) +T(i_M(t),S)+L_{m1}+T_{va}+T(1,w_M(t))> \frac{K}{2} +T_{nm}>= T^M_{lag}(t) +T(i_M(t),S)$, which means that the pallet will join the second staging queue that will be formed by the pallets waiting in front of staging lane M at time t. There are many possibilities about the time of the new pallet's arrival. It could arrive as early as right after the second queue forms or as late as before the $w_M(t)$th pallet leaves its space. Therefore, we use the average time of the above extreme values to represent the expected time for the pallet to arrive at the staging space[3]. Note that this condition does not exist if $w_M(t)=0$.

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[3] Hozo, Djulbegovic and Hozo (2005) estimate the sample mean $\bar{x} \approx$ (the minimum value +2* the median value+ the maximum value)/4, which does not require an assumption of the distribution of underlying data. This mean equals to the average of the two extreme values, assuming the median value is equal to the average of the two extreme values.

$C_{NM'}(t,p)=T_{nm}+L_{m1}+K+T_{va}+T(1,1)-T_{1m'}$, (5.6)

if $\frac{K}{2}+T_{nm}+L_{m[w_M(t)+1]} \geq T_{lag}^{M}(t)+T(i_M(t),S)+L_{m1}+T_{va}+T(1,w_M(t))$, which means that the staging lane is cleared when the pallet arrives. Note that if $w_M(t)=0$, the previous "if" condition becomes "$\frac{K}{2}+T_{nm} \geq T_{lag}^{M}(t)+T(i_M(t),S)$".

The above five cases are summarized in Table 5.1.

Table 5.1 Transfer Cost for a Pallet at Five Different Cases

Case	Staging Lane Situation at Time *t*	Staging Lane Situation When the Pallet arrives	Transfer cost ($C_{NM'}(t,p)$)
A	Not blocked	Not cleared	$T_{lag}^{M}(t)+T(i_M(t),j_M(t)+1)-T_{1m'}$
B	Not blocked	Cleared	$T_{nm}+L_{m1}+K+T_{va}+T(1,1)-T_{1m'}$
C	Blocked	Not cleared	$T_{lag}^{M}(t)+T(i_M(t),S)+L_{m1}+0.5K+T_{va}+T(1,w_M(t)+1)-T_{1m'}$
D	Blocked	First queue is cleared	$T_{nm}+K+Tva-T_{1m'}+0.5[L_{m1}+T(1,w_M(t)+1)+L_{m[w_M(t)+1]}+T(w_M(t)+1,w_M(t)+1)]$
E	Blocked	Cleared	$T_{nm}+L_{m1}+K+T_{va}+T(1,1)-T_{1m'}$

5.2.3 An example

After establishing the above transfer cost functions, we use a simplified example to show how these costs vary with the number of pallets, the locations of pallets and whether the staging lane is blocked.

In this example, we consider only one staging lane with four spaces serving pallets from four receiving doors. The following values are specified: $T_{lag}^{M}(t)=0$, T_{nm}=0.5 minute, K=0.5 minute, T_d=0.2 minute, $T_{1m'}$=0.4 minute and T_{va}=0.4 minute (also shown in Figure 5.1). Table 5.2 shows the expected cost (time) needed for transporting a new pallet to its shipping door under the state of $[i_M(t),j_M(t),w_M(t)]$ at the time of assigning the pallet (that is, time t).

Table 5.2 The Expected Cost (in minutes) Needed to Transport a Pallet in a 4-to-4 Staging Crossdock with Four-Space Staging Lane

State $[i_M(t),j_M(t),w_M(t)]$	Cost to arrive at a space	Cost to arrive at the shipping door	Number of pallets using the lane (including the new one)
(0,0,0)	1.8	3.1	1
(1,1,0)	1.8	3.1	2
(1,2,0)	1.4	4.7	3
(1,3,0)	**1.2**	**7.2**	**4**
(1,4,0)	**8.65**	**9.95**	**5**
(1,4,1)	8.45	11.65	6
(1,4,2)	8.25	13.75	7
(1,4,3)	8.05	16.25	8
(2,2,0)	1.4	3.4	2
(2,3,0)	1.2	5.9	3
(2,4,0)	7.35	8.65	4
(2,4,1)	7.15	10.35	5
(2,4,2)	6.95	12.45	6
(2,4,3)	6.75	14.95	7
(3,3,0)	1.2	4.2	2
(3,4,0)	5.65	6.95	3
(3,4,1)	5.45	8.65	4
(3,4,2)	5.25	10.75	5
(3,4,3)	5.05	13.25	6
(4,4,0)	3.55	4.85	2
(4,4,1)	3.35	6.55	3
(4,4,2)	3.15	8.65	4
(4,4,3)	2.95	11.15	5

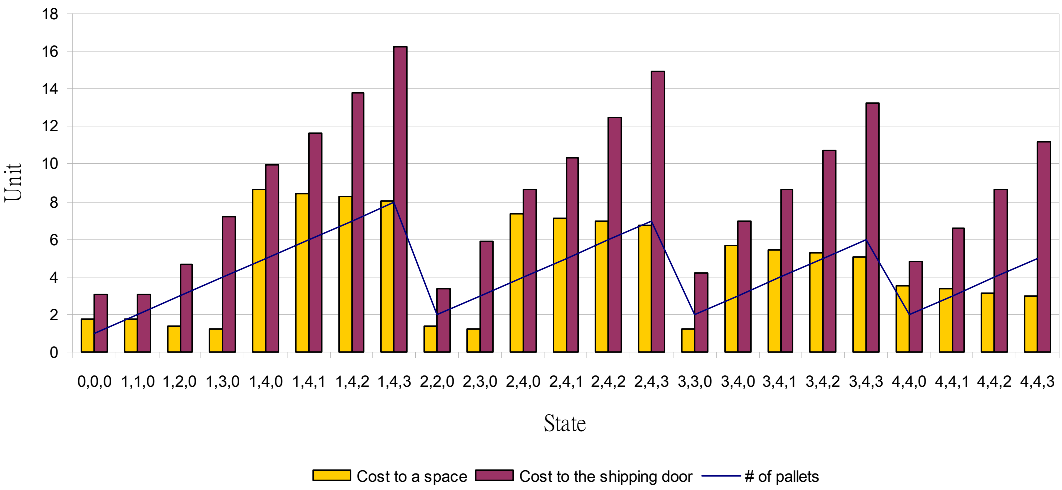


Figure 5.2 The Expected Cost (in minutes) Needed to Transport a Pallet in a 4-to-4 Crossdock with Four-Space Staging Lane

Generally speaking, the cost needed for a pallet to arrive at a shipping door is proportional to the number of pallets in a staging lane. When the staging lane is blocked, a stripper needs to wait in front of the staging lane and thus incurs a longer time period for a pallet to get a space. Remember that we construct transfer cost functions under situations with or without blocking and clearance of a staging lane. The value T_{nm} plays an important role in evaluating whether a staging lane will be cleared when a new pallet arrives. So under the situation with a bigger value of T_{nm} (that is, a longer travel time from a receiving door to a staging lane), the chance of encountering a cleared staging lane could be higher because a stacker can have more time to clear a short queue, which is the case of state (1,1,0) in our example.

5.3 Congestion Smoothing Strategies

As we may find from Figure 5.2, the cost to travel to a space increases sharply when the staging lane is blocked. Take states (1,3,0) and (1,4,0) (in bold font in Table 5.2) for example. The latter one has a value that is almost seven times as high as the former one! Even though the increased transfer cost for adding a pallet does not grow much because of blocking, the stripper who transports the pallet endures lots of waiting. Therefore, reducing the congestion in front of staging lanes is one of the most important things for us to consider.

Here we introduce our congestion smoothing strategy. We assume that each pallet may have a secondary destination in addition to its designated primary destination. A secondary destination can be viewed as a retail outlet that also requires the same contents on a pallet as the pallet’s primary outlet. When transferring a pallet in a single-stage crossdock, if the staging lane of the pallet's primary destination is blocked, we could deliver the pallet to its secondary destination and satisfy the primary destination's demand later. Thus workers' efficiency could be improved because they could reduce waiting time caused by lane blockage.

Two things must be considered in this strategy. First, since we may change the destinations of pallets during the course of transferring, we need to put them back later so that we can match the supply of pallets to the demands of destinations. Second, we need to construct a mechanism to compare the congestion levels in front of staging lanes. The transfer cost function, Equation (5.4), obtained in the previous section, can help us make the comparison.

Thus, the congestion smoothing strategy can be formulated as:

Find *M'* such that

$$\textbf{Minimize } C_{NM'}(t,p) = T_{lag}^{M}(t) + T(i_M(t),S) + L_{m1} + 0.5K + T_{va} + T(1,w_M(t)+1) - T_{1m'}$$

Subject to: (5.7)

$$D_{M'}(t) > 0$$

$$\forall M' \in R(p)$$

5.3.1 Congestion smoothing—total-limit rule

To control the total demand of each destination, we introduce the total-limit rule.

The total-limit rule uses the total number of pallets bound for each destination as the mechanism for allowing the exchange of destinations during the transfer process. When this total of an alternate destination has been reached, no more pallets can be diverted there. However, if a pallet's primary destination and alternate destination(s) have all reached their limits because of the randomness of changing destinations, the pallet still goes to its primary destination since we have no other place to transfer it. So this rule is actually a soft limitation for controlling the total number of destinations.

The process of implementing this congestion smoothing—total limit (CSTL) strategy is diagrammed in Figure 5.3. This strategy is not hard to implement since we only need the information of whether a staging lane is blocked, how many pallets are in the staging lane and whether its demand is satisfied.

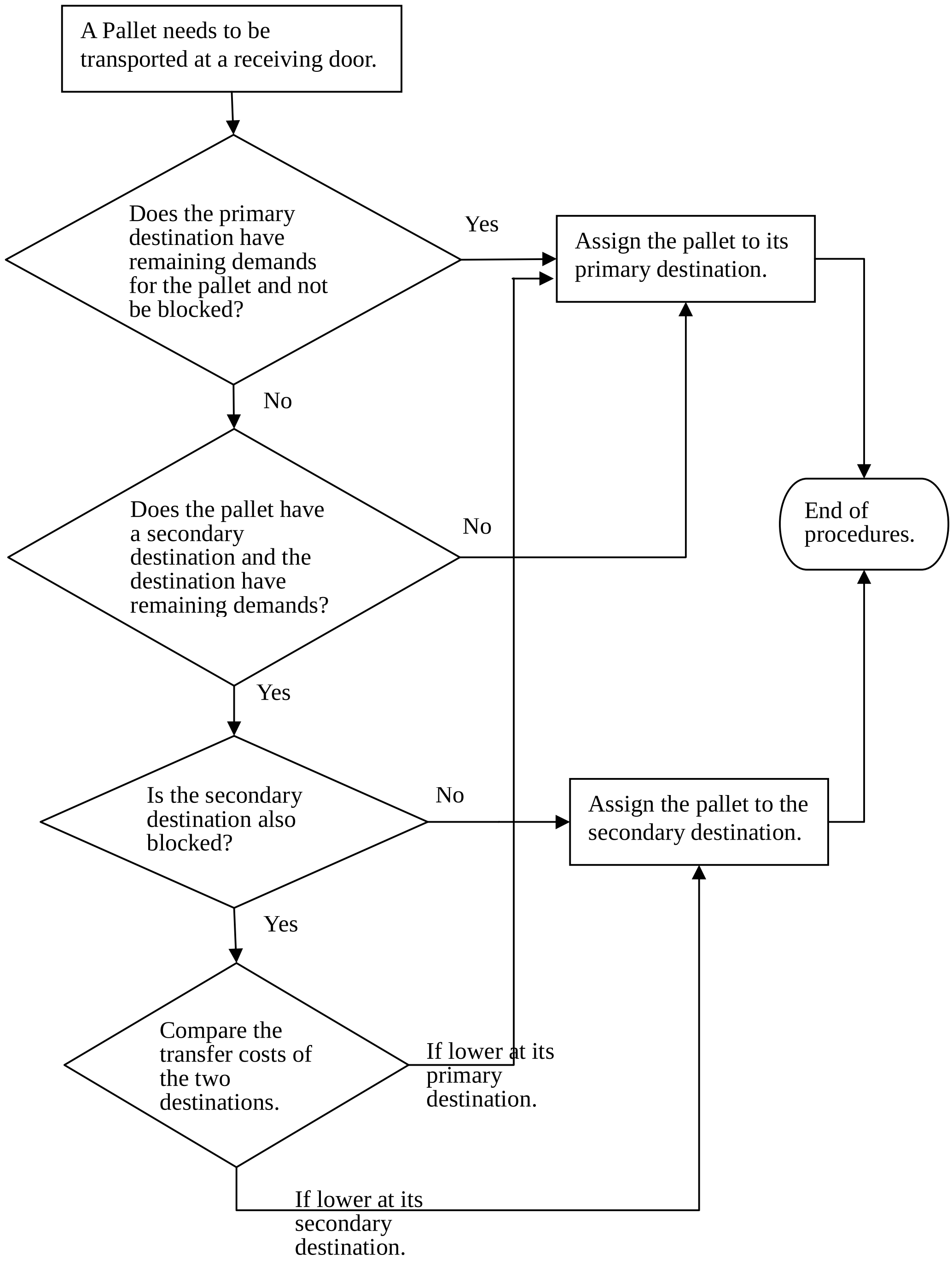


Figure 5.3 The Procedures for Implementing the Congestion Smoothing Strategies

5.3.2 Congestion smoothing—rolling-limit rule

The total-limit rule gives a lot of freedom to exchange destinations of pallets. However, due to the nature of its lenient constraint, the results of its total deliveries may not exactly match actual demands, which will be discussed later in Section 5.7. Due to this drawback, we propose a rolling-limit rule to more aggressively control the permission to allow exchanging of destinations. This rule is similar to the total-limit rule except that the controlling limits for each destination are smaller and change overtime.

The rolling-limit rule builds a set of limits according to the number of existing pallets bound for different destinations whenever a new trailer arrives at a receiving door. The "existing" pallets include the ones at receiving doors, in staging lanes and at shipping doors, not including the pallets in the trailer waiting line and those having left the crossdock. The numbers of existing pallets for each destination are calculated according to their primary destinations, and these numbers work as limits for allowing destination exchange during the time period between two consecutive unloading trailer arrivals. Through this mechanism, we have better control to meet the demands.

The logic for applying this congestion smoothing—rolling-limit (CSRL) strategy is the same as that of the total-limit rule, as shown in Figure 5.3.

5.4 Minimizing a Pallet's Transfer Cost Strategy

Except for the concept of congestion smoothing, we can assign a pallet's destination according to the transfer costs of its alternate destinations. Equations (5.2)-(5.6) are used in this strategy. The steps for minimizing a pallet's transfer cost (MPTC) strategy are as follows:

Step 0: Pallet *p* at receiving door *N* needs to be assigned to a destination.

Step 1: Check if pallet *p* has an alternate destination or more. If not, assign pallet *p* to its primary destination and exit this procedure.

Step 2: Find *M'* such that

Minimize $C_{NM'}(t,p)$

Subject to: (5.8)

Equations (5.2)-(5.6) and their "if" conditions.

$D_{M'}(t)>0$

$\forall M' \in R(p)$

Step 3: Assign pallet *p* to shipping door *M'* and exit this procedure.

Note that when deciding the state of $[i_M(t),j_M(t),w_M(t)]$, the pallets en route to staging lane *M* should be counted to be able to correctly estimate pallet *p*'s staging cost. Hence, the information on the locations of pallets is required and thus this strategy is more complex than the congestion smoothing strategies. We assume the pallets on their way to staging lane *M* at time *t* can arrive at the staging lane before pallet *p* does, and we adopt the rolling-limit rule to allow for exchange for among alternate destinations.

5.5 Minimizing a Stripper's Transport Cost Strategy

The above three strategies focus on minimizing a pallet's transfer cost, while, in this section, we focus on minimizing a stripper's transport cost to increase his or her transporting efficiency. Remember in Figure 5.2 we portray the situation in which a stripper endures lots of waiting time due to blocking. Hence, looking at a staging system via a stripper's standpoint will be useful.

From the view point of the stripper at receiving door N, the time needed for him or her to finish a task to staging lane M and return (to the receiving door) for the next task is:

1. Under the situation that staging lane M is not blocked ($j_M(t) < S$) at time t:

$$C_{NM}(t,s) = 2T_{nm} + 2L_{m[j_{M(t)+1}]} + K, \tag{5.9}$$

if $\frac{K}{2} + T_{nm} + L_{m[j_{M(t)+1}]} < T_{lag}^{M}(t) + T(i_M(t), j_M(t))$, that is, the staging lane is not cleared when the pallet arrives.

$$C_{NM}(t,s) = 2T_{nm} + 2L_{m1} + K, \tag{5.10}$$

if $\frac{K}{2} + T_{nm} + L_{m[j_{M(t)+1}]} \geq T_{lag}^{M}(t) + T(i_M(t), j_M(t))$, that is, the staging lane is cleared when the pallet arrives.

2. Under the situation that staging lane M is blocked ($j_M(t)=S$), and the number of the waiting pallets in front of staging lane m is $w_M(t)$ at time t:

$$C_{NM}(t,s) = T_{lag}^{M}(t) + T(i_M(t), S) + 2L_{m[w_{M(t)+1}]} + T_{nm} + \frac{K}{2}, \tag{5.11}$$

if $\frac{K}{2} + T_{nm} < T_{lag}^{M}(t) + T(i_M(t), S)$.

$$C_{NM}(t,s) = 2T_{nm} + 2L_{m[w_{M(t)+1}]} + K, \tag{5.12}$$

if $T_{lag}^{M}(t) + T(i_M(t), S) + L_{m1} + T_{va} + T(1, w_M(t)) > \frac{K}{2} + T_{nm} >= T_{lag}^{M}(t) + T(i_M(t), S)$. Note that this condition does not exist if $w_M(t)=0$.

$$C_{NM}(t,s) = 2T_{nm} + 2L_{m1} + K, \tag{5.13}$$

if $\frac{K}{2} + T_{nm} + L_{m[w_{M(t)+1}]} \geq T_{lag}^{M}(t) + T(i_M(t), S) + L_{m1} + T_{va} + T(1, w_M(t))$. Note that if $w_M(t)=0$, the previous "if" condition becomes "$\frac{K}{2} + T_{nm} \geq T_{lag}^{M}(t) + T(i_M(t), S)$".

The transport cost formulations under the five possible cases are summarized in Table 5.3.

Table 5.3 Transport Cost for a Stripper at Five Different Cases

Case	Staging Lane Situation at Time t	Staging Lane Situation When the Pallet arrives	Transport cost ($C_{NM}(t,s)$)
A	Not blocked	Not cleared	$2T_{nm}+2L_{m[j_M(t)+1]}+K$
B	Not blocked	Cleared	$2T_{nm}+2L_{m1}+K$
C	Blocked	Not cleared	$T_{lag}^{M}(t)+T(i_M(t),S)+2L_{m[W_M(t)+1]}+T_{nm}+\frac{K}{2}$
D	Blocked	First queue is cleared	$2T_{nm}+2L_{m[W_M(t)+1]}+K$
E	Blocked	Cleared	$2T_{nm}+2L_{m1}+K$

The steps for minimizing a stripper's transport cost (MSTC) strategy are as follows:

Step 0: Pallet p at receiving door N needs to be assigned to a destination.

Step 1: Check if the pallet has an alternate destination or more. If not, assign the pallet to its primary destination and exit this procedure.

Step 2: Find M such that

Minimize $C_{NM}(t,s)$

Subject to: (5.14)

Equations (5.9)-(5.13) and their "if" conditions.

$D_M(t)>0$

$\forall M \in R(p)$

Step 3: Assign pallet p to staging lane M (shipping door M') and exit this procedure.

The rolling-limit rule is also applied to this strategy when calculating $D_M(t)$.

5.6 Simulation Models

5.6.1 Crossdock layouts and transferring processes

We use two single-staging crossdock layouts for our alternate destination strategies. The 8-to-8 staging crossdock has the same size (75 feet wide) as the one used in Chapter Four but has twelve staging spaces between each pair of receiving and shipping doors. These twelve staging spaces are a typical common staging length in crossdocks (Bartholdi, Gue and Kang, 2007). The 4-to-4 crossdock is only equipped with four staging spaces and hence is 50 feet in width to reflect the difference in travel distance needed in different staging layouts. The detailed layouts are shown in Appendix B.

A staging lane is loaded starting with its first staging space and pallets are removed to a shipping door from the foremost staging space of the staging lane. When a staging lane is blocked, a new pallet moving to the staging lane is also blocked, and so are the strippers carrying the pallet and the receiving door exporting that pallet. The transition of all possible states can be expressed using an example of a 4-to-4 with four staging-space crossdock. If we assume the mean pallet arrival rate from four receiving doors to a staging lane is λ, the mean service rate of the staging lane is μ, state e as the initial state with no pallets in the staging lane and state ($\underline{0,0},0$) as the state in which there are no pallets waiting in the staging lane but one pallet being served by a stacker, the transition of states, $(i_M(t),j_M(t),w_M(t))$, for staging lane M can be shown in Figure 5.4.

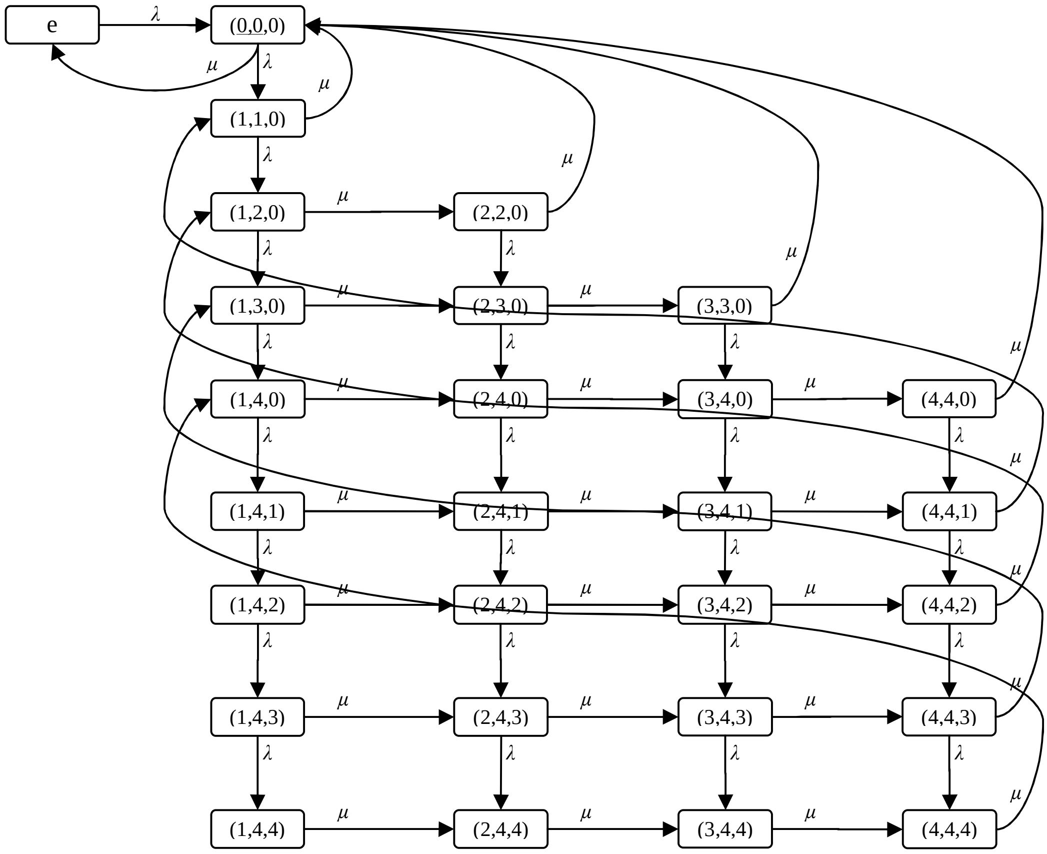


Figure 5.4 Transition Diagram for a 4-space Staging Lane in a 4-to-4 Staging Crossdock

The transfer processes of our alternate destination strategies (Figure 5.5) are similar to the ones used in the trailer scheduling part except that (1) we only use the FCFS policy to assign unloading trailers, (2) adding staging lanes between receiving doors and shipping doors, and (3) excluding the waiting phase in outbound trailers. The above modifications aim at focusing only on the effect of our alternate destination strategies to not be distracted by other procedures.

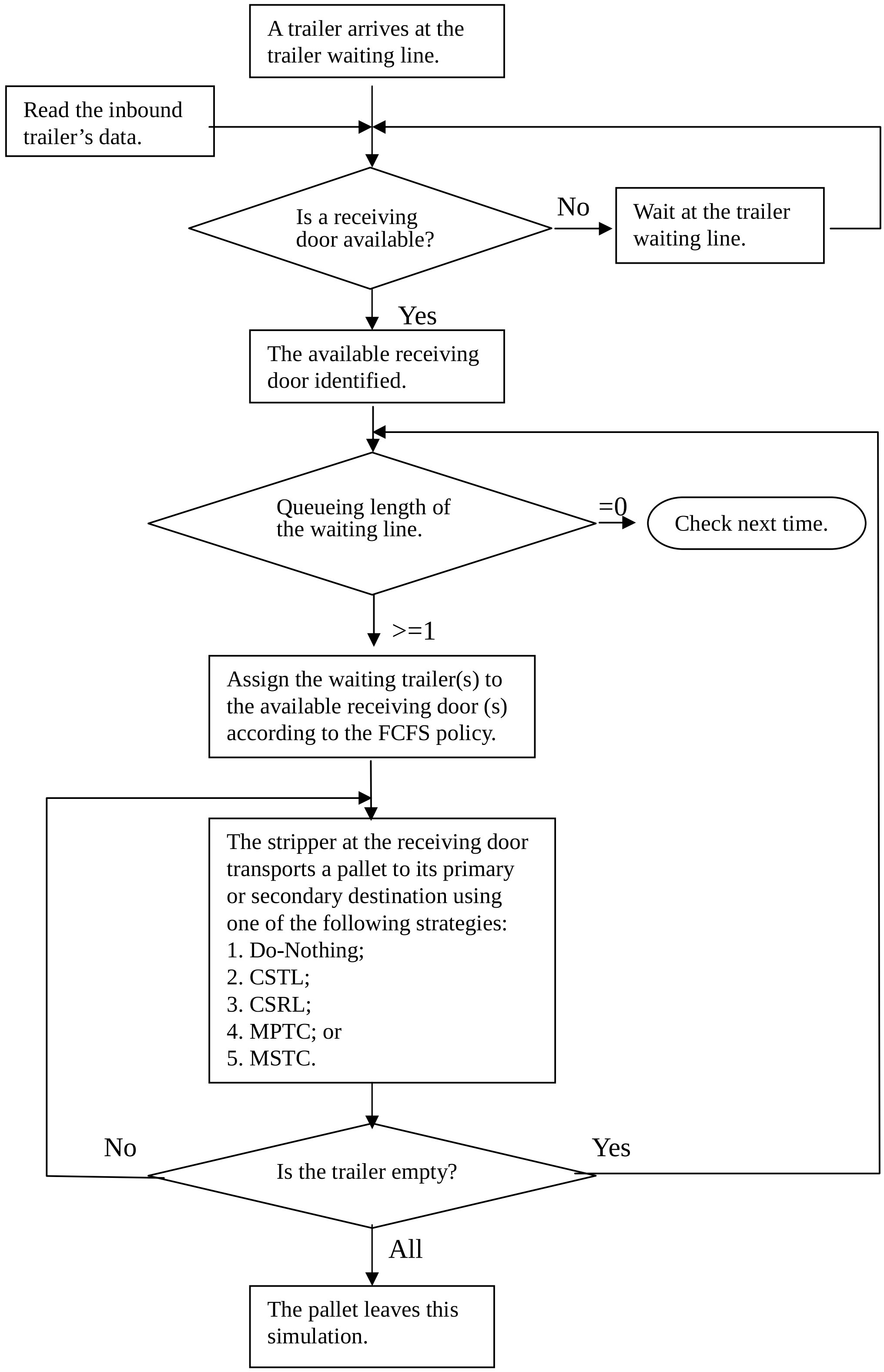


Figure 5.5 The Logic of the Simulation Models Used in the Alternate Destination Study

5.6.2 Model basics and assumptions

Our five simulation models for the alternate destination strategies are also built using Arena (version 11). Each inbound trailer used in this chapter carries 28 pallets and we simulate trailer inter-arrivals using exponential distributions with means of 10, 20 and 30 minutes for the 4-to-4 staging models and 10, 15 and 20 minutes for the 8-to-8 staging models. These three different arrival levels represent congested, moderate and slack conditions, respectively. In each scenario we obtain average results from a 20-replication simulation and each replication has to finish transferring 80 trailers (2,240 pallets). Here we use a different termination criterion from the one used in Chapter Four because we need the measurement of demand mismatch for the flow freight control strategies, which is only attainable after transferring all pallets.

In the 4-to-4 simulations, the following parameters are assumed: the speed of strippers and stackers driving forklifts=60 feet/minute; T_d≈0.08 minute; $T_{1m'}$=0.25 minute; K=0.5 minute; T_{va}=0.5 minute. The T_{nm} matrix and the $T(i_M,j_M)$ matrix for the 4-to-4 staging crossdock are calculated in Table 5.4 and 5.5. While in the 8-to-8 simulations, the speeds of strippers and stackers, K and T_{va} are the same, but T_d becomes 0.07 and $T_{1m'}$ becomes 0.2 because of different distances. The T_{nm} matrix and the $T(i_M,j_M)$ matrix for the 8-to-8 staging crossdock are calculated in Table 5.6 and 5.7.

Table 5.4 Travel Times (T_{nm}) of the 4-to-4 Staging Crossdock between Receiving Doors* and Staging Lanes* (Unit: Minutes)

	S1	S2	S3	S4
R1	0.25	0.46	0.81	1.18
R2	0.45	0.25	0.46	0.81
R3	0.80	0.45	0.25	0.46
R4	1.18	0.80	0.45	0.25

*: Receiving doors are R1, R2, R3 and R4; staging lanes are S1, S2, S3 and S4.

Table 5.5 Values of $T(i_M, j_M)$ of the 4-to-4 Staging Crossdock (Unit: Minutes)

i_M \ j_M	1	2	3	4
1	1	2.16	3.48	4.96
2	--	1.16	2.48	3.96
3	--	--	1.32	2.80
4	--	--	--	1.48

Table 5.6 Travel Times (T_{nm}) of the 8-to-8 Staging Crossdock between Receiving Doors* and Staging Lanes* (Unit: Minutes)

	S1	S2	S3	S4	S5	S6	S7	S8
R1	0.25	0.46	0.81	1.18	1.55	1.93	2.31	2.69
R2	0.45	0.25	0.46	0.81	1.18	1.55	1.93	2.31
R3	0.80	0.45	0.25	0.46	0.81	1.18	1.55	1.93
R4	1.18	0.80	0.45	0.25	0.46	0.81	1.18	1.55
R5	1.55	1.18	0.80	0.45	0.25	0.46	0.81	1.18
R6	1.93	1.55	1.18	0.80	0.45	0.25	0.45	0.80
R7	2.32	1.93	1.55	1.18	0.80	0.45	0.25	0.45
R8	2.70	2.32	1.93	1.55	1.18	0.80	0.45	0.25

*: Receiving doors are R1, R2, R3 R4, R5, R6, R7 and R8; staging lanes are S1, S2, S3, S4, S5, S6, S7 and S8.

Table 5.7 Values of $T(i_M, j_M)$ of the 8-to-8 Staging Crossdock (Unit: Minutes)

i_M \ j_M	1	2	3	4	5	6	7	8	9	10	11	12
1	0.90	1.94	3.12	4.44	5.90	7.50	9.24	11.12	13.14	15.30	17.60	20.04
2	--	1.04	2.22	3.54	5.00	6.60	8.34	10.22	12.24	14.40	16.70	19.14
3	--	--	1.18	2.50	3.96	5.56	7.30	9.18	11.20	13.36	15.66	18.10
4	--	--	--	1.32	2.78	4.38	6.12	8.00	10.02	12.18	14.48	16.92
5	--	--	--	--	1.46	3.06	4.80	6.68	8.70	10.86	13.16	15.60
6	--	--	--	--	--	1.60	3.34	5.22	7.24	9.40	11.70	14.14
7	--	--	--	--	--	--	1.74	3.62	5.64	7.80	10.10	12.54
8	--	--	--	--	--	--	--	1.88	3.90	6.06	8.36	10.80
9	--	--	--	--	--	--	--	--	2.02	4.18	6.48	8.92
10	--	--	--	--	--	--	--	--	--	2.16	4.46	6.90
11	--	--	--	--	--	--	--	--	--	--	2.30	4.74
12	--	--	--	--	--	--	--	--	--	--	--	2.44

Other characteristics such as empty-start in each replication and deterministic processing times other than trailer arrival headways are the same as in Chapter Four.

5.6.3 Datasets

Datasets 1, 3 and 4 that were used in Chapter Four are also used in this chapter. Because 4-staging-space is not typical for crossdocking, only dataset 1 is used to test the effectiveness of our strategies in a small crossdock. The other two datasets containing skewed and relatively balanced destination distributions, respectively, are for the 8-to-8 staging models. In this control strategy simulation, a secondary destination for each pallet is assumed and is randomly generated from 4 destinations (for the 4-to-4 staging model) or 8 destinations (for the 8-to-8 staging model). When a same destination as a pallet's primary destination is produced, it means that the pallet does not have a secondary destination. The three datasets are summarized in Table 5.8.

Table 5.8 Summary of Three Datasets (Unit: Pallets)

Dataset	Destination	Primary Destination	Secondary Destination	Two Destinations Are the Same
Dataset 1 (skewed)	Shipping Door 1	703	584	586
	Shipping Door 2	341	552	
	Shipping Door 3	890	505	
	Shipping Door 4	306	599	
	Total	2240	2240	
Dataset 3 (skewed)	Shipping Door 1	430	275	278
	Shipping Door 2	172	274	
	Shipping Door 3	206	272	
	Shipping Door 4	319	272	
	Shipping Door 5	285	281	
	Shipping Door 6	452	302	
	Shipping Door 7	136	295	
	Shipping Door 8	240	269	
	Total	2240	2240	
Dataset 4 (relatively balanced)	Shipping Door 1	294	276	309
	Shipping Door 2	271	292	
	Shipping Door 3	322	294	
	Shipping Door 4	228	275	
	Shipping Door 5	294	290	
	Shipping Door 6	208	249	
	Shipping Door 7	233	242	
	Shipping Door 8	390	322	
	Total	2240	2240	

5.6.4 Performance measures

The measures mentioned hereafter are average values obtained from twenty replications of a simulation run. First, the same measure used in the previous trailer scheduling part, the "cycle time" needed for a pallet starting from arriving at the trailer waiting line to leaving a crossdock at the shipping side is considered. However, since we are evaluating the efficiency of alternate destinations for easing congestion in staging lanes, we disregard the waiting time in shipping trailers. That is, the counting of a pallet's cycle time ends once it arrives at its shipping door.

Second, when strippers' time is minimized, we see how much their efficiency is improved by checking "wait time at trailer line" and "wait time at receiving doors". If strippers' efficiency is increased, they can transport pallets more quickly and hence the values of these two measurements would be lower. The value of "wait time at receiving doors" is calculated using the same weighted average method as in Chapter Four and the "wait time at trailer line" is the original value from the simulation since there is only one trailer waiting line.

Third, since the alternate destination policies aim at decreasing the blocking before staging lanes, the performance of "total number blocked" is also an essential measurement. This measurement sums up the number of the average blocked pallets for all staging lanes.

Fourth, because we may change pallets' destinations during transferring, it is important to check how well we can maintain the demand for each destination. "Demand mismatch percentage" measures the average percent of deviations from the real demands of the do-nothing models.

Finally, the average number of changes to pallet destinations during a simulation is also displayed in the model results, for the sake of completeness.

5.7 Simulation Results

5.7.1 4-to-4 staging scenarios

Table 5.9 shows the average values of measurements obtained from 20-replication simulations under three different trailer arrival headways. From these results, we find that our alternate destination strategies can effectively reduce staging congestion and improve the operations of crossdocks. In Table 5.10, it shows that the CSTL, CSRL and MPTC policies can save about 16% to 38% of pallets' cycle time compared to the do-nothing model. In addition, these three models show similar levels of the cycle time measurement.

Table 5.9 Performance of the Alternate Destination Strategies in the 4-to-4 Staging Crossdock Scenarios under Dataset 1

Trailer Arrival Headway	Model Name	Cycle Time (minutes)	Wait Time at Trailer Line (minutes)	Wait Time at Receiving Doors (minutes)	Number Blocked	Demand Mismatch Percentage	Destination Changed
Exponential with mean of 10 mins	Do-Nothing	423.48	377.35	37.69	0.94	0.00%	---
	CSTL*	234.35	195.90	30.86	0.83	10.00%	516
	CSRL*	329.73	288.57	33.23	1.10	1.35%	417
	MPTC*	331.42	289.90	33.58	0.64	1.63%	633
	MSTC*	321.86	280.83	32.95	0.70	1.47%	620
Exponential with mean of 20 mins	Do-Nothing	114.87	69.60	37.00	0.79	0.00%	---
	CSTL	52.19	14.96	29.90	0.52	8.25%	438
	CSRL	73.28	33.45	32.11	0.82	1.21%	383
	MPTC	73.55	32.86	32.86	0.48	1.47%	614
	MSTC	70.87	30.63	32.39	0.51	1.19%	602
Exponential with mean of 30 mins	Do-Nothing	52.74	9.76	35.33	0.43	0.00%	---
	CSTL	38.94	3.36	28.60	0.25	5.70%	362
	CSRL	42.68	5.13	30.33	0.40	0.93%	283
	MPTC	44.36	5.34	31.68	0.22	1.08%	593
	MSTC	43.19	4.79	31.02	0.25	0.92%	556

*: CSTL—congestion smoothing total-limit strategy; CSRL—congestion smoothing rolling-limit strategy; MPTC—minimizing a pallet's transfer cost strategy; MSTC—minimizing a stripper's transport cost strategy.

Table 5.10 Improvements of the Alternate Destination Strategies in the 4-to-4 Staging Crossdock Compared to the Do-Nothing Policy under Dataset 1

Trailer Arrival Headway	Model Name	Cycle Time	Wait Time at Trailer Line	Wait Time at Receiving Doors	Total Number Blocked
Exponential with mean of 10 mins	Do-Nothing	--	--	--	--
	CSTL	44.66%	48.09%	18.12%	11.62%
	CSRL	22.14%	23.53%	11.83%	-16.67%
	MPTC	21.74%	23.17%	10.91%	32.25%
	MSTC	24.00%	25.58%	12.57%	25.62%
Exponential with mean of 20 mins	Do-Nothing	--	--	--	--
	CSTL	54.57%	78.50%	19.19%	34.17%
	CSRL	36.21%	51.94%	13.21%	-3.33%
	MPTC	35.97%	52.80%	11.20%	39.39%
	MSTC	38.31%	56.00%	12.47%	35.25%
Exponential with mean of 30 mins	Do-Nothing	--	--	--	--
	CSTL	26.16%	65.59%	19.07%	41.39%
	CSRL	19.08%	47.39%	14.17%	6.80%
	MPTC	15.90%	45.26%	10.34%	48.60%
	MSTC	18.11%	50.92%	12.22%	42.27%

The CSTL strategy can save up to 55% of the cycle time, but on the contrary it has more unstable and higher demand mismatch percentages that may cause trouble during transferring. So we cannot claim that this model is the best overall. However, our simulations indicate that destination flexibility can lead to higher efficiency. If a better control rule at the same level of flexibility of the total-limit rule can be developed so that a very low demand mismatch rate can be maintained, great improvement can be expected. We will work on this issue in Section 6.3.

Besides the CSTL strategy, the other three strategies all have good improvement on the "wait time at trailer line" and the "wait time at receiving doors". Most simulations of our strategies show the abilitity to reduce blockage, with the exception of the rolling-limit policy under the headways of 10 and 20 minutes. The causes might be:

1. The strategy activates only when the primary destination is blocked and hence one more pallet's arrival will cause an overflow;
2. This strategy has a higher restriction on changing destinations than the total limit rule and hence it may encounter more situations in which the quota for a secondary destination is filled and the pallet under assignment has to go to its primary destination which is blocked;
3. This strategy does not consider pallets en route to staging lanes when deciding destinations, so another pallet may be assigned to the last space of a staging lane during the period of the pre-assigned pallet travelling to the staging space.

This problem diminishes when longer staging lanes are set up in the following 8-to-8 staging models.

5.7.2 8-to-8 staging scenarios

The results from both the skewed dataset and the relatively balanced dataset of the 8-to-8 staging scenarios are consistent, as shown in Tables 5.11 to 5.14. From the results of the "cycle time", the "wait time at trailer line" and the "wait time at receiving doors", they all show that the performance from the best to the worst are the MSTC, MPTC, CSTL, CSRL and do-nothing strategies. Our four alternate destination strategies can all improve the operations of crossdocks. The improvements of the four strategies in the "cycle time" measure range from 8.89% to 33.03% in the dataset 3 scenarios (Table 5.12) and from 6.44% to 33.99% in the dataset 4 scenarios (Table 5.14). In addition, our strategies perform especially well in scenarios with congested and moderate trailer arrivals both for the 4-to-4 and the 8-to-8 staging crossdocks. This shows the ability of our strategies in mitigating congestion.

Table 5.11 Performance of the Alternate Destination Strategies in the 8-to-8 Staging Crossdock under Dataset 3

Trailer Arrival Headway	Model Name	Cycle Time (minutes)	Wait Time at Trailer Line (minutes)	Wait Time at Receiving Doors (minutes)	Number Blocked	Demand Mismatch Percentage	Destination Changed
Exponential with mean of 10 mins	Do-Nothing	288.20(±23.94)*	216.02	62.36	1.13	0.00%	---
	CSTL	207.36(±23.46)	142.39	56.17	0.34	8.776%	208
	CSRL	234.97(±24.42)	167.24	58.23	0.70	0.688%	252
	MPTC	205.57(±22.84)	141.31	55.13	0.42	3.084%	778
	MSTC	204.11(±23.64)	140.02	54.11	0.85	3.238%	692
Exponential with mean of 15 mins	Do-Nothing	132.61(±22.50)	61.75	61.06	1.00	0.00%	---
	CSTL	92.38(±10.65)	28.01	55.59	0.26	7.942%	185
	CSRL	106.84(±15.45)	39.82	57.90	0.57	0.508%	225
	MPTC	90.97(±10.92)	27.67	54.35	0.28	2.971%	759
	MSTC	88.81(±10.08)	25.94	53.35	0.63	2.700%	675
Exponential with mean of 20 mins	Do-Nothing	77.93(±3.98)	9.26	59.71	0.63	0.00%	---
	CSTL	68.80(±2.28)	4.84	55.55	0.15	6.016%	144
	CSRL	71.00(±2.37)	5.53	56.77	0.32	0.469%	181
	MPTC	66.87(±2.07)	4.43	53.69	0.15	1.905%	731
	MSTC	65.78(±2.11)	4.04	52.66	0.36	1.687%	641

*: (288.20-23.94, 288.20+23.94) is the 95% confidence interval of the cycle time measure.

Table 5.12 Improvements of the Alternate Destination Strategies Compared to the Do-Nothing Policy under Dataset 3

Trailer Arrival Headway	Model Name	Cycle Time	Wait Time at Trailer Line	Wait Time at Receiving Doors	Number Blocked
Exponential with mean of 10 mins	Do-Nothing	--	--	--	--
	CSTL	28.05%	34.09%	9.93%	69.62%
	CSRL	18.47%	22.58%	6.62%	37.80%
	MPTC	28.67%	34.59%	11.60%	63.07%
	MSTC	29.18%	35.18%	13.23%	24.83%
Exponential with mean of 15 mins	Do-Nothing	--	--	--	--
	CSTL	30.34%	54.64%	8.95%	73.76%
	CSRL	19.43%	35.51%	5.17%	43.03%
	MPTC	31.40%	55.20%	10.98%	72.02%
	MSTC	33.03%	58.00%	12.62%	36.71%
Exponential with mean of 20 mins	Do-Nothing	--	--	--	--
	CSTL	11.71%	47.69%	6.97%	75.93%
	CSRL	8.89%	40.33%	4.94%	49.55%
	MPTC	14.19%	52.18%	10.09%	76.59%
	MSTC	15.59%	56.36%	11.82%	42.53%

Table 5.13 Performance of the Alternate Destination Strategies in the 8-to-8 Staging Crossdock under Dataset 4

Trailer Arrival Headway	Model Name	Cycle Time (minutes)	Wait Time at Trailer Line (minutes)	Wait Time at Receiving Doors (minutes)	Number Blocked	Demand Mismatch Percentage	Destination Changed
Exponential with mean of 10 mins	Do-Nothing	254.09(±24.46)*	183.38	61.85	0.84	0.00%	---
	CSTL	206.83(±21.74)	141.15	57.58	0.27	3.39%	175
	CSRL	212.63(±21.25)	146.21	57.91	0.45	0.82%	213
	MPTC	180.42(±21.29)	118.55	53.75	0.06	1.80%	866
	MSTC	168.98(±22.33)	108.03	51.99	0.53	2.36%	719
Exponential with mean of 15 mins	Do-Nothing	119.50(±16.31)	49.59	61.40	0.68	0.00%	---
	CSTL	97.10(±11.89)	31.93	56.82	0.22	2.84%	159
	CSRL	100.69(±13.22)	34.46	58.07	0.35	0.58%	182
	MPTC	83.56(±8.97)	21.99	53.41	0.07	1.42%	844
	MSTC	78.88(±7.06)	18.10	51.89	0.40	2.24%	702
Exponential with mean of 20 mins	Do-Nothing	76.04(±2.87)	7.98	59.96	0.44	0.00%	---
	CSTL	70.43(±2.76)	5.50	56.88	0.14	2.08%	122
	CSRL	71.14(±2.62)	5.68	57.60	0.22	0.30%	159
	MPTC	65.69(±4.07)	3.89	53.80	0.03	1.57%	781
	MSTC	64.61(±1.61)	3.50	52.53	0.24	2.81%	653

*: (254.09-24.46, 254.09+24.46) is the 95% confidence interval of the cycle time measure.

Table 5.14 Improvements of the Alternate Destination Strategies Compared to the Do-Nothing Policy under Dataset 4

Trailer Arrival Headway	Model Name	Cycle Time	Wait Time at Trailer Line	Wait Time at Receiving Doors	Number Blocked
Exponential with mean of 10 mins	Do-Nothing	--	--	--	--
	CSTL	18.60%	23.03%	6.91%	67.37%
	CSRL	16.32%	20.27%	6.38%	46.71%
	MPTC	28.99%	35.35%	13.09%	92.40%
	MSTC	33.49%	41.09%	15.94%	37.21%
Exponential with mean of 15 mins	Do-Nothing	--	--	--	--
	CSTL	18.75%	35.63%	7.47%	67.82%
	CSRL	15.74%	30.52%	5.43%	48.05%
	MPTC	30.08%	55.67%	13.02%	90.03%
	MSTC	33.99%	63.50%	15.50%	41.54%
Exponential with mean of 20 mins	Do-Nothing	--	--	--	--
	CSTL	7.37%	31.09%	5.13%	68.10%
	CSRL	6.44%	28.80%	3.94%	51.06%
	MPTC	13.61%	51.25%	10.27%	92.39%
	MSTC	15.03%	56.20%	12.40%	46.41%

Our results show that the “number blocked” has been reduced under our strategies. The high blockage situation for the CSRL policy that occurred in the 4-to-4 staging crossdock scenarios is not an issue in the 8-to-8 staging crossdock. Instead, one thing worth noticing is that the values for the MSTC policy are the highest among the four alternate destination strategies. That is because the closer to the receiving side the staging space is, the shorter travel time will be for strippers. Since the last spots of staging lanes are the closest, strippers tend to get them whenever possible and this might sometimes incur one or more pallets waiting before the blocking lane because of destination limits or relatively lower congestion—that is, a pallet might have to go to a blocked lane because the demand of its other destination is full or its other destination has even higher congestion. However, once blocking is detected, the MSTC policy will avoid sending pallets to blocked lanes and thus it can still attain high efficiency.

Similar to the 4-to-4 staging crossdock cases, the “demand mismatch percentage” of the CSTL policy is still higher than the other three strategies, but the policy is no longer the best one in the 8-to-8 staging crossdock cases. In the 8-to-8 staging crossdock scenarios, the performance of the MSTC and MPTC policies are better than the CSTL policy’s. This means that we can get better performance without sacrificing more on demand mismatch.

The “destination changed” shows the complexity of implementing these strategies. The CSTL and CSRL policies are relatively effortless because the policies are only activated when blocking is encountered.

5.8 Concluding Remarks

In the recent past, researchers have become aware of the effects of staging congestion, but to date, no solutions for avoiding it have been developed. In this study, using the postponement of each pallet’s destination decision, we show the effectiveness of our alternate destination strategies on mitigating congestion in single-stage crossdocks.

In this study, the transfer cost for a pallet to travel through a crossdock and the transport cost for a stripper to move a pallet to a staging lane are formulated to test our four alternate destination strategies. According to our simulation results, our strategies can effectively improve the operation of single-stage crossdocks, including the reduction in staging congestion, pallet’s cycle time and stripper’s transport time. The cycle time saving can be as high as 34% using the MSTC strategy compared to the do-nothing policy in the 8-to-8 staging crossdock with the moderate trailer arrival scenario. The effect of this time saving could be enormous for a supply chain, including more reliable on-time delivery, higher throughput and shorter transportation lead-time, as discussed in Chapter Four.

In addition, this study also suggest the capability of real-time location information to help the operation of crossdocking. The CSTL and CSRL strategies are relatively easier to implement and require less real-time information. If more detailed real-time pallet location information is attainable in a crossdock, applying the MPTC or MSTC strategy is sure to gain more benefits.

Chapter Six

Extensions of the Alternate Destination Models

6.1 Time-Saving Effect if Alternate Destination Assignments Incur More Time for Value-Added Activities

In Chapter Five, we assumed that the time of value-added activities (Value-Added Time; VAT) for each pallet is the same no matter whether it is assigned to a primary or an alternate destination and find that our alternate destination strategies outperform the do-nothing policy. However, what if a destination-change for a pallet results in more time for value-added activities? The increased time may be caused by cleaning old labels, changing packing or revising shipment information.

The VAT for each pallet is assumed to be 0.5 minute in Chapter Five. In this section, an extra VAT of 0.1, 0.5 or 1 minute is added to a pallet if its destination is changed by one of our alternate destination strategies. The 8-to-8 staging crossdock scenarios are tested using the MPTC and MSTC strategies under dataset 3, and the results from 20 replications are shown in Table 6.1.

Table 6.1 The Relationship between Extra VAT and Cycle Time

Trailer Arrival Headway	Model Name	VAT for Primary Destinations (minute)	VAT for Alternate Destinations (minutes)	Cycle Time (minutes)	Destination Changed
Exponential with mean of 10 mins	Do-Nothing	0.5	--	288.20	--
	MPTC		0.6	206.78	769.05
	MSTC			205.93	692.90
	MPTC		1.0	205.63	748.90
	MSTC			209.26	701.50
	MPTC		1.5	209.45	692.65
	MSTC			209.44	702.40
Exponential with mean of 15 mins	Do-Nothing	0.5	--	132.61	--
	MPTC		0.6	90.03	751.75
	MSTC			88.33	671.30
	MPTC		1.0	92.94	714.10
	MSTC			91.53	683.10
	MPTC		1.5	93.75	674.10
	MSTC			92.13	673.75
Exponential with mean of 20 mins	Do-Nothing	0.5	--	77.93	--
	MPTC		0.6	66.56	728.05
	MSTC			65.74	651.10
	MPTC		1.0	66.47	684.30
	MSTC			65.72	645.85
	MPTC		1.5	67.28	628.10
	MSTC			65.84	655.20

According to the results, even though extra VATs are incurred to destination-changed pallets, the time-saving effect is still solid for the MPTC and MSTC strategies. The cycle times do not increase much even when the extra VAT reaches double the original value. Why does the increase of VAT not enlarge much of the cycle times? The reasons are the following:

1. The MPTC strategy chooses the lowest transfer costs between a pallet's primary and alternate destinations when making an assignment. From the results in the "destination changed" column in Table 6.1, we can find that the number of choosing alternate destinations decreases with the increase of extra VAT. The

extra VAT does add extra costs to alternate destinations, but the MPTC strategy can maintain low cycle times by choosing destinations with lower transfer costs.

2. The MSTC strategy is mainly concerned with a stripper's transport cost rather than a pallet's transfer cost, so the increase of VAT does not affect many of the strategy's choices on primary or alternate destinations. This characteristic can be found from the close values in the "destination changed" column in Table 6.1. However, the extra VAT does incur longer staging time in staging lanes and hence delay a little cycle time.

6.2 Combination of the Trailer Scheduling and Alternate Destination Strategies

In Chapters Four and Five, we have discussed our trailer scheduling and alternate destination strategies, and they all show a great deal of improvement over the FCFS or do-nothing policies. The trailer scheduling strategies deal with the unloading orders for inbound trailers. After the assignment for trailers, the alternate destination strategies handle the delivery of pallets to avoid congestion inside a single-stage crossdock. It seems likely that combining these two kinds of strategies in crossdock operations could double their effects. However, when assigning a waiting inbound trailer to a receiving door, what we consider is minimizing its weighted time (travel time, processing time or cycle time) according to the "primary" destinations of the pallets in the waiting trailer. Unfortunately, this basic condition changes when we later let a pallet have alternative destinations. Hence, the gain from using one of our trailer scheduling algorithms may be offset a little bit by the change of pallets' destinations in the pallet delivery phase.

Even though it is not clear whether combining these two types of strategies will benefit the operations, it is interesting to examine their combined effects. A series of simulations for the combination models are made and their results are shown in Table 6.2. The top two best performing models from the trailer scheduling algorithms and the alternate destination strategies are used to constitute the combination models. The results of these combination models are later compared to the baseline model which uses the FCFS policy to assign waiting trailers and delivers pallets by their primary destinations. The improvements for the combination models are shown in Table 6.3. In these five models, the waiting phase in outbound trailers is resumed (this phase is used in Chapter Four, but not in Chapter Five) and their performance within the first 1000 minutes are recorded. Also, the results are obtained after 20-replication runs and under dataset 3.

Table 6.2 Performance of the Combination Models of the Trailer Scheduling and Alternate Destination Strategies in the 8-to-8 Staging Crossdock

Trailer Arrival Headway	Model Name	Cycle Time (minutes)	Wait Time at Trailer Line (minutes)	Wait Time at Receiving Doors(minutes)	Number Blocked	Throughput (in 1000 minutes)
Exponential with mean of 10 mins	FCFS+Do-Nothing	275.55	167.28	42.54	1.32	1537.20
	MPTC+MPT	172.04	92.39	41.65	0.71	1941.80
	MPTC+MCT	160.68	85.74	41.76	0.63	1953.00
	MSTC+MPT	173.74	92.72	41.61	1.26	1969.80
	MSTC+MCT	160.49	86.67	41.66	1.21	1948.80
Exponential with mean of 15 mins	FCFS+Do-Nothing	178.76	50.24	38.73	1.20	1437.80
	MPTC+MPT	135.56	17.46	35.55	0.39	1556.80
	MPTC+MCT	135.55	16.43	35.75	0.37	1555.40
	MSTC+MPT	135.55	17.44	34.88	0.81	1559.60
	MSTC+MCT	133.87	15.58	34.96	0.81	1561.00
Exponential with mean of 20 mins	FCFS+Do-Nothing	152.40	9.67	30.20	0.82	1138.20
	MPTC+MPT	141.75	3.43	27.13	0.18	1162.00
	MPTC+MCT	142.00	3.43	27.16	0.18	1162.00
	MSTC+MPT	141.49	3.72	27.16	0.45	1164.80
	MSTC+MCT	141.80	3.63	27.14	0.45	1164.80

Table 6.3 Improvements of the Combination Models Compared to the FCFS+Do-Nothing Models in the 8-to-8 Staging Crossdock

Trailer Arrival Headway	Model Name	Cycle Time (minutes)	Wait Time at Trailer Line (minutes)	Wait Time at Receiving Doors(minutes)	Number Blocked	Throughput (in 1000 minutes)
Exponential with mean of 10 mins	FCFS+Do-Nothing	--	--	--	--	--
	MPTC+MPT	37.56%	44.77%	2.10%	46.19%	26.32%
	MPTC+MCT	41.69%	48.74%	1.83%	51.92%	27.05%
	MSTC+MPT	36.95%	44.57%	2.19%	4.75%	28.14%
	MSTC+MCT	41.76%	48.19%	2.08%	8.55%	26.78%
Exponential with mean of 15 mins	FCFS+Do-Nothing	--	--	--	--	--
	MPTC+MPT	24.17%	65.24%	8.19%	67.34%	8.28%
	MPTC+MCT	24.17%	67.31%	7.68%	68.67%	8.18%
	MSTC+MPT	24.17%	65.28%	9.92%	32.03%	8.47%
	MSTC+MCT	25.11%	68.98%	9.72%	32.43%	8.57%
Exponential with mean of 20 mins	FCFS+Do-Nothing	--	--	--	--	--
	MPTC+MPT	6.99%	64.53%	10.16%	78.03%	2.09%
	MPTC+MCT	6.82%	64.57%	10.08%	77.96%	2.09%
	MSTC+MPT	7.16%	61.50%	10.05%	44.98%	2.34%
	MSTC+MCT	6.95%	62.50%	10.15%	44.87%	2.34%

From the above results, we can find that the more congested the freight flow is, the more effective the combination models are. Under the most congested trailer arrival headway, Expo(10), the combination models improve the cycle times about 37% to 41%, which is higher than the improvements of only implementing the MPTC or MSTC strategy[4] (see Table 5.12). At the same time, the throughputs are improved about 26% to 28%. This shows a good way to resolve the situation when inbound trailer arrivals are suddenly increasing or a part of resources are temporarily unavailable. On the other hand, under the moderate and slack trailer arrival scenarios, the combination models may not be able to improve the performance that the MPTC or MSTC strategy could have for the

[4] Note that this is a rough comparison because the models in Chapter Five do not have the waiting process for outbound trailers.

crossdock. Under these two situations, solely implementing the alternate destination strategies should get better performance.

6.3 Full Destination Substitution for Alternate Destination Models

In Chapter Five, because we only allow at most one alternate destination for a pallet, it results in the mismatch of demands. In this section, we further give more alternate destination choices for a pallet—pallets are categorized according to their contents and a pallet can alternatively be sent to any destination that needs that specific type of pallet.

6.3.1 Dataset adjustments

We test the 8-to-8 staging crossdock with datasets 3 and 4. To further fit in our objective, we randomly classify the 2,240 pallets in each dataset into 20 types of products. The classification results are shown in Tables 6.4 and 6.5. The pallets in the same type of product are identical and thus any of these pallets can satisfy the demand for the specific type of product. We call this a full substitution of demand.

Table 6.4 Pallet Demand Distribution of Dataset 3 by Destinations and Types

Destination \ Product Type	A	B	C	D	E	F	G	H	I	J
Shipping Door 1	37	7	22	41	27	31	28	3	26	12
Shipping Door 2	8	3	8	13	16	16	4	5	2	0
Shipping Door 3	12	10	10	3	25	36	3	15	1	12
Shipping Door 4	16	7	11	18	21	16	11	21	24	17
Shipping Door 5	28	3	5	15	19	15	20	13	3	18
Shipping Door 6	20	14	12	57	13	23	12	18	5	36
Shipping Door 7	0	1	3	25	11	14	6	0	5	13
Shipping Door 8	3	0	2	17	14	13	12	9	23	5
Total	124	45	73	189	146	164	96	84	89	113

Table 6.4 (Continued) Pallet Demand Distribution of Dataset 3 by Destinations and Types

Destination \ Product Type	K	L	M	N	O	P	Q	R	S	T	Total
Shipping Door 1	29	23	16	13	14	29	0	44	15	13	430
Shipping Door 2	8	1	18	2	14	4	4	6	20	20	172
Shipping Door 3	6	1	17	2	19	8	2	6	3	15	206
Shipping Door 4	10	23	6	31	10	14	16	31	8	8	319
Shipping Door 5	13	16	14	23	8	23	0	29	12	8	285
Shipping Door 6	19	27	12	19	37	17	25	24	35	27	452
Shipping Door 7	2	16	6	9	2	7	4	3	9	0	136
Shipping Door 8	20	17	24	12	11	6	13	8	11	20	240
Total	107	124	113	111	115	108	64	151	113	111	2240

Table 6.5 Pallet Demand Distribution of Dataset 4 by Destinations and Types

Destination \ Product Type	A	B	C	D	E	F	G	H	I	J
Shipping Door 1	29	4	11	12	23	21	0	9	7	13
Shipping Door 2	10	10	35	30	8	38	15	0	7	17
Shipping Door 3	15	28	22	27	5	7	0	9	11	17
Shipping Door 4	17	22	15	12	28	18	8	15	11	7
Shipping Door 5	10	15	3	8	35	2	15	2	27	34
Shipping Door 6	19	21	2	17	9	0	9	5	17	12
Shipping Door 7	14	5	14	19	9	11	10	11	16	21
Shipping Door 8	31	30	36	6	10	19	10	10	35	12
Total	145	135	138	131	127	116	67	61	131	133

Table 6.5 (Continued) Pallet Demand Distribution of Dataset 4 by Destinations and Types

Destination \ Product Type	K	L	M	N	O	P	Q	R	S	T	Total
Shipping Door 1	18	50	21	9	13	8	4	14	11	17	294
Shipping Door 2	6	5	13	16	1	18	10	3	19	10	271
Shipping Door 3	19	7	16	19	16	10	25	18	29	22	322
Shipping Door 4	5	3	11	3	0	12	3	4	8	26	228
Shipping Door 5	20	12	28	16	5	26	1	5	17	13	294
Shipping Door 6	3	17	16	6	3	10	6	14	20	2	208
Shipping Door 7	14	1	19	7	12	12	10	1	7	20	233
Shipping Door 8	32	26	15	24	36	17	8	12	15	6	390
Total	117	121	139	100	86	113	67	71	126	116	2240

Under our alternate destination strategy, for example, in Table 6.4, if we find a type B pallet is expected to be blocked at shipping door 1, we can deliver the pallet to one of the destinations among shipping doors 2 to 7 with a lower cost if the demands of these shipping doors are not fulfilled yet. And later we compensate a unit of demand for shipping door 1 when its transfer cost is lower.

6.3.2 Model adjustments

After a series of pre-tests on the previous alternate destination models using the new datasets, we confirm that the full-substitution rule can make the final deliveries of pallets completely match the demands of all destinations. Hence, the full-substitution rule is applied for the simulation models in this section instead of the full-limit or rolling-limit rule that was used in Chapter Five. Now we only need one congestion smoothing strategy and it is called as the CS-F strategy. The previous MPTC and MSTC models are also modified with the new rules and now called as the MPTC-F and MSTC-F models. In addition, since destination demands can be fully matched, we add the inbound trailer waiting process onto all simulation models again and measure the throughputs that can be achieved in 1000 minutes.

The CS-F strategy is still being activated whenever a pallet encounters a blocking for its primary destination, but its alternate destination is decided by the lowest travel cost to a staging lane among its feasible destinations, which are destinations that have no blocking and with non-zero demands for that type of pallet.

6.3.3 Simulation results

From the results in Tables 6.6 and 6.7, we find that the improvements of the full destination substitution models are generally much better than the single alternate destination models (in Tables 5.12 and 5.14), with the only exceptions for the CS-F strategy in the cycle time measurements when trailer arrival rates are mediate or slack (marked with bold types in Tables 6.6 and 6.7). However, these exceptions are still better than the baseline scenarios.

Table 6.6 Performance of the Alternate Destination Strategies with Full Substitution in the 8-to-8 Staging Crossdock Scenarios under Dataset 3

Trailer Arrival Headway	Model Name	Cycle Time (minute)	Wait Time at Trailer Line (minute)	Number Blocked (unit/min)	Throughput (in 1000 minutes)	Destination Changed
Exponential with mean of 10 mins	Do-Nothing	276	167	1.32	1537	---
	CS-F	190(31%)*	92(45%)	0.24	1921(25%)	375
	MPTC-F	138(50%)	44(74%)	0.47	2156(40%)	1865
	MSTC-F	116(58%)	29(83%)	0.70	2030(32%)	1752
Exponential with mean of 15 mins	Do-Nothing	179	50	1.20	1438	---
	CS-F	133**(26%)**	13(74%)	0.18	1561(9%)	262
	MPTC-F	107(40%)	3(93%)	0.03	1585(10%)	1428
	MSTC-F	101(44%)	2(96%)	0.11	1599(11%)	1425
Exponential with mean of 20 mins	Do-Nothing	152	10	0.82	1138	---
	CS-F	141**(7%)**	3(70%)	0.11	1161(2%)	154
	MPTC-F	116(24%)	1(94%)	0.00	1161(2%)	1088
	MSTC-F	107(30%)	0.26(97%)	0.01	1168(3%)	1076

*: the value in the parentheses is the percentage of improvement compared to the do-nothing scenario.

Table 6.7 Performance of the Alternate Destination Strategies with Full Substitution in the 8-to-8 Staging Crossdock Scenarios under Dataset 4

Trailer Arrival Headway	Model Name	Cycle Time (minute)	Wait Time at Trailer Line (minute)	Number Blocked (unit/min)	Throughput (in 1000 minutes)	Destination Changed
Exponential with mean of 10 mins	Do-Nothing	248	144	0.96	1588	---
	CS-F	191(23%)*	93(36%)	0.21	1891(19%)	325
	MPTC-F	127(49%)	39(73%)	0.18	2052(29%)	1767
	MSTC-F	112(55%)	26(82%)	0.40	2062(30%)	1780
Exponential with mean of 15 mins	Do-Nothing	164	38	0.79	1445	---
	CS-F	136**(17%)**	15(61%)	0.15	1548(7%)	233
	MPTC-F	106(36%)	3(92%)	0.01	1597(11%)	1423
	MSTC-F	101(39%)	2(94%)	0.11	1599(11%)	1424
Exponential with mean of 20 mins	Do-Nothing	149	6	0.50	1147	---
	CS-F	141**(5%)**	3(54%)	0.10	1144(-0.2%)	142
	MPTC-F	114(24%)	0.48(93%)	0.00	1166(2%)	1075
	MSTC-F	109(27%)	0.26(96%)	0.02	1176(3%)	1071

*: the value in the parentheses is the percentage of improvement compared to the do-nothing scenario.

The MPTC-F and MSTC-F strategies can improve a pallet's cycle time 24% to 58%, an inbound trailer's waiting time 73% to 97%, and a crossdock's throughput 2% to 40% compared to the do-nothing scenarios (except for the throughput of the CS-F strategy under dataset 4 and trailer arrival headway Expo(20)). Their performance is especially good in congested trailer arrival scenarios, which indicates their ability to mitigate congestion and provide higher productivities. These strategies will be useful for busy crossdocks or solving occasional short-term bursts.

More importantly, we find that higher crossdocking improvements can be achieved by allowing more alternate destination choices. With only a single alternate destination choice in Chapter Five, the MPTC and MSTC strategies improve pallet cycle times about 13% to 34% and inbound trailer wait time about 35% to 64% under datasets 3 and

4, while the MPTC-F and MSTC-F strategies with multiple destination choices in this section improve about 24% to 58% and 73% to 97%, respectively.

Chapter Seven

Summary and Conclusion

7.1 Summary of Findings

There are several types of crossdocks; however, in this research we focus on single-stage crossdocks because of their unique characteristics of staging queues and superiority relative to the other types. A detailed review on crossdocking and related issues are provided and the freight flow features in crossdocks are also discussed in this study. In this dissertation, we examine the operational factors that can affect the performance of crossdocking and two kinds of strategies are proposed accordingly: trailer scheduling and alternate destination strategies. We summarized the main findings in the following:

1. Among the factors that affect crossdocking performance, arrival variability, processing time, processing time variability, worker utilization, trailer scheduling and congestion/blocking are those which might be adjustable during operations. These factors are proven valid theoretically and empirically in this research.
2. Our two time-based trailer scheduling algorithms, the MCT and MPT algorithms, can save cycle times as high as 64%, 57% and 30% in the 4-to-4, 4-to-8 and 8-to-8 crossdock scenarios, respectively, compared to the FCFS policy; these time savings are also more than the look-ahead algorithm (the only available method in the literature except for the FCFS policy) can attain while trailer arrivals are not sparse. In addition, crossdocking throughputs can be improved as high as about 30% and 15% in the 4-to-8 and 8-to-8 crossdock

scenarios, respectively.

3. The staging costs in a staging lane are non-linear. The costs vary with the number of pallets, the locations of pallets and whether a staging lane is blocked. When a staging lane is blocked, the cost incurred to a stripper increases sharply. Hence, reducing blocking is the key to improve crossdocking performance.
4. In our 8-to-8 staging crossdock scenarios, our four alternate destination strategies, the CSTL, CSRL, MPTC and MSTC strategies, can save about 8% to 33% (under the skewed demand distribution) or about 6% to 34% (under the relatively balanced demand distribution) of the cycle times compared to the do-nothing scenarios. In addition, the times of staging lane blocking are reduced and strippers can have more time to transport pallets instead of waiting for staging spots. Among the four alternate destination strategies, the MSTC strategy is the best one in terms of cycle time.
5. If extra value-added time is needed for a destination-changed pallet, our simulation results show that our MPTC and MSTC strategies can still maintain shorter cycle times. When the extra value-added time is increased from 20% to 200% of the original value-added time, the time-saving effect can still attain 14% to 33% improvement (calculated from Table 6.1) compared to the do-nothing policy under the 8-to-8 staging crossdock and dataset 3 scenarios.
6. The models combining a trailer scheduling algorithm and an alternate destination strategy are tested. We find that the combination models can shorten cycle times about 37% to 41% under the most congested trailer arrival headway scenarios than the baseline model, which is higher than the improvements that

only implementing the MPTC or MSTC strategy. In addition, their throughputs are increased about 26% to 28%.

7. If the choices of alternate destinations can be enlarged, we find that the MPTC-F and MSTC-F strategies can improve a pallet's cycle time 24% to 58%, an inbound trailer's waiting time 73% to 97%, and a crossdock's throughput 2% to 40% compared to the do-nothing scenarios. This indicates that a higher flexibility on choosing alternate destinations can bring higher performance for crossdocks.

7.2 Contributions

1. This dissertation is the first research that integrates the processes of trailer scheduling, pallet assignment and stage queueing in crossdocking using a dynamic approach, which could help further understand the real nature of internal freight flows and the operations of crossdocks.
2. This dissertation develops two dynamic trailer scheduling algorithms that both generate shorter pallet cycle times and higher crossdock throughputs than the most known FCFS and look-ahead policies. In addition, four dynamic alternate destination strategies are proposed to mitigate freight flow congestion and reduce pallet cycle times. In the extension study, it also shows that the MPTC-F and MSTC-F strategies can attain higher crossdock throughputs. These findings will be helpful for operators' decision making.
3. This dissertation formulates the staging costs and transfer costs that describe the freight flow costs in a crossdock. These cost formulations can provide researchers

further understanding of and inspirations to study staging queues.

4. Freight cycle time is always a challenge for operators seeking to bring it down. Our strategies are able to reduce cycle time in the freight transferring hubs—crossdocks, which will have great impacts on supply chain networks: including shorter transportation lead-time, more reliable on-time deliveries and less inventory costs.
5. Last but not least, through the applications of our strategies, this dissertation shows the effectiveness that the real-time information about the contents of inbound and outbound freight and their locations can be used to improve crossdocking performance.

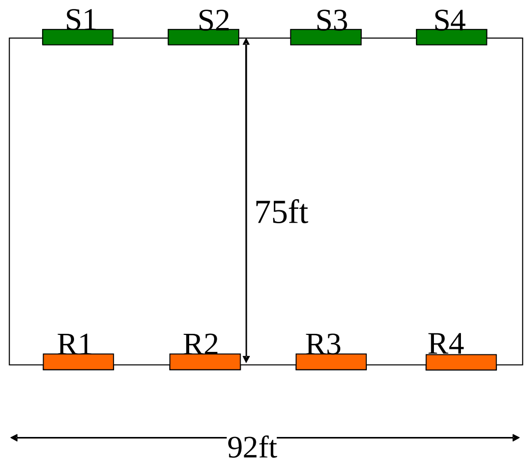
7.3 Future Research

This research developed strategies to assign a waiting trailer to an available receiving door or an unloading pallet to a less-congested destination. During these assignments, what we considered were the situations of outbound trailers, existing pallets, available receiving doors, and/or staging lanes that are directly related to a waiting inbound trailer or an unloading pallet to be assigned. In the future, applying multiple trailer or pallet assignments for the trailer scheduling or alternate destination strategies can be studied. Available strippers, receiving doors, pallets and staging spaces can be estimated for a short period of time (for example, five minutes) and we could allocate them with minimum total costs. In these multiple assignments, the arriving orders of pallets to shipping doors or staging lanes should be treated very carefully because waiting costs, staging costs and transfer costs could vary a lot with different orders.

Other extensions could also be possible for this research.

1. The return trip of a stripper could be assign to a different receiving door to attain shorter personal or group travel time;
2. Incorporate interference among workers while traveling;
3. Set up trailer arrival and departure schedules to take into account delivery reliability.

Appendix A Crossdock Layouts Used in the Trailer Scheduling Models



(The doors initialed with R are receiving doors and the doors initialed with S are shipping doors.)

Figure A.1 The Layout of the 4-to-4 Crossdock

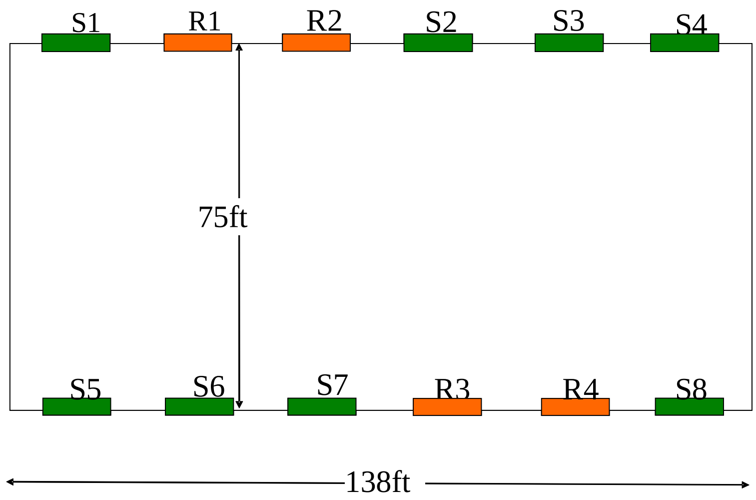


Figure A.2 The Layout of the 4-to-8 Crossdock

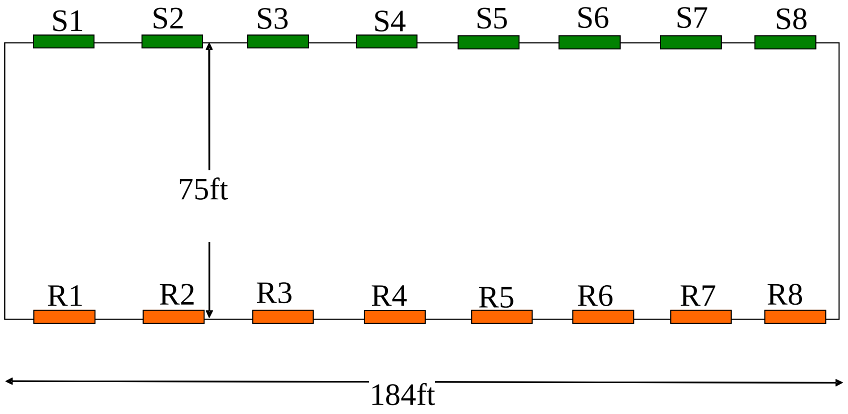


Figure A.3 The Layout of the 8-to-8 Crossdock

Appendix B Crossdock Layouts Used in the Alternate Destination Models

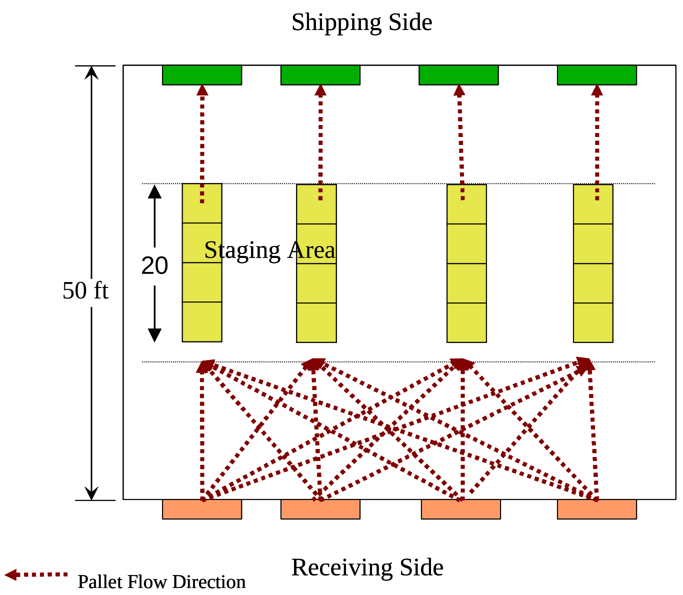


Figure B.1 The Layout of the 4-to-4 with 4 Staging-Space Crossdock (Unit: feet)

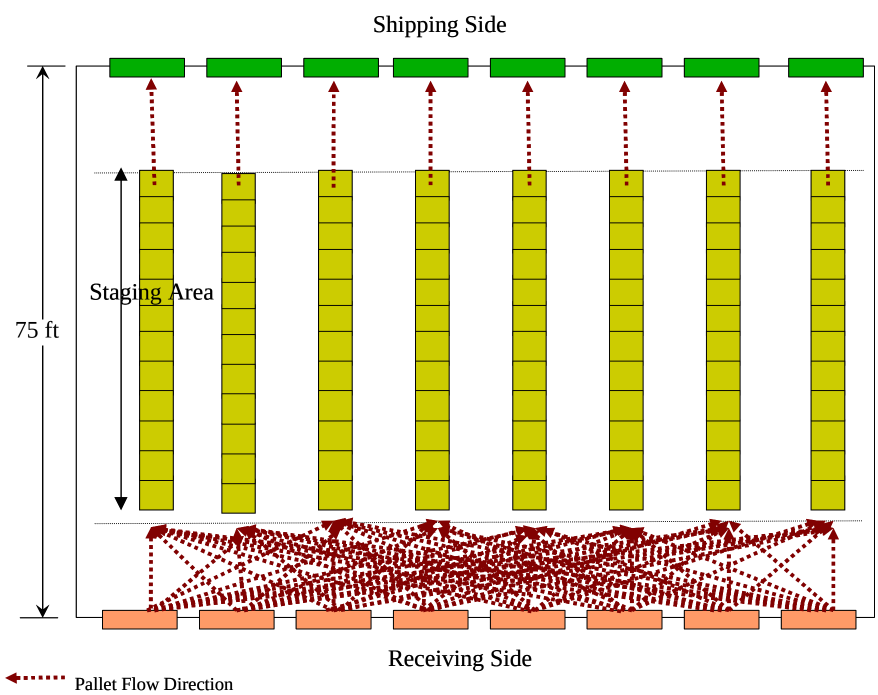


Figure B.2 The Layout of the 8-to-8 with 12 Staging-Space Crossdock (Unit: feet)

Appendix C. Statistical Analyses for the 8-to-8 Staging Scenarios

This appendix explains whether we can compare the effectiveness of the alternate destination strategies.

In Tables 5.11 and 5.13, we list the 95% confidence intervals of cycle times for the scenarios under datasets 3 and 4. When unfolding these intervals, as shown in Figures C.1 to C.6, we can find that in most cases the intervals of our strategies are lower than and distinguishably better than the do-nothing policy, which means that our strategies are better than the do-nothing policy statistically. However, it is difficult to directly judge which strategy is superior to another among the four alternate destination strategies by confidence intervals because there are some overlaps. Hence, in this appendix, we first use the Tukey test to see if we can rank all policies using our 20-replication results for the 8-to-8 staging crossdock, and then further explore if conducting more simulation replications can get non-overlapping confidence intervals among the four alternate destination strategies.

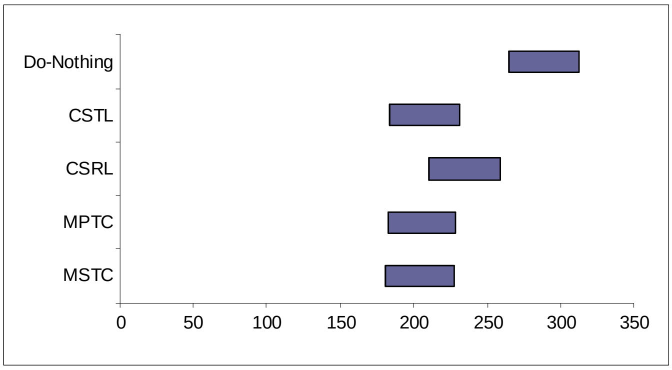


Figure C.1 95% Confidence Intervals of Cycle Time under Expo(10), Dataset 3

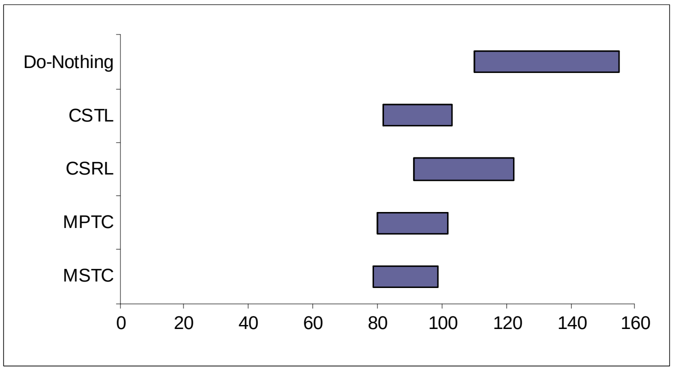


Figure C.2 95% Confidence Intervals of Cycle Time under Expo(15), Dataset 3

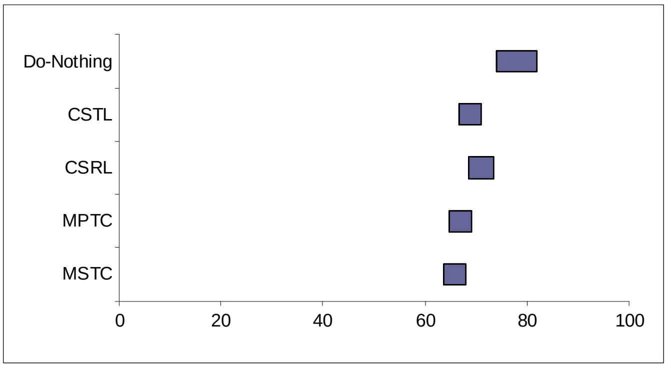


Figure C.3 95% Confidence Intervals of Cycle Time under Expo(20), Dataset 3

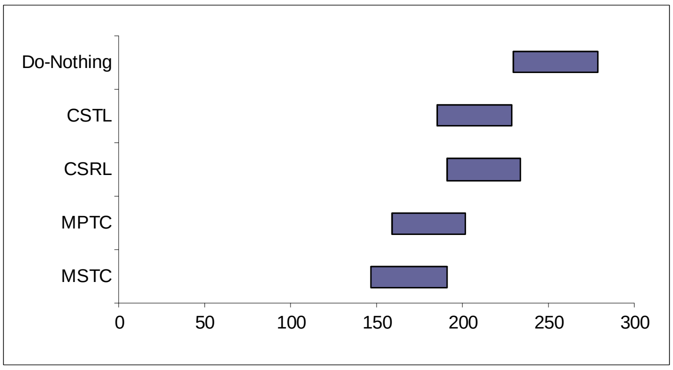


Figure C.4 95% Confidence Intervals of Cycle Time under Expo(10), Dataset 4

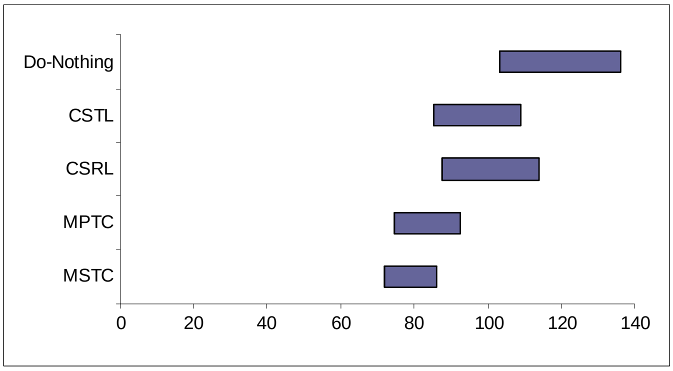


Figure C.5 95% Confidence Intervals of Cycle Time under Expo(15), Dataset 4

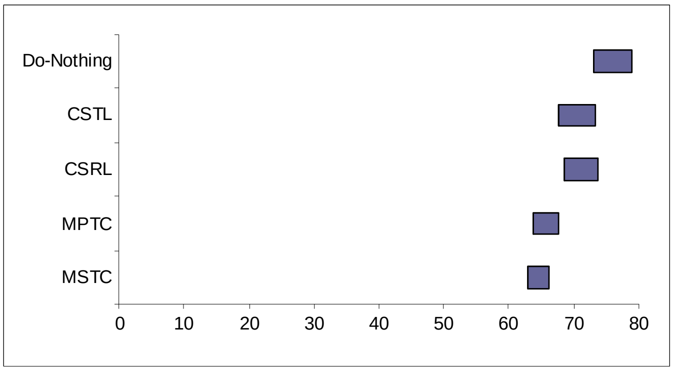


Figure C.6 95% Confidence Intervals of Cycle Time under Expo(20), Dataset 4

C.1 Tukey Tests for the 8-to-8 Staging Scenarios

The common method for comparing two alternatives is the paired t-test, which measures dependent or grouped samples (Law, 2007). As for all pairwise comparisons of more than two alternatives, the most acceptable method is the Tukey test (Hsu, 1996). The Tukey test uses the studentized range distribution and compares the differences between the means of all measured groups to see if they are larger than a critical value, HSD (honestly significant difference).

$$HSD = q_{\alpha}\sqrt{\frac{MS_{within}}{n}},$$

where q_α can be looked up from the Tukey's sig/probability table; (1-α) is the confidence interval; MS_{within} is the mean square value in the ANOVA table; and n is the number of values in each group.

SPSS (version 15) is used to perform the Tukey tests for comparing the cycle times of the five strategies at a confidence level of 95%. The cycle time data used in a Tukey test is from the 20 replications of a scenario run in Section 5.7.2 under datasets 3 or 4. Therefore, 6 sets of rankings are conducted and the results are shown in Tables C.1 and C.2.

Table C.1 Rankings of the Alternate Destination Strategies under Dataset 3

Trailer Arrival / Strategy	Expo(10) Ranking	Expo(15) Ranking	Expo(20) Ranking
Do-Nothing	5	4	5
CSTL	1	1	2
CSRL	1	4	2
MPTC	1	1	2
MSTC	1	1	1

Table C.2 Rankings of the Alternate Destination Strategies under Dataset 4

Trailer Arrival / Strategy	Expo(10) Ranking	Expo(15) Ranking	Expo(20) Ranking
Do-Nothing	4	3	5
CSTL	1	3	3
CSRL	4	3	3
MPTC	1	1	1
MSTC	1	1	1

From Tables C.1 and C.2, we can find that the MPTC and MSTC strategies are ranked above the do-nothing strategy in all six scenarios. The results also show that the CSTL strategy ranks higher than the do-nothing policy in five scenarios out of six; the CSRL strategy has higher ranks than the do-nothing policy only in three scenarios.

On the other hand, the Tukey test also has the same problem as using confidence intervals on ranking our four alternate destination strategies—some strategies in some scenarios are ranked at the same ordinal levels. However, if we make a joined comparison out of the six rankings, we can have the following overall ranking in Table C.3.

Table C.3 The Overall Ranking of the 5 Strategies

Strategy	Ranking
Do-Nothing	5
CSTL	3
CSRL	4
MPTC	2
MSTC	1

The above results indicate that even the 20-replications are not enough to distinguish the performances of our four alternate destination stretegies by confidence invertals, we may rank their effectivenesses using the Tukey test.

C.2 Theoretical Number of Replications to Have Non-overlapping Confidence Intervals

In the last section, we discussed the difficulty in getting non-overlapping confidence intervals using the 20-replication results. Then, how many replications may be enough to show the differences of confidence intervals among the strategies? Theoretically, the half width of a confidence interval is calculated from the following formula (Kelton, Sadowski and Sturrock, 2007).

$$h = t_{n-1,1-\alpha/2} \cdot \frac{s}{\sqrt{n}} \qquad \text{(c-1)}$$

where h: the half width of the (1-α) confidence interval;

s: the standard deviation of samples; and

n: the size of samples.

When n is more than 30, we can use $z_{1-\alpha/2}$ to replace $t_{n-1,1-\alpha/2}$ in equation (c-1).

Hence, we get

$$n \cong z_{1-\alpha/2}^{2} \cdot \frac{s^2}{h^2} \qquad \text{(c-2)}$$

When we have an initial number of replications, n_0, and an initial half width of confidence interval, h_0, we can calculate how many replications are needed to approach a specific half-width h. (Assuming s is still the same in a bigger sample.)

$$n : n_0 = (z_{1-\alpha/2}^{2} \cdot \frac{s^2}{h^2}) : (z_{1-\alpha/2}^{2} \cdot \frac{s^2}{h_0^2})$$

$$n \cong n_0 \cdot \frac{h_0^2}{h^2} \qquad \text{(c-3)}$$

Using equation (c-3), we can calculate the size of replications needed to attain certain half-widths to evaluate the superiority of the MPTC and MSTC strategies under dataset 3, as shown in Table C.4. In the table, to avoid overlapping, we set the expected new half-widths of the 95% confidence intervals as a half of the deviations of the average cycle times between a pair of the MPTC and MSTC strategies.

Table C.4 Theoretical Calculation of Replication Sizes for Non-Overlapping Confidence Intervals

Headway	Strategy	Average Cycle Time	Initial Half-Width (h_0)	New Half-Width (h)	Size of Replications (n)
Expo(10)	MPTC	205.57	22.84	0.73	19579
	MSTC	204.11	23.64	0.73	20974
Expo(15)	MPTC	90.97	10.92	1.08	2045
	MSTC	88.81	10.08	1.08	1743
Expo(20)	MPTC	66.87	2.07	0.545	289
	MSTC	65.78	2.11	0.545	300

In Table C.4, the required new half-width is so small in the Expo(10) scenario that the theoretical number of replications needed is more than 20,000, which is very time-consuming. Hence, we picked the Expo(20) scenario to perform 300 and 500 replications to see if their 95% confidence intervals can become non-overlapping. According to the new results in Table C.5, increasing the number of replications does reduce the range of a 95% confidence interval. However, even increasing the number of replications to 500, those intervals still exceed our expected range. By the same token, if we really want to try to distinguish the superiority between the MPTC and MSTC strategies in the Expo(10) scenario, simulations with much more than 20,000 replications are expected—this might cost more than two days of program running for a scenario and we still may not get non-overlapping intervals.

Table C.5 Confidence Intervals of the 300- and 500-Replication Results

Strategy	Number of Replication	Average Cycle Time	Lower Bound of the 95% Confidence Interval	Upper Bound of the 95% Confidence Interval
MPTC	300	68.7227(±0.87)	67.8527	69.5927
MSTC	300	68.0148(±0.92)	67.0948	68.9348
MPTC	500	68.4351(±0.67)	67.7651	69.1051
MSTC	500	67.7633(±0.71)	67.0533	68.4733

These results show again that using confidence intervals may not be a good criterion to judge the effectiveness of our alternate strategies because of the closeness of their performances. Other statistical analysis methods such as the paired t-test or Tukey test could be a better way for our cases—a paired t-test is performed using the 300-replication results, as presented in Table C.6, it shows significantly better performance for the MSTC strategy at a 95% confidence level.

Table C.6 Paired T-Test for the 300-replication results

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
MPTC - MSTC	.70767	2.46832	.14251	.42722	.98811	4.966	299	.000

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