STAGING APPROACHES TO REDUCE OVERALL COST IN A CROSSDOCK ENVIRONMENT

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by

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ABSTRACT

Crossdocking operations seek to move materials from inbound locations to outbound locations as quickly as possible. In some cases this can be achieved without intermediate product staging. However, in an environment with limited space, limited material handling resources, multiple operations and realistic scheduling needs, some short-term staging is required. The objective of this research is to determine what staging strategy is most appropriate in a crossdocking operation as a function of freight attributes (dimensions and number of different types of boxes), and container loading requirements.

The problem is described in mathematical terms and then a hybrid analytic/simulation approach is used as the basis of a cost analysis and analyzing operational performance of the different staging strategies. Staging strategies are evaluated with respect to average and maximum staging requirements, average crossdock flow time, outbound trailer cube utilization, and material flow system / space cost.

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Chapter 1 INTRODUCTION

1.1 Crossdocking

In today's highly dynamic and competitive business environment we are seeing new ways of doing things, whether it is buying books online from Amazon or making flight and hotel reservations at Yahoo. The idea is to not only improve efficiency and lower overall cost by improving processes, but also to eliminate the un-necessary ones, which in case of Amazon are retail outlets and travel agents in case of Yahoo. Crossdocking is one such new logistic technique used in the retail and trucking industries to rapidly consolidate shipments from disparate sources and realize economies of scale in outbound transportation. Four functions of warehousing (receiving, storing, picking, and shipping) and the interaction between them is constantly analyzed to study operational efficiencies. Crossdocking has the potential of eliminating storing and picking, the two most expensive warehousing operations. Bartholdi and Gue (2004, pg. 2) define crossdocking as "a logistic technique that effectively eliminates storage and order picking functions of a warehouse while still allowing it to serve its receiving and shipping functions." The shipment typically spends less than 24 hours in a crossdock or sometimes less than an hour. Crossdocking has an additional advantage. By eliminating the storage function, one increases inventory turns thus reducing inventory carrying costs and speeding the flow of product to the consumer.

This idea of crossdocking is visible in other fields as Schaffer (1997) has pointed out that crossdocking is not new – for example:

- “Opportunistic” crossdocking: this technique involves filling existing orders with received product even when it is in storage or shipping received product to fill back orders.
- JIT (Just-In-Time) is crossdocking for the receipt of components or raw materials.
- Distribution crossdocking involves the receipt of full unit loads (pallets) and shipping of either the same unit loads or shipping of unit loads composed of sorted pallets.
- Terminal crossdocking is truck sorting and consolidation of orders where unit loads that are received from two or more manufacturing or distribution operations are placed on the outbound truck so that they can be shipped to a customer at the same time (Schaffer, 1997, Pg. 2).

The end product of a crossdock operation is a loaded container bound to its intermediary or terminal destination. Thus cost of overall logistic operation can be reduced if the space in outbound trailer is utilized to its maximum. To ensure this optimal loading different approaches and heuristics are used. The following section discusses some of these approaches.

1.2 Container Loading Problem

A container loading problem is where a number of rectangular boxes are loaded into a container of fixed dimension. The problem has been studied since the seminal work of Gilmore and Gomory (1965), and numerous research papers and algorithms have been presented for its solution. Although authors talk about the “container loading problem” or “loading problem” there are several versions of the problem with respect to different objective function and constraints.

One type of loading problem is the knapsack loading problem. In the knapsack loading of a container each box has an associated profit and the problem is to choose a subset of the boxes that fits into a single container so that maximum profit is loaded. If the profit of a box is set to its volume, this problem corresponds to the minimization of the wasted space. The knapsack loading problem matches to the problem identified for this study where freight in shape of rectangular boxes are to be loaded in trailer cube of a given size with an objective to maximize its cube utilization.

1.3 Motivation

The initial motivation for this study is provided by the issues and ideas related to staging strategies raised by Taylor and Noble (2004). They suggested that staging needs can vary depending upon different staging methods and the scenarios considering different factors (demand type in their case). According to a study by Delaney (1999), transportation and warehousing account for over 10% of U.S. Gross Domestic Product (GDP). Much improvement in the performance of the supply chain can be achieved if one considers the inventory and transportation decisions jointly. In order to reduce the logistics costs, companies are increasingly moving towards consolidation and crossdocking is considered as a way to facilitate consolidation.

According to the US Interstate Commerce Commission (Swan, 1996), shipments in the trucking industry are classified into two major categories: Less-than-Truck-Load (LTL <10000 pounds) and Truck-Load (TL > 10000 pounds). Looking at the three major components of the crossdock operation (Inbound, Staging, and Outbound), it is the staging and outbound operations that have the most impact on the overall profit of an operation. The shipper (customer) is usually billed a rate per mile for the length of the trip. It has been observed that the average LTL container utilization is less than 50% (Thompson, 2004). Low container utilization means that each container is carrying fewer loads which translate into more number of trips. Looking at the revenue of the overall trucking industry (Table 1), LTL share of 1% out of total 701 billion, is motivating enough to bring costs down. The cost associated with the container utilization can amount to a significant number. This provides the goal of gauging the impact of staging strategies on the outbound container utilization. This may also apply to truckload and private industries involved in similar operations.

Table 1 Revenues - Trucking industry overview (ATA, 2004)

	Volume (billions of Tons)	Share	Revenue (billions of $)	Share
Truck	9.06	68.9%	$610.1	86.9%
Truckload	4.31	32.8%	$269.7	38.4%
LTL	0.13	1%	$61.9	8.8%
Private	4.62	35.1%	$278.5	39.7%
Rail	1.70	12.9%	$36.0	5.1%
Rail intermodal	0.12	0.9%	$7.6	1.1%
Air	0.18	0.1%	$13.1	1.9%
Water	1.02	7.7%	$7.8	1.1%
Pipeline	1.24	9.4%	$27.3	3.9%
Total	13.16	100%	$701.9	100%

The largest LTL carriers spend $300-500 million annually handling freight (about 20% of total costs) and approximately 10-15% of that cost is due to workers traveling the dock while transferring freight from incoming to outgoing trailers (Gue, 1999). Thus this research has the potential to affect approximately 2-3% of the total costs of a carrier. This small percentage is significant because of the thin profit margins posted by most large carriers. In fact, none of the three largest carriers (Yellow Freight, Roadway Express, or Consolidated Freightways) has posted more than 2% profit in the years 1994-96, and all lost money in at least one of those years (Bowman, 1996).

1.4 Problem Description

Crossdocks in the distribution industry exist in a wide variety of configurations. The simplest crossdock resembles a trucking terminal with a long, narrow building with doors around the perimeter. More complex facilities may have pallet racks for short term storage, conveyors for sorting and transporting packages, or automated storage devices (Napolitano, 2000). A typical less-than-truckload (LTL) crossdock is 60-120 feet wide (Bartholdi and Gue, 2004) with doors on both sides as visible in Figure 1. Doors on either side can be used as inbound or outbound. Forklifts are the common means of moving freight within a crossdock. Freight staging becomes an issue when it does not arrive at the outgoing trailer in the sequence in which it must be loaded. The space is also used for intermediate staging for number of other reasons:

- To allow value added processing, such as pricing and labeling ,
- To wait for other items on an order to arrive,
- To facilitate building tightly packed loads, or
- To load in reverse order of delivery if there will be multiple stops. (Bartholdi, et al., 2001)

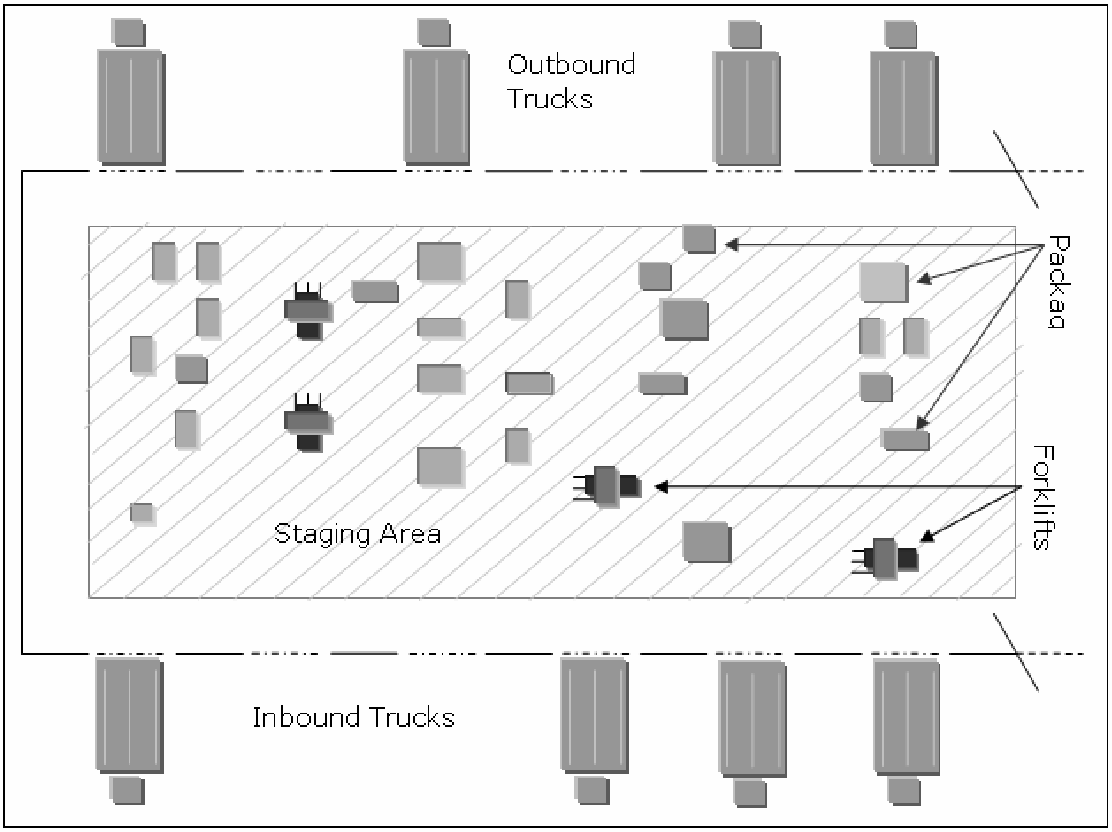

Figure 1 Exmaple of a typical crossdock setup

The objective of this research is to look at different strategies to stage freight during a crossdock operation in order to support optimal loading of the outbound trailers. Loading in a desired sequence can involve extra shuffling and sorting of packages. This means more material handling and a greater chance of freight getting damaged, eventually leading to an increase in the operating cost. Thus factors such as material handling and space utilization must be considered while examining different staging strategies so as to strike a balance between different parameters.

The problem considered in this thesis is a maximization type applied to the set up of a LTL crossdock facility. The overall objective function (Equation (a)) maximizes the profit for a crossdock operation. This requires both maximizing outbound container utilization and minimizing material handing and space cost. Constraints to this objective function are listed in Equations (1), (2), (3) and (4). Equations 1 to 3 are the dimension constraints which make sure that the width, depth and height of the boxes loaded on to the container do not exceed the respective dimensions of the outbound trailer. Equation (4) ensures that total weight of all the boxes loaded stays below the specified limits. The exact location where each box is placed in the trailer is also known in terms of x, y, z co-ordinates to maximize the revenue. Details of the information available are described in the Chapter 3 discussing model approach and assumptions. The objective function described is only used to represent the problem for the purpose of problem definition and not for generation of a solution.

The formulation consists of following objective function and constraints:

$$\text{Max } \sum \mu_{\text{jk}} \times \text{R}_{\text{jk}} \times \text{N}_{\text{jk}} - \text{c}_1 \sum \text{n}_{\text{ipjkl}} \times X_{\text{ijk}} - \text{c}_2 \text{A} \qquad (a)$$

such that

$$\mu_{\text{jk}} = \frac{\sum \text{box}_{isxyz}(X_{ijk})}{T_{WHD}}$$

$$\sum X_{ijk}\, x_{irs} \le W \quad \forall\, r \text{ and } s \qquad (1)$$

$$\sum X_{ijk} \max(y_{irs}) \le H \quad \forall\, r \qquad (2)$$

$$\sum X_{ijk} \max(z_{irs}) \le D \quad \forall\, s \qquad (3)$$

$$\sum X_{ijk} w_i \le E \qquad (4)$$

$$0 \le \mu_{\text{jk}} \le 1$$

$$\text{X}_{\text{ijk}} = \begin{cases} 1 \text{ if box i is loaded to truck j of type k} \\ 0 \text{ if box i is not loaded to truck j of type k} \end{cases}$$

$$\text{n}_{\text{ipjkl}} \ge 0\,,\ \text{A} \ge 0$$

$$r, s \ge 0$$

where

μ_{jk} = cube utilization of truck j of type k

R_{jk} = revenue generated by truck j of type k per mile

n_{ipjkl} = number of feet required to move package i from inbound door p to truck j of type k to outbound door l

N_{jk} = Average number of miles per trip travelled by truck j of type k

box_{irsxyz} = volume of box i with dimension of x, y and z in strip s of row r of the out

$T_{WHD} = W \times H \times D$ (Total volume of the container)

c_1 = cost to move material per ft

c_2 = cost per sq. ft of space

A = total available staging area in sq. ft.

W = width of the trailer

H = height of the trailer

D = depth of the trailer

E = maximum weight that can be loaded in a outbound truck j of type k

$x = x$ dimension of box i

$y = y$ dimension of box i

$z = z$ dimension of box i

r = single row or vertical layer as loaded from bottom to top of the trailer

s = strip of which a row is comprised of

w = weight of box i or unit freight in pounds

In this research we consider several different scenarios based on different staging strategies to examine their effect on final outbound container utilization. Utilization of the container is assumed to be totally volume based, with the weight constraint of each trailer not being exceeded. Three different staging cases are examined with respect to two staging strategies. Case 1 - all the freight is staged before it can be loaded to an outbound container, and Case 2 - freight is either loaded into the trailer or staged based on the scheduled loading sequence. Case 3 is where freight is not staged at all and is loaded directly from the inbound to the outbound trailers irrespective of their loading ranks.

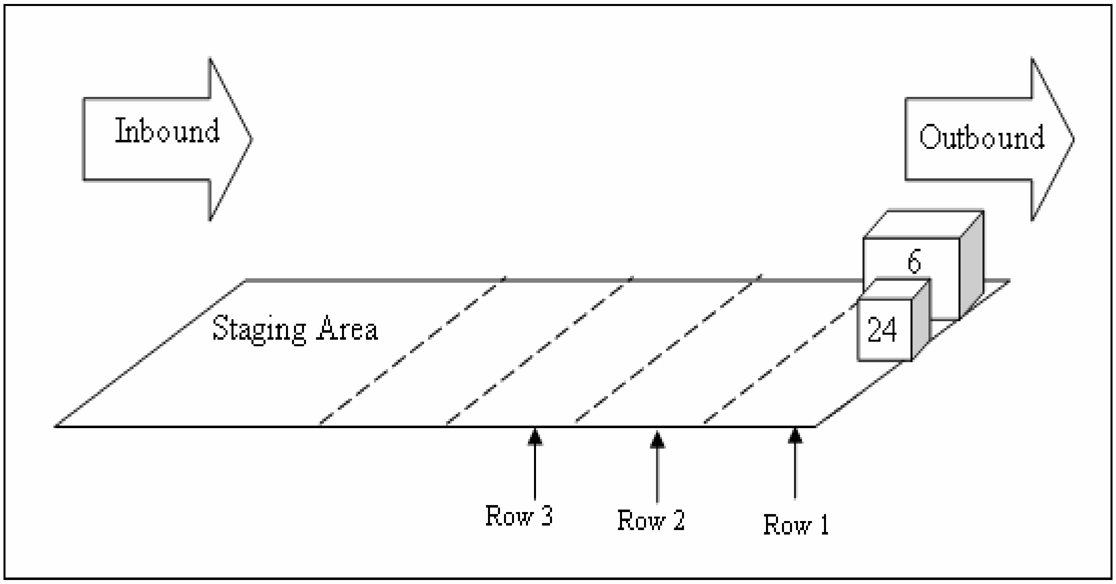

Figure 2 Freight flow in random staging strategy

1. Random Staging in a Single Queue (RS) – In this strategy the staging area is dedicated to each outbound door and is treated as a single resource, where items are staged on a first come, first loaded basis. Figure 2 shows the flow of freight into the staging area where the whole staging area can be seen as divided into imaginary rows or queues. As the packages are unloaded from inbound trailer, they are staged first in row 1 irrespective of their rank, then row 2 gets filled and so on and so forth.
2. Zoned Staging (ZS) – In this strategy the staging space available for each outbound door is divided into three equal zones based on the ranking of an item's scheduled loading sequence. Items scheduled to be loaded first (High rank) would

be staged in zone 1 and items scheduled to be loaded last (Low rank) are staged in zone 3. Figure 3 shows the freight flow according to the zoned staging strategy in the staging area. For example a list of 12 boxes ranked from 1-12 will have 1-4 staged in zone 1, 5-8 in zone 2 and 9-12 in zone 3.

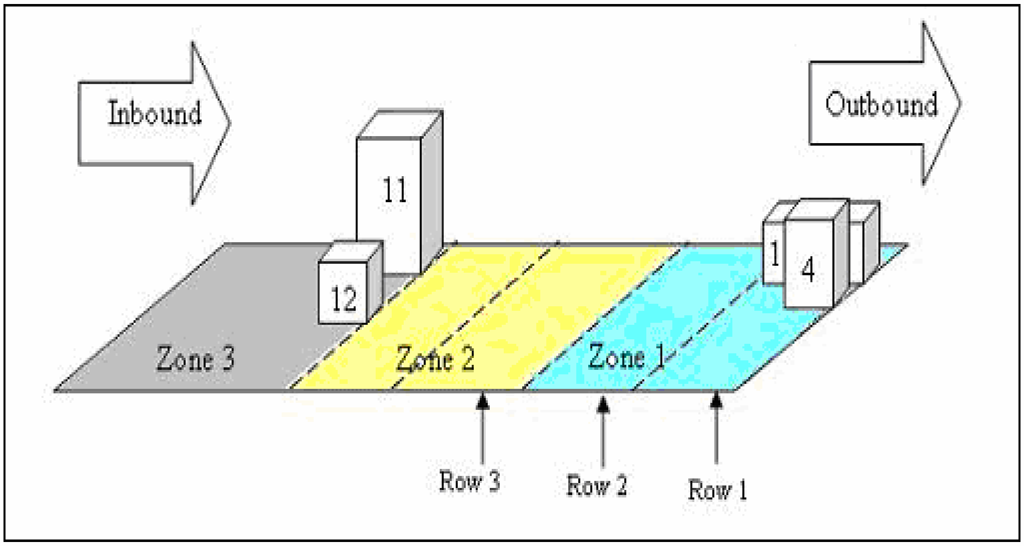

Figure 3 Freight flow in zoned staging strategy

This research utilizes discrete event simulation models (using the simulation software Arena®), integrated with a tree search heuristic that produces the optimal loading sequence for the freight; to study various aspects of the above mentioned staging strategies. Container volume utilization, staging space utilization, entity wait and transfer time and average material handling time per package metrics are captured during the simulation run to ascertain the performance of the staging strategies.

The rest of this thesis is organized as follows. Chapter 2 reviews the literature in the area of crossdocking, warehousing, and container loading problem. Chapter 3 presents the approach taken and assumptions made during this study and describes the inbound, staging, and outbound components of the crossdock model as modeled in Arena®. Chapter 4 discusses the results generated by the experiments and chapter 5 presents concluding remarks and future work on this research problem.

Chapter 2 LITERATURE REVIEW

2.1 Crossdocking

Crossdocking evolved from a need to have a more dynamic Just-In-Time warehouse. Crossdocking makes it possible to almost eliminate inventory storage. Crossdocking enables very short lead times for products. Many authors have looked at different aspects of crossdocking. Moore and Roy (1998) and Schaffer (1997) talk about the factors important to successfully implement crossdocking. They mention that the relationship with suppliers and all partners in the supply chain has to be reliable. Products should be delivered at the right time, in the right quantities and of right quality. Transportation should be reliable to prevent delays.

A crossdocking center must be efficiently designed to achieve the desired performance. Schaffer (1998) discusses in detail how crossdocking can improve efficiency. Efficiency of a crossdock can be improved by addressing planning and operational problems that involves dock door assignment and design issues such as shape and size of a crossdock facility. Tsui and Chang (1990) present a heuristic to assign trucks to dock doors such that the total travel distance in the facility is minimized. A branch-and-bound procedure for this problem is described in Tsui and Chang (1992). Gue (1995) constructed an LP-model to determine the material flow in a facility, where the flow is influenced by the supervisor who assigns incoming trailers to dock doors. A parameter is used to capture this affect. Bartholdi and Gue (2000a) use a simulated annealing approach to interchange designations of dock doors (i.e. which trailers load at which doors). The objective is to minimize worker's travel time and waiting time due to congestion. Roodbergen and Vis (2002) sought to minimize travel distance in a crossdock when pallets cannot be staged along the shortest path between inbound and outbound doors. They model the problem as a network and solve it as a cost flow problem.

Bartholdi and Gue (2004) discuss in detail the best shape of a crossdock. They found that "as size increases, the most labor-efficient shapes for a crossdock are I, T and X-shapes, successively". Also the size at which T-shape is preferred to I-shape, and X-shape preferred to T-shape, depends on the number of receiving doors and the concentration of flows. Experiments suggest that I–shape is most efficient for docks of fewer than 150 doors. A T-shape is best for docks of intermediate size (150 – 200 doors); for more than about 200 doors the X-shape is best.

Several authors have addressed operational problems of crossdocking: Peck (1983), Tsui and Chang (1990, 1992), Gue (1999) and Bartholdi and Gue (2000a). All of these authors address labor costs due to the placement of trailers into doors. Bartholdi, et. al., (2001) examine the staging issue at a crossdock in retail distribution and discuss approaches to pallet queuing and the implications for crossdock design. They describe a model for the queues of staged freight under two scenarios: staging pallets on the floor versus staging in a flow rack. They classify crossdocks according to the type of staging: single-stage, two-stage, or free staging. Crossdocks in the less-than-truckload (LTL) trucking industry have free staging area. This method is necessary because LTL crossdocks have shipping doors on both sides of the dock, and the docks are typically very narrow, which allows access to the staging area from only one side. This is also because of the great variety of freight that LTL must accommodate. They find that staging queues in a crossdock are less efficient than flow rack queues. Gue and Kang (2001) examined single versus parallel staging queues and determined that with “random choice” rules in force for queuing arrivals and servers its best to have one long queue instead of two short ones. Taylor and Noble (2004) examine three material staging alternatives in various crossdock environments, mainly looking at layout method (door assignment), outbound demand scenario, and staging method (flow rack, single queue & double queue). They introduce the concept of a common overflow queue when the outbound queues fill. This is analogous to the two-stage queue used by Gue and Kang (2001) but it is centrally located near the inbound doors in the center of the facility. They conclude that demand type is more important than either the facility layout in terms of inbound and outbound assignments or the type of staging made available, and layout only matters for make-span determination.

2.2 Warehousing and Container Loading Problem

Warehousing in logistics is defined as the storage of goods. The important function of a warehouse is to breakdown large chunks of packages and redistribute them in smaller quantities. The key four functions involved in accomplishing this are receiving, storing, order-picking and shipping. “Typically, storage and order-picking operations take up the bulk of handling activity in a warehouse. These operations include stock locating, stock arrangement, product sequencing, order splitting and item batching, all of which are labor intensive and expensive" (Li et al., 2004, pg. 1). Crossdocking attempts to reduce or eliminate these by reducing warehouses to purely trans-shipment centers where receiving and shipping are its only functions. In a typical warehouse stock is maintained until a customer order is filled causing the product to be picked, packed and shipped. Replenishments, if necessary, are stored until the next demand. This is different from a crossdock where the customer is predetermined before the truck arrives and there is no need for storage. Li et al. (2004) gives two NP-hard scheduling formulations for JIT scheduling in a warehouse to eliminate storing and picking functions.

A number of publications deal with warehouse design problems. Rouwenhort et al. (2000) provides a reference framework and a classification of warehouse design and control problems. Ven Den Berg (1999) also surveyed literature on planning and organization of warehousing systems and defines a hierarchy of warehousing decisions that provides solutions to these complex problems. Research on warehouse design and control has generally been concerned with individual warehouse functions, examples include: Azadivar, 1986; Bozer and White, 1996; and Brynzer and Johanssons, 1996. For instance, when replenishment and order picking patterns are known, several models are available in the literature to compute alternatives for optimally storing a specific number of pallets of a set of Stock Keeping Units (SKU), examples include: Goetschalckx et al., 1989; and Ratliff, 1991; Han et al., 1988; and Jarvis and McDowell, 1991, and to evaluate the alternative with regard to performance and cost. Other warehousing subjects cover a wide range of topics and include material handling systems Apple, 1984; and Goetschalckx, and McGinnis 1989; storage policies Bozer and White, 1990; Rosenblatt and Roll, 1984); facility layout and location Price, 1999; Cormier and Gunn, 1992; and order picking Jarvis and McDowell, 1991.

Although warehouses and crossdocks fall under the same umbrella, they are quite different in the nature of their function and hence in their needs and design characteristics. Most warehouses are designed with order picking and storage in mind as they impact the overall cost of a warehouse the most. A study in the United Kingdom (Drury, 1988) revealed that 55% of all operating cost in a typical warehouse can be attributed to order picking. It is this function that a concept of crossdock is trying to eliminate. In a warehouse products are stored for a long duration on the floor, racks or automated storing/retrieving aisles with an objective to maximize the utilization of storage/rack space and minimize the retrieval time of the package from a particular location. The products are usually similar or belong to same class based on size, shape, or value. In case of a crossdock facility, especially an LTL, there is lot of variation in the incoming freight and it does not stay there for long. So, temporary storage is done just to facilitate the loading of outbound container which is different from long term storage / retrieval.

This research focuses on identifying effective short term staging strategies so as to facilitate the outbound loading process. A tree-search heuristic for the container loading problem (Pisinger 1999a), is used to provide the loading sequence of the already known list of items which is then used in the simulation to evaluate alternative staging strategies. The problem presented in the thesis is closely related to the loading problem, where it is assumed that the profit of a box equals its volume. The boxes may be rotated in any orthogonal direction, but no other restriction is put on the solution. Heuristics for the knapsack loading problem have been presented by Gehring et al., 1990 and Scheithauer, 1992. There are other versions of knapsack where boxes are to be packed into one container with fixed width and height, but infinite depth. The objective is to find a feasible solution which minimizes the depth. Several algorithms for this problem are compared in Bischoff and Marriott (1990). The Bin-Packing problem is also related in that all boxes are orthogonally packed into a minimum number of containers and all containers have fixed dimensions. This problem is considered in Scheithauer, 1991; Chen et al., 1995; and Martello et al., 1998. For a general classification of packing and loading problems refer to Dyckhoff (1990) and Dyckhoff et al., 1997.

2.3 Summary

The literature related to the areas of crossdock design, warehousing and the container loading problem have been reviewed during the course of this research. No literature was found related to the study of staging strategies with respect to the cube utilization of an outbound container, which is the focus of this study. Chapter 3 presents a modeling approach and assumptions to analyze different staging strategies.

Chapter 3 MODEL APPROACH AND ASSUMPTIONS

3.1 Simulation Modeling

Discrete event simulation is a technique widely used to model real world problems in a virtual environment for experimentation purposes. This is motivated by the fact that other modeling approaches are very expensive to perform or infeasible due to other real environment.

Kelton, et al., (2004) refer to computer simulation as “methods for studying a wide variety of models of real world systems by numerical evaluation using software designed to imitate the system’s operations or characteristics, often over time”. Discrete event simulation (DES) is used where system that is being modeled changes its state instantaneously at discrete points in time (Peacock, et al., 1980). Discrete event simulation provides statistics to perform analysis (e.g. response times and resources utilizations). This helps describing the DES model’s characteristics under the experiment’s operating conditions (Kaudel, 1987).

In simulation modeling the first step is the design of the conceptual model and this step is very important for the quality of the final results produced. The next step is the model design and implementation based on the conceptual model. The first step is crucial for the success of the second step as the implementation model heavily depends on the basic concepts of the conceptual model (Arons, 1999). To aid the process of simulation modeling there has been extensive development of modeling languages with enhanced graphical modeling abilities. Arena (successor of Siman) and ProModel (other versions like ServiceModel and Medmodel) are well known examples.

3.2 Model Approach

A simulation model is built to represent different scenarios under consideration and analyze the problem presented in this research. The crossdock operation studied is modeled based on three components as shown in Figure 4.

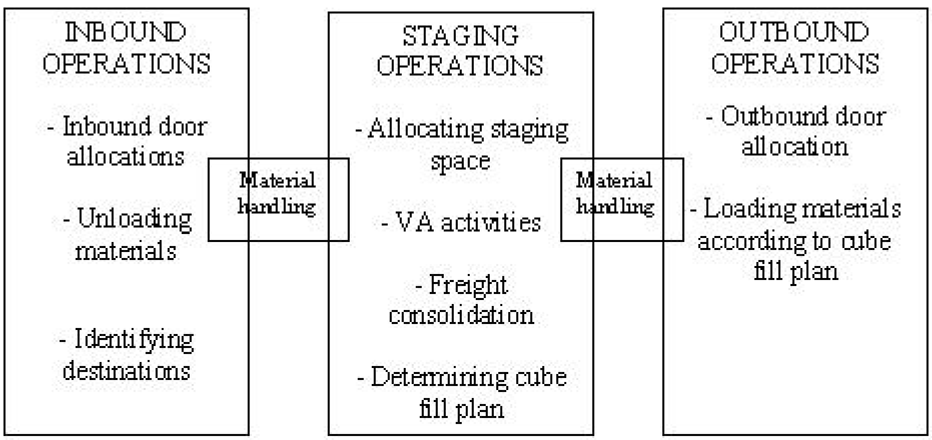

Figure 4 Crossdock components

The simulation model is built using Arena® Professional Version 7.01. The initial loading sequence schedule and freight mix (weight and dimensions) for each outbound trailer is generated by based on a knapsack loading algorithm (Pisinger 1999b), which is used as input to the Arena model. The algorithm used for the container loading is based on a tree-search heuristic for the container loading problem developed by Pisinger (1999a). The code is modified to add a weight constraint that is currently only based on volume. The utilization given by the algorithm is volume based and it stops filling a container when it reaches a threshold. The container loading algorithm is written in ANSI-C, and has been compiled with the GNU-C compiler. A sample of the output generated by the code based on the loading algorithm can be seen in Figure 5.

CONTAINER LOADING PROBLEM 25-115 90 20
printinstance n=81
TOTAL VOLUME 28141804 OF 31211000 FILL 0.901663
TOTAL WEIGHT 15230
1 : n 81 fill 90.2 miss 0 time 3.56

S/no	no	dx	dy	dz	x	y	z	Weight
1	48	78	107	112	0	0	0	146
2	64	93	102	113	78	0	0	107
3	58	57	95	57	171	0	0	135
4	67	72	88	57	0	107	0	42
5	22	102	93	113	76	107	0	107
6	10	52	61	115	178	107	0	75
7	51	52	61	115	178	168	0	75
8	41	76	35	92	0	195	0	139
9	25	84	30	85	76	200	0	68
10	18	57	95	57	171	0	57	135
11	56	72	88	57	0	107	57	42
12	77	52	86	106	0	0	115	107
13	27	52	86	106	52	0	115	107
14	34	52	86	106	104	0	115	107
15	1	72	88	57	156	0	115	42

Figure 5 Sample of the data output from the container loading algorithm.

Various fields contained in the input file are dx, dy, dz dimensions of the packages and x, y, z are co-ordinates of bottom left of rear side of the package as placed in the trailer assuming that bottom left corner of the rear side of the trailer to be (0,0,0). Packages are filled from left to right and back to front. Serial number/rank of each box in terms of loading sequence, weight, and package destination in terms of outbound door (example: outbound door 1, door 2 or door 3) are also part of the information generated.

The container loading algorithm output is used to define various attributes of the entities (packages in this case) created in the simulation model. The model uses different metrics to capture performance of the operational aspects of a crossdock, such as material handling time, floor staging space utilization, throughput time, container cube utilization, and material handling congestion. These metrics are presented in a report or an output file that are analyzed to draw inferences. Figure 6 displays the conceptual frame work of the simulation model. The next two sections describe the various assumptions made and the way in which components of the crossdock operation are modeled.

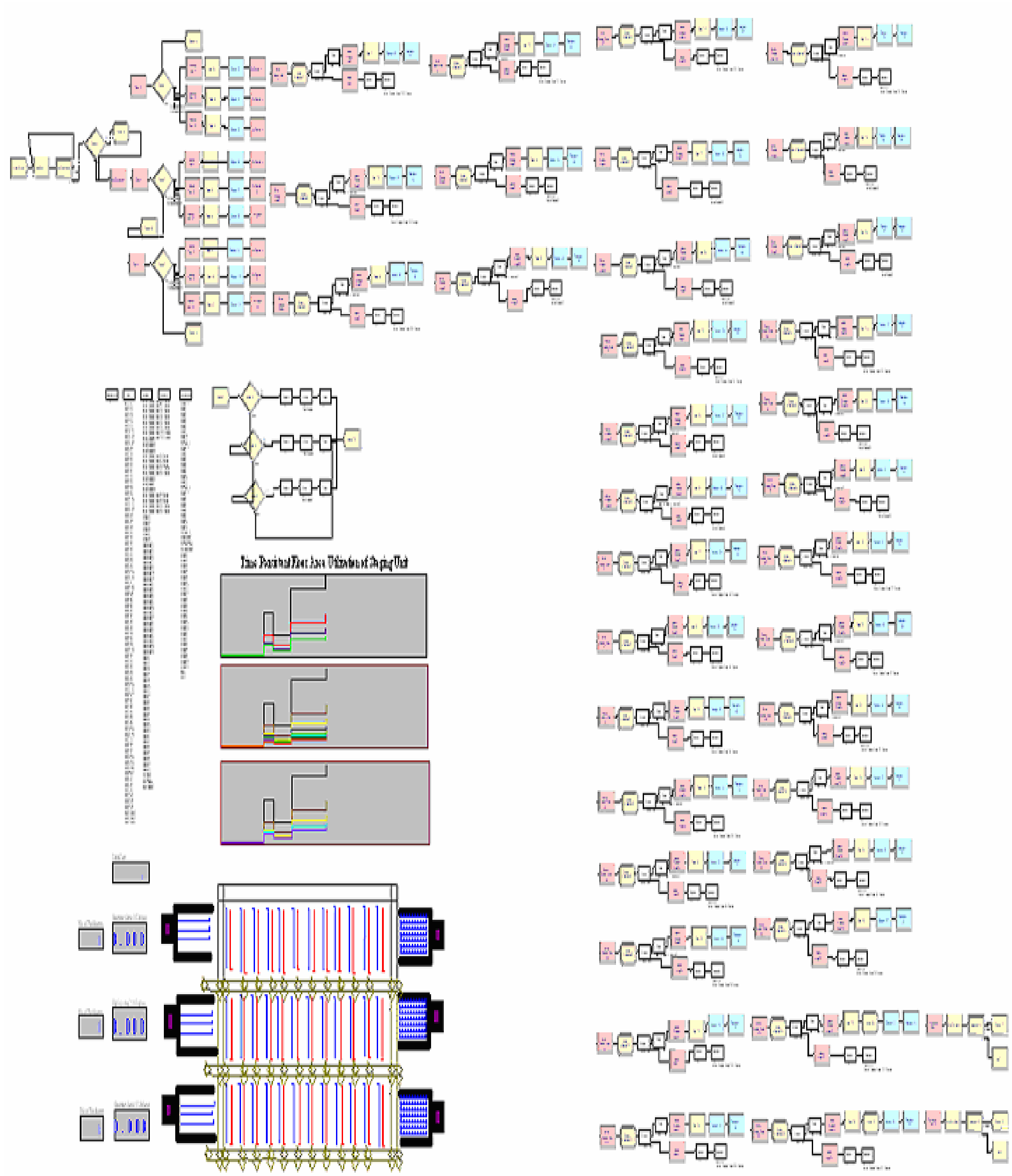

Figure 6 Crossdock model in Arena®

3.3 Model Assumptions

The literature, combined with tours of existing crossdock facilities, was used to support several design considerations and assumptions. Crossdocks can be classified according to pre-distribution or post-distribution operations. In predistribution, shipments arrive at the crossdock with their destinations (retail outlets or other terminals) already determined and labeled. Workers simply take shipments directly to outbound trailers. In post-distribution, workers at the crossdock assign destinations to products (Bartholdi, et al., 2001). This study assumes a crossdock setup with pre-distribution operation. Crossdock assumed during this study is an I-shaped with 6 doors. The dimensions assumed for the I-shaped crossdock can be seen in the Figure 7 and are in accordance with the 5-10 door-widths rule given by Bartholdi and Gue (2004). Bartholdi and Gue (2004) suggest that the I-shape is best for small crossdocks. Each inbound door is allocated a dedicated forklift that carries the freight for that door and is responsible for unloading it and then loading it to the outbound trailer. This is consistent with the practice found at the three LTL crossdock facilities that were visited.

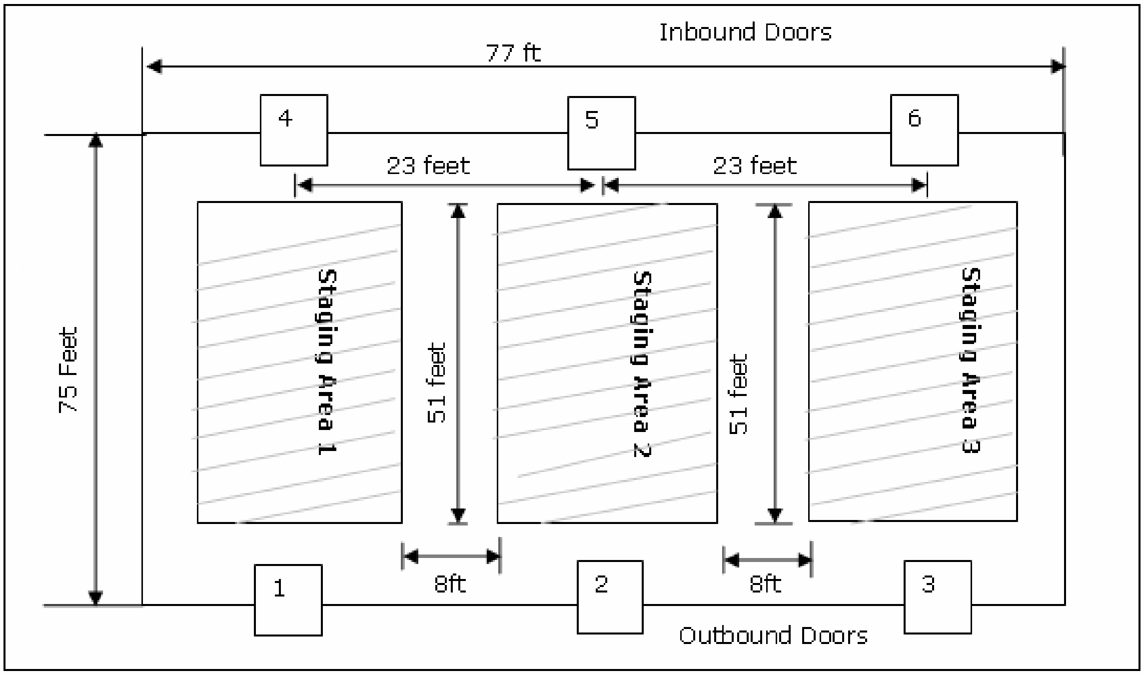

Figure 7 Example crossdock dimensions

The crossdock operation under study is broken down into three major components: Inbound, Staging, and Outbound. Following are some of the assumptions that are made related to these components.

Inbound

The inbound trailer doors are assigned to fixed locations. The trucks are assumed to be docked and ready for unloading. The mix of freight is generated randomly within a given range of dimensions and weight. It is assumed that all packages are cubical in shape and all dimensions (height, width and depth) vary within 0.8 ft to 3.8 ft. The weight of the packages varies within 20 to 150 pounds. The destinations to which these packages are bound are also assigned randomly, which means that a given container might contain items bound for different destinations. The number of packages generated is a function of outbound trailer cube volume. Packages are generated randomly until the total volume of the generated packages equals or exceeds 90% of container volume.

Staging

Each destination trailer door has independent staging space of its own, but can be treated differently depending on the allocation strategy while staging. Items are staged on the floor in a single layer. No racks are used for storage. Medium size forklifts with a weight capacity of 5000 lb are used as the transporting equipment to move items from inbound to outbound and within the staging area. The Speed of the forklift is assumed to be 70 ft/min. Times of 1 min/load and 0.5 min/load is assumed as the loading and unloading time for a box, respectively. A box as a unit load has been assumed here. One forklift is allocated to one pair of inbound and outbound doors. This is common practice in all the facilities that were visited. This practice avoids more than one forklift working on the same trailer resulting in congestion in front of that door. It is assumed that no value added activities are performed in the crossdock facility.

Outbound

The outbound trailer door locations are fixed. An equal outbound demand scenario has been assumed (Taylor and Noble, 2004), where all outbound locations have equal freight flows. The dimensions of the trailer considered are 7.6 ft, 7.6 ft, and 20 ft as width, height and depth respectively.

3.4 Crossdocking in Arena® - Modules and Blocks

The Basic building blocks for Arena® models are modules. These are the objects that help define the process to be simulated (Kelton, et al., 2004). The crossdock model in Arena® is built with the following modules and blocks as they fall under different components of the crossdock operation:

3.4.1 Inbound Operations

1. The Entities (packages) are created in the create module. The number of entities created is equal to the number of packages contained in the inbound containers already docked and ready for unload. The Create module also specifies the time of their creation. In this case they are created at the same time, which is at time zero of the simulation.
2. The ReadWrite module reads in the data from an Excel file, which contains the output generated from the container loading heuristic. It also assigns the read data as entity attributes such as entity dimensions, weight and entity rank in the outbound loading sequence.
3. The Separate module works in tandem with the ReadWrite module. It duplicates the only entity created by the Create module and sends into the systems with its attributes as read via the ReadWrite module and sends back the original entity to the ReadWrite module to read the second entity and so forth. This allows the model to read as many entities as are in an Eexcel file, without constraining us to enter the exact number of entities that will be needed to be created every time we run our simulation.
4. The Route Module in the inbound operations logic randomly distributes the created

entities to different inbound locations with an equal opportunity for each entity to be at any inbound door. This is used to imitate the randomness associated with the real incoming freight but can be bypassed with real time freight data, which has predetermined information about the inbound door location of each entity.

5. The Station module represents the physical inbound door locations where all entities will wait to be unloaded and either staged or transferred to the respective outbound doors destinations.
6. The Delay module is used to imitate the time taken for loading the package on to the forklift. The Delay module forwards the simulation time by 60 seconds every time a package is loaded on to a forklift.
7. The Request module is used to request a transporter and allocate it to the requesting entity that is waiting at the inbound door to be transferred. In this case it requests a forklift, allocates it to the requesting box and moves the forklift to the station where the requesting entity is waiting to be transferred.
8. The Transport Module transports the entity by moving it to the destination station. It considers the speed of the forklift (70 ft/min in this case) and route as defined in the guided network.

3.4.2 Staging Operations

The floor space of the staging area is broken down into smaller units to capture material handling behavior aspect. The idea behind dividing the staging area into parts is to imitate the real situation where distance comes into play when moving from one part of the staging area to another; unlike a queue in Arena® that is just a point where all entities accumulate. Each independent staging area (between a pair of doors – one inbound and one outbound) is divided into 12 units. A unit area represents 61.76 square feet (@ 1ft. = 30.48 cm) of floor space. The unit floor space is a variable and can be changed as per requirements. The unit staging floor space as modeled can be seen in Figure 8 and replicating this unit 12 times represents the staging area between a pair of doors. The following modules and logic are used for this purpose.

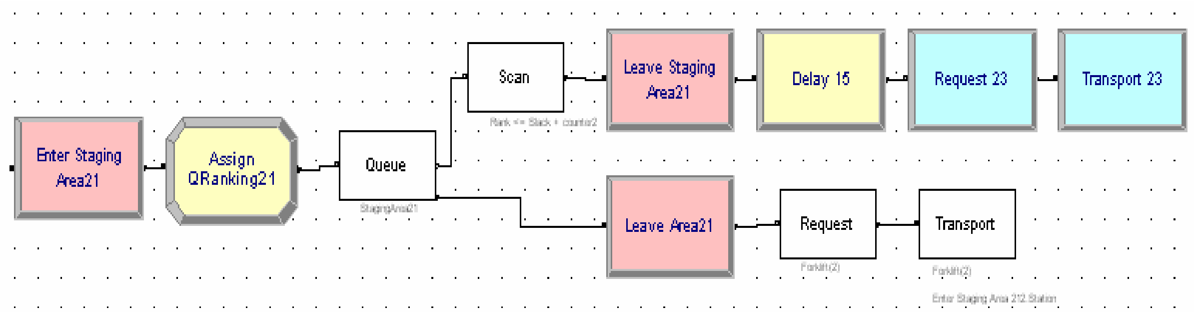

Figure 8 Unit staging area as modeled in Arena®

1. The Station Module represents the entry and exit points of each unit staging area. This is where a transporter (forklift) drops and picks up packages during the process of staging.
2. The Assign module is used to model part of the material handling logic. It assigns a queue rank attribute whenever an entity enters a particular staging area. Rank is assigned equal to the number of entities already waiting in the queue (staged in that staging area) plus one. For example, if an entity enters a queue where four entities are already waiting, it will be assigned a queue rank of five. Based on this ranking the

delay in loading a forklift represents the extra time involved to pick a package from further down the queue when other entities are waiting in front to be loaded.

3. The Queue Block is the Arena® element that is used to model the actual floor space with capacity of 61.76 square feet. This capacity is defined as a variable *unitcap*, which can be changed as needed. This also defines a conditional expression (FULLWHEN expression described in next section), which is evaluated every time an entity tries to enter the floor space. The defined expression compares the surface area of the package and the surface area available. If the available area is more than the package area, it allows the entity to be staged, otherwise, it balks and the entity goes to the next unit of floor space. The queue and capacity expression definition can be seen in the Figure 9. Using this module a time-persistent statistic is captured and plotted during the simulation run that shows the utilization of each staging space area during the simulation run. This gives an overview of the floor space requirements.

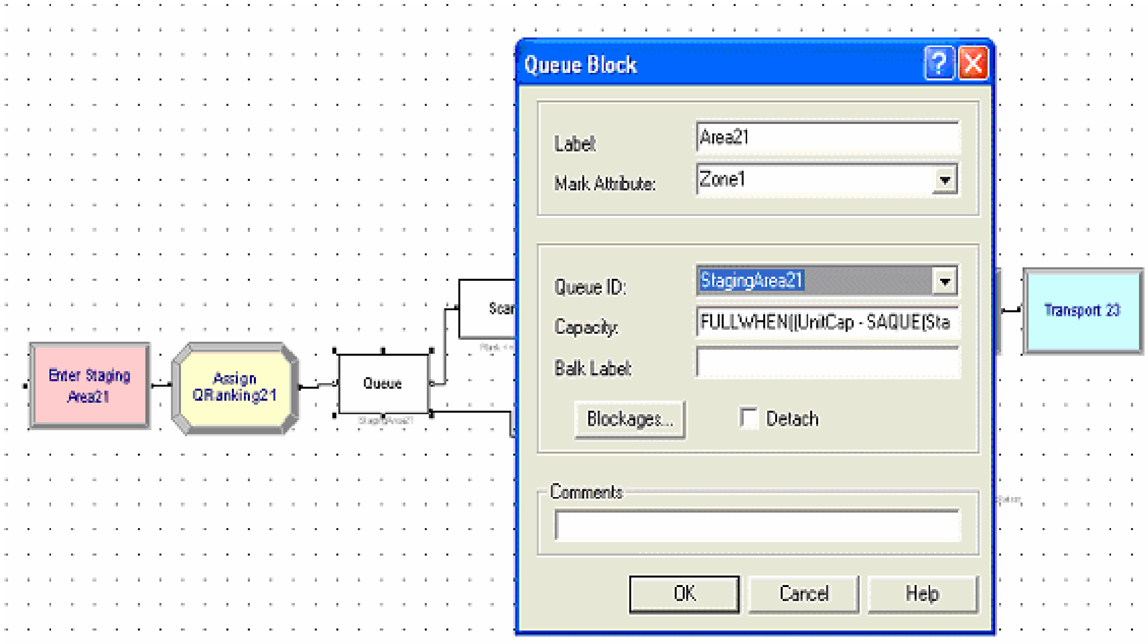

Figure 9 Expression defining floor capacity in Arena®

4. The Scan Block is used to provide the logic of when an entity (package) should be released from the staging area to the outbound door for loading into the outbound trailer. Each entity is released based on its loading rank already determined by the container loading heuristic. The Scan block keeps checking the rank of entities already loaded onto the outbound container and as soon as all the entities ranked higher are loaded, it releases the next ranked entity waiting at the staging area. Slack is a variable that is defined to control the range or difference in ranking of entities already loaded and entities waiting to be loaded. If the difference between ranks of the lowest ranked entity loaded and the rank of next entity waiting in staging queue is equal or lower than slack that entity is allowed to be loaded. As in a real situation, depending on the freight mix a box ranked 3 can be loaded before rank 1. Thus, if the value of the slack is only one, the immediate next rank should be loaded or if the

value of slack is 5 the entity ranked 5th can be loaded before entity ranked 1st and entity 10th before 6th. This scan condition can be seen in the Figure 10.

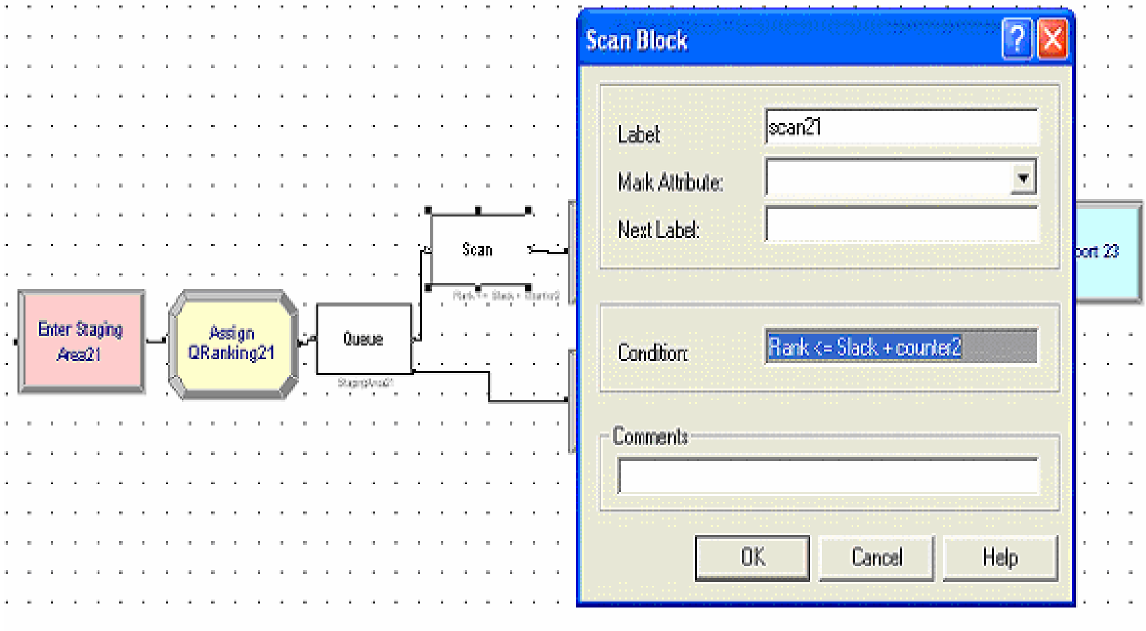

Figure 10 Release logic of package from the staging area

5. The Delay module used in modeling the staging area plays a key role in capturing the material handling behavior where a forklift driver might require more than just the loading time to remove a package from the staging area, such a case can occur when a package to be removed is blocked by other boxes that have to be moved or time spent just locating a specific box. The expression used to calculate the delay is a function of queue rank (position of a box from an exit point) and the zone rank (variable Zone defined earlier). This expression causes an extra 5 seconds of delay for every box in front of the one needed plus a 30 second delay for loading. The expression can be seen in the Figure 11.

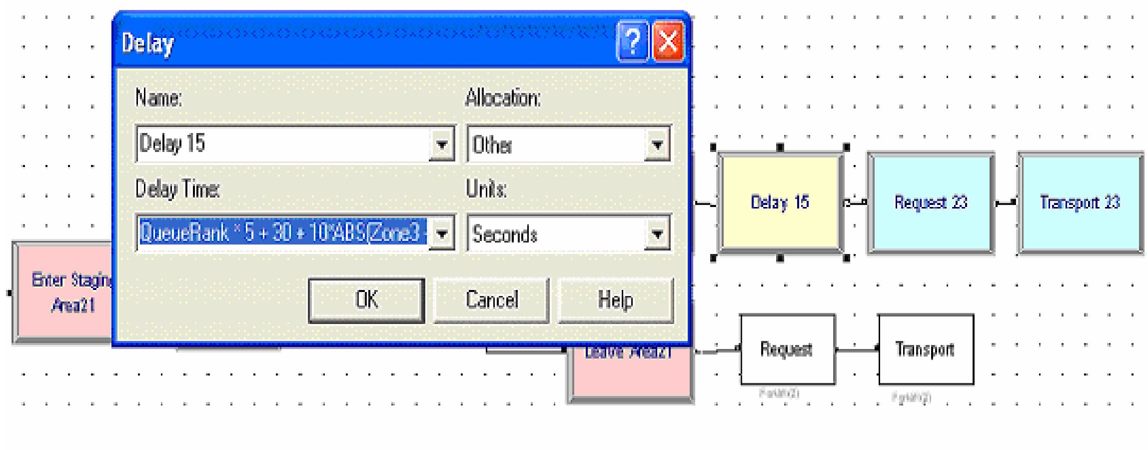

Figure 11 Module as defined in a modeling staging area

The Request and transport modules used in the staging area perform similar functions of requesting, moving and transporting entities from the staging area.

3.4.3 Transporter modeling in Arena®

The transporters (forklifts) used for all the material movement are modeled as a guided vehicle running on a predefined network of aisles and intersections (links and nodes). Defining a network system is important to capture the congestion that occurs at a real crossdock. In the defined system the transporter travels the shortest distance routes between two stations given by a distance matrix automatically generated by Arena® based on the length of defined aisles and intersections. Figure 12 displays this system. The modules and blocks used are described below.

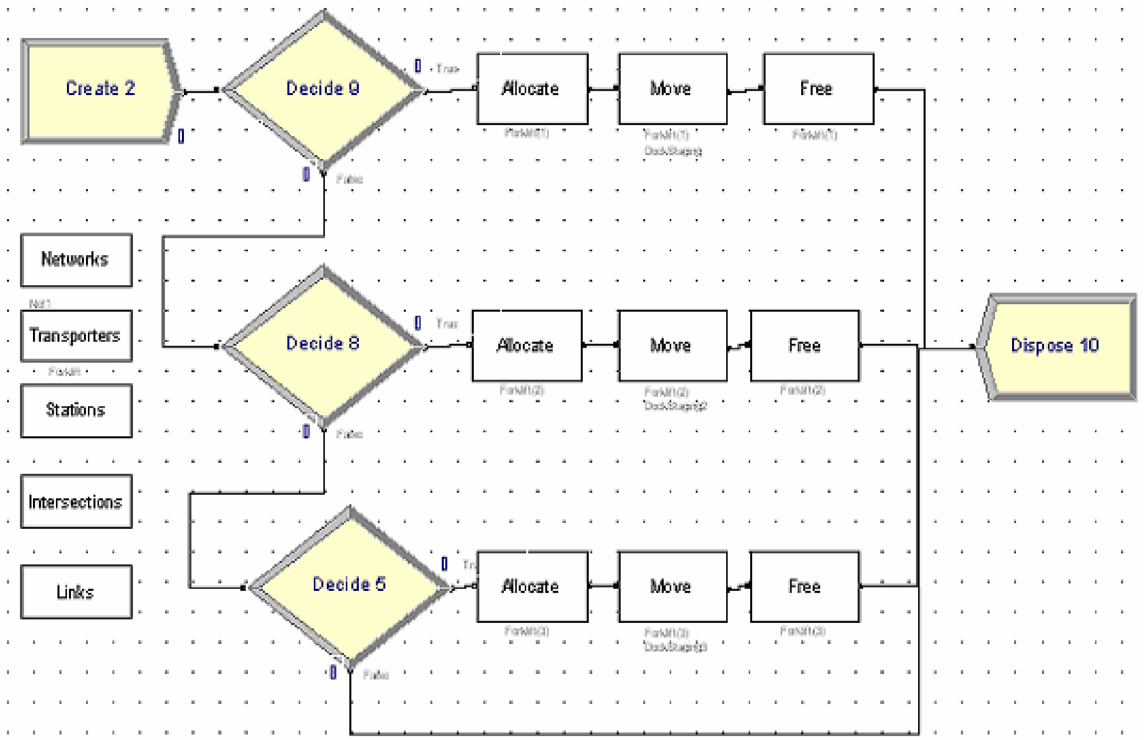

Figure 12 Guided vehicle network for transporters in a crsossdock

1. Links Element: Aisles in the guided transporter system in the model are represented by the variable links defined by the Links Element. Every link can be defined to be of any required length and has a starting and ending point or intersection. A link can be unidirectional or bi-directional. The detailed network diagram can be seen in Figure 19 in Appendix.

2. The intersection Element defines the point where two or more links meet. It is also used to define the starting and ending of a link and has a length of its own. Each intersection in this model has been defined with a length of 4 units (4ft). Intersections are also used to represent any point where transporter interacts with the main model logic, such as all loading and unloading occurs at intersections. This is accomplished

by defining an intersection for every entry and exit station and associating intersections with the respective stations defined in the main logic. Not every intersection is necessarily associated with a station.

3. The Station Element is used to define various stations in the guided network corresponding to stations in the main logic.
4. The Transporter Element defines the number of forklifts and their attributes, such as size, speed and their location at the start of the simulation. For this study 3 forklifts are defined each of 4 feet in length.
5. The Network Element is used to describe a complete system of guided transporters comprising of specific links, intersections, stations and transporters. This is also useful when alternative routes are considered as a set of links and intersections which can overlap in two different networks.

The operation of the defined guided network is characterized by the control logic presented in Figure 12. The logic avoids the real time situation such as dead lock in aisles and at intersections, which in practice are avoided by forklift drivers waiting or taking alternative routes. The control logic moves an idle forklift (not currently requested by any entity) from the guided network to its docking station, thus avoiding any chance of congestion caused by an active forklift being blocked by an idle one. A docking station can be associated with any link or intersection in the network representing any physical location in the staging area. Transporters then take entities to their final destination which is their respective outbound door location for loading into the trailers. The following section explains the outbound operation.

3.4.4 Outbound Operations

The key function of the outbound operation is to receive packages from the staging area and load them in respective trailers as ranked by the loading heuristic. The outbound trailer door locations are fixed. This study assumes an equal outbound demand scenario where all outbound locations have equal freight flows. The dimensions of the trailer are 7.6 ft, 7.6 ft, and 20 ft with respect to width, height and depth, respectively. The outbound operation in essence initiates and drives the simulation model. Inbound and staging operations are based on the loading sequence generated by the optimal container loading heuristic. Packages are received by the outbound component of the simulation shown in Figure 13 and finally disposed out of the system representing as being loaded onto the container. The rank of a package as it is received is captured and written to an output file which is then compared to the ideal loading rank given by the heuristic. The results generated by the simulation models are discussed in the next chapter.

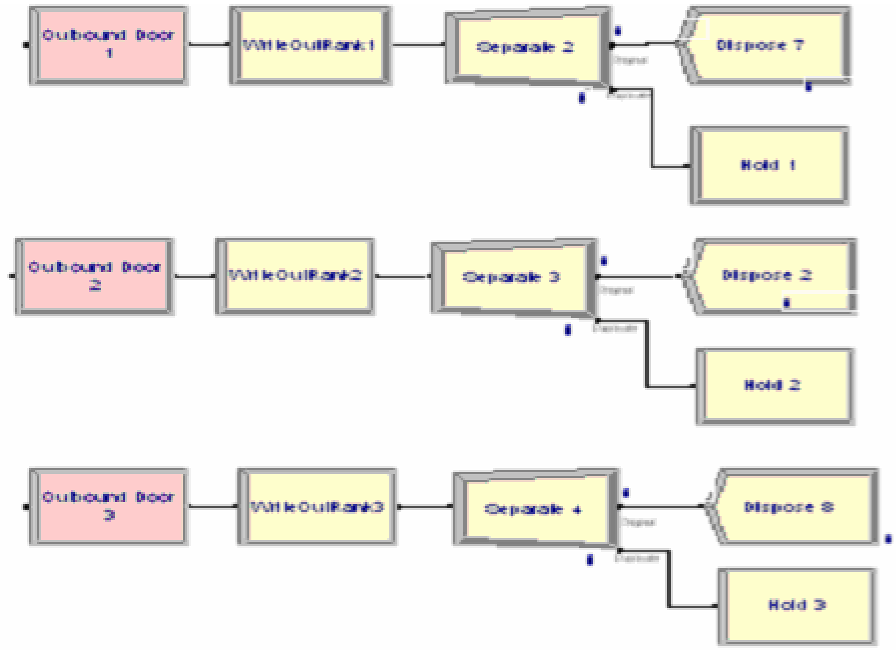

Figure 13 Outbound component of crossdock operation

Chapter 4 RESULTS AND ANALYSIS

4.1 Experimental Results

The results of the scenarios examined under each case are shown in Tables 2 and 3. These results are captured from the simulations models built for each crossdock scenario. For the simulation runs a different random mix of freight is used for each pair of doors, but this set is the same for the corresponding doors in every replication for all different scenarios under study. The loading algorithm generates freight data and packing schemes, achieving an average filling of 90.2% of container volume. The simulation is run until all items reach their respective outbound destinations to let the container be loaded fully based on the given loading sequence; however there is a penalty based on the extra cost due to the loading sequence not being the same as an optimal loading sequence. The further apart the actual loading sequence during the simulation runs is from the optimal, the higher the penalty cost. Each simulation scenario is run for 15 replications. Number of replications produced reasonably accurate calculations. Half-width at 95% confidence interval for some of the parameters are produced in Appendix.

Table 2 Results of simulation – penalty cost

	All Staged						Simultaneous						Direct Loading		
	Random			Zoned			Random			Zoned					
	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3
Container Vol. Utilization	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	72%	60%	74%
Penalty Cost	**0**	**0**	**0**	**0**	**0**	**0**	**102.4**	**84.8**	**98.6**	**99.6**	**82**	**97.8**	**2426**	**2234**	**1923**

The penalty cost results (Table 2) indicate that staging all freight is an ideal case causing no penalty. The Scenario that includes simultaneous loading incurs a marginal penalty cost but still gives 90% cube utilization, where as direct loading is undesirable due to high penalty cost leading to low cube utilization. Penalty costs for direct loading are the highest due to it having almost no flexibility while loading because of first in first out (FIFO) method (from inbound to outbound). The penalty cost is an indirect representation of the lost efficiencies in the container utilization, as any loading sequence other than the optimal one, given by the heuristic, would lower cube utilization. This underutilization could mean that an extra container is required to accommodate the left out packages. This also represents the opportunity cost of extra packages that could be packed into the container with optimal loading. It is assumed that that the supply of packages is unlimited. A marginal increase in the penalty cost for both cases, random and zoned, in the scenario of 'Simultaneous' loading in comparison to the 'All Staged' scenario is due to the fact that simultaneous loading allows any of the boxes within a +/- 3 range of the loading sequence to be loaded without staging versus the loading sequence for the strategy 'All freight staged' is almost perfectly matched with the schedule. For example, consider the case when no boxes have been loaded into the trailer and the first 5 boxes unloaded from the inbound trailer have a rank of 3, 9, 29, 11, and 37. In this case the box ranked # 3 will be sent to the outbound trailer causing a marginal increase of 2 to be added to the penalty cost. In other case where first 5 boxes loaded have a rank of 9, 29, 11 and 37; all boxes will wait in the staging area until at least box ranked 6 is loaded on to the outbound container, which will bring box with rank 9 in range for loading. Although in the actual situation this would not matter much as the boxes to be placed in one single row of a container could be loaded irrespective of their rank. The ranking given by the algorithm is based on boxes being loaded from left to right, whereas in application box # 2 could be loaded before # 1 as long as they lie in the same row (horizontally) as shown in the Figure 14.

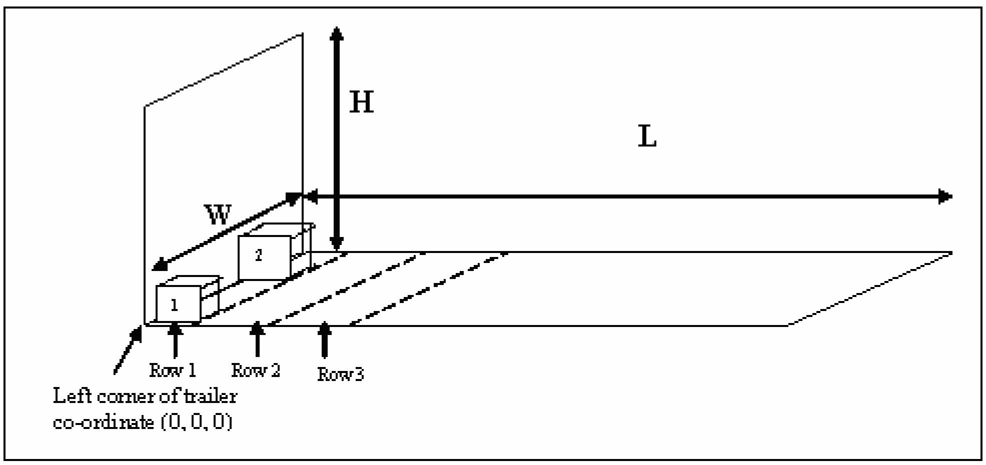

Figure 14 Trailer loading by rows

Another scenario tested is where a slack of +/-5 boxes is allowed while loading directly without staging. Results in Table 4 show that it reduced total operation time by 16% from the case with Slack 3, although it caused penalty cost to go up slightly. It is a trade off between the penalty cost and the material handling time. The value of slack can be decided based on the compromise that could be made in the scheduled loading sequence. In practice it can be continuously varied during the operation run based on the number of boxes being loaded that are independent of the higher ranked boxes.

The range for slack is based on the dimension distribution of the freight mix. For larger dimensions of box (dimensions greater than 3.8 ft) mix, slack range can be low due to lack of flexibility in rearranging within the trailer. Table 3 lists the results from the simulation showing how different strategies perform in regard to performance indicators such as material handling and space utilization. Results show that 'Simultaneous Loading' scenario is a better choice than 'All Staged' for the crossdock environment considered during this study.

Parameters used to ascertain the performance of the different scenarios are defined as follows:

1. Wait time : Includes the waiting time of an entity in the staging area and/or in a place waiting for a transporter to be transported
2. Sorting Time: It is the time spent in locating the right package (as per loading sequence) from a queue/staging area
3. Max Area Utilization: It is the maximum utilization of the individual staging area between each pair of doors during the entire simulation run.
4. Total Operation Time/Outbound Trailer: It is the total time taken to complete the operation of loading an outbound trailer, starting from unloading the inbound

trailer and ending at loading the last package on to the outbound trailer (i.e. the makespan time).

Table 3 Performance indicators for crossdock scenarios with Slack 3

	All Staged						Simultaneous						Direct Loading		
	Random			Zoned			Random			Zoned					
	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3
Material Handling															
Avg. Transfer Time/Entity (Min.)	5.26	5.25	5.6	4.51	4.22	4.23	4.56	4.70	4.99	4.09	3.95	4.12	3.07	2.97	3.17
Avg. Sorting Time/Entity (Min.)	16	16.06	15.12	11.82	12.9	12.04	14.22	14.23	12.84	10.57	11.63	10.62	1.5	1.5	1.5
Container Utilization															
Container Volume Utilization	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	72%	60%	74%
Number of Boxes Missed	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**12**	**14**	**8**
Average Total Boxes	**87**	**80**	**76**	**87**	**80**	**76**	**87**	**80**	**76**	**87**	**80**	**76**	**87**	**80**	**76**
Space															
Max Area utilization (time persistant)	55%	48%	50%	55%	48%	50%	50.3%	43.6%	43.9%	50%	43.6%	43.5%	0%	0%	0%
Control															
Total MH-hours/ year	16332			12034			7666			6010			2682		
Total Operation Time/Outbound Trailer (Min.)	1423	1167	1179	916	940	921	674	555	540	483	449	455	200	212	207
Avg. Entity Wait Time (Min.)	978	899	855	748	726	685	447	437	417	355	357	345	165	166	153
Penalty Cost	**0**	**0**	**0**	**0**	**0**	**0**	**102.4**	**84.8**	**98.6**	**99.6**	**82**	**97.8**	**2426**	**2234**	**1923**

Looking at the results, the 'Direct loading' scenario performs the best with respect to material handling time, space utilization and total operation time. This closely resembles the ideal crossdocking situation where no intermediate staging takes place, but it does not fare well in outbound container utilization which is the lowest among all scenarios and also has highest penalty cost. The container cube utilization is lowest owing to the absence of the opportunity to rearrange while loading. This low figure of container utilization averaging around 69% in actuality could be even lower because in practice human judgment is used to load containers. Whereas, for this calculation the modified loading heuristic is used. The modified loading algorithm loads one row at a time (Figure 14). This represents the case where in real time boxes are loaded one row at a time without much flexibility, except that the algorithm loads individual rows optimally improving utilization. Not only is the container utilization low, but the packages being loaded might not be in the required sequence from the unloading perspective if there is more than one destination for the outbound trailer (which is most likely the case with LTL freight). This will require more material handling down the distribution stream thus increasing cost. The scenario where All Freight is staged gives the best combination of cube utilization and penalty cost, but increases the material handling time and the total time spent by the package during the process. Although the Zoned Strategy shows some improvement in material handling time in comparison to the Random Strategy; it is the Simultaneous Loading scenario with Zoned Strategy which is observed to perform the best. It results in less material handling time with virtually the same container volume utilization (90%) as in the All Staged strategy. There is not a significant difference in the space utilization between random and zoned strategies but the Simultaneous Loading scenario requires around 5% less space for its operation. The Simultaneous loading with the Random Staging strategy can be considered a good representation of the staging strategy used in practice, except that no optimal loading sequence is used while loading outbound trailers. Thus it is observed that there is a decrease of 21% in average total operation time with the use of Simultaneous Loading with Zoned Staging strategy. Savings due to reduced operation time are supplemented by the improved container volume utilization.

Table 4 Performance indicator for crossdock scenario with slack 5

	All Staged						Simultaneous						Direct Loading		
	Random			Zoned			Random			Zoned					
	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3
Material Handling															
Avg. Transfer Time/Entity	5.26	5.25	5.6	4.51	4.22	4.23	4.10	4.34	4.60	3.86	3.77	3.96	3.07	2.97	3.17
Avg. Material Handling Time/Entity	16	16.06	15.12	11.82	12.9	12.04	12.99	12.77	12.08	9.9	10.7	10.11	1.5	1.5	1.5
Container Utilization															
Container Volume Utilization	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	90.6%	90.2%	90.8%	72%	60%	74%
Number of Boxes Missed	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**12**	**14**	**8**
Average Total Boxes	**87**	**80**	**76**	**87**	**80**	**76**	**87**	**80**	**76**	**87**	**80**	**76**	**87**	**80**	**76**
Space															
Max Area utilization (time persistant)	55%	48%	50%	55%	48%	50%	46.7%	40.7%	39.9%	46%	41.7%	39.1%	0%	0%	0%
Control															
Total MH-hours/ year	16332			12034			5980			5018			2682		
Total Operation Time	1423	1167	1179	916	940	921	518	403	459	423	342	393	200	212	207
Avg. Entity Wait Time	978	899	855	748	726	685	344	344	338	289	291	286	165	166	153
Penalty Cost	**0**	**0**	**0**	**0**	**0**	**0**	**200.4**	**190.8**	**194**	**213**	**194**	**207**	**2426**	**2234**	**1923**

Four other scenarios are considered with respect to freight. Number of different type of boxes that constitute the freight mix are varied and cases with 10 and 30 different types are studied keeping all other assumptions same. Another factor varied is the range of box dimensions: 0.8 ft – 2.3 ft and 2.3 cm – 3.8 ft. This means that dimensions of all boxes constituting freight will vary within these ranges. The case and results discussed earlier had 20 different types of boxes with box dimensions ranging from 0.8 ft – 3.8 ft. Table 5, 6, 7 and 8 presents the results for cases: Number of Type of boxes is 10, Number of Type of boxes is 30, box dimensions ranging from 0.8 ft – 2.3 ft, and box dimension ranging from 2.3 ft – 3.8 ft, respectively. It is observed that number of different type of boxes does not affect the results significantly; it is the box size that can heavily impact the results. Results show that number of different types of boxes does not impact container volume utilizations as long as the dimension range of boxes is constant. This is evident from the consequent cases studied where box dimension range is varied. Freight consisting boxes with greater dimensions resulted in reduced material handling time significantly and container utilizations by 10%. Large number of boxes (around 250) is generated for low dimension range in comparison to very small number (around 35) for the same volume resulting in increased operation time. To gauge the impact of various factors (labor cost and revenue/mile) and overall strategies on the profit maximization objective function, an extensive cost and sensitivity analysis is performed and is discussed in the following section.

Table 5 Performance indicator for crossdock scenario with number of type of boxes as 10

	All Staged						Simultaneous						Direct Loading		
	Random			Zoned			Random			Zoned					
	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3
Material Handling															
Avg. Transfer Time/Entity (Min)	5.08	4.93	5.22	4.4	4.08	4.31	4.45	4.37	4.53	4.10	3.86	3.88	3.15	2.97	3.22
Avg. Sorting Time/Entity (Min)	16.17	16.55	14.71	12.69	12.07	12.23	14.94	15.06	12.91	12.12	11.45	11.36	1.5	1.5	1.5
Container Utilization															
Container Volume Utilization	90.7%	90.7%	90.5%	90.7%	90.7%	90.5%	90.7%	90.7%	90.5%	90.7%	90.7%	90.5%	72.0%	60.0%	73.0%
Number of Boxes Missed	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**17**	**19**	**6**
Average Total Boxes	**88**	**95**	**75**	**88**	**95**	**75**	**88**	**95**	**75**	**88**	**95**	**75**	**87**	**80**	**76**
Space															
Max Area utilization	57%	58%	49%	58%	57%	49%	53.4%	52.7%	41.6%	55%	52.3%	42.7%	0%	0%	0%
Control															
Total Operating-hours/ year	20761			13273			9455			6890			3155		
Total Operation Time / Outbound Trailer (Min)	1380	2193	1218	1048	1153	862	643	957	582	510	594	486	233	265	230
Avg. Entity Wait Time (Min)	934	978	707	754	731	586	441	464	333	368	377	291	178	181	161
Penalty Cost	**0**	**0**	**0**	**0**	**0**	**0**	**75**	**91**	**79**	**76**	**102**	**72**	**2109**	**2400**	**1290**

Table 6 Performance indicator for crossdock scenario with number of type of boxes as 30

	All Staged						Simultaneous						Direct Loading		
	Random			Zoned			Random			Zoned					
	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3
Material Handling															
Avg. Transfer Time/Entity (Min)	5.05	4.90	5.14	4.36	4.16	4.28	4.28	4.30	4.55	3.95	3.84	3.88	3.08	2.98	3.19
Avg. Sorting Time/Entity (Min)	15.89	15.7	14.56	12.47	12.5	11.78	14.22	14.08	12.68	11.68	12.02	10.94	1.5	1.5	1.5
Container Utilization															
Container Volume Utilization	90.7%	90.7%	90.5%	90.7%	90.7%	90.5%	90.7%	90.7%	90.5%	90.7%	90.7%	90.5%	73%	64%	74%
Number of Boxes Missed	0	0	0	0	0	0	0	0	0	0	0	0	12	14	8
Average Total Boxes	83	85	79	83	85	79	83	85	79	83	85	79	83	85	79
Space															
Max Area utilization	52%	56%	49%	51%	55%	50%	41.4%	40.2%	40.2%	41%	40.5%	40.5%	0%	0%	0%
Control															
Total Operating-hours/ year	14928			11869			6808			5785			2782		
Total Operation Time / Outbound Trailer (Min)	1119	1228	1098	879	1012	848	522	537	512	443	462	430	236	214	192
Avg. Entity Wait Time (Min)	836	830	685	676	682	575	395	387	336	335	332	293	172	170	156
Penalty Cost	0	0	0	0	0	0	89	97	81	85	94	79	1743	1711	1405

Table 7 Performance indicator for crossdock scenario with box dimension range of 0.8 ft – 2.3 ft

	All Staged						Simultaneous						Direct Loading		
	Random			Zoned			Random			Zoned					
	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3
Material Handling															
Avg. Transfer Time/Entity (Min)	6	5.54	5.98	5.48	4.62	4.86	5.62	5.19	5.66	5.14	4.52	4.67	3.1	2.97	3.29
Avg. Sorting Time/Entity (Min)	39.1	37.48	38.57	20.72	16.29	18.35	44.65	40.9	44.5	19.64	18.62	18.22	1.5	1.5	1.5
Container Utilization															
Container Volume Utilization	90.3%	90.2%	90.2%	90.3%	90.2%	90.2%	90.3%	90.2%	90.2%	90.3%	90.2%	90.2%	73.0%	63.0%	74.0%
Number of Boxes Missed	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**12**	**14**	**8**
Average Total Boxes	**266**	**250**	**275**	**266**	**250**	**275**	**266**	**250**	**275**	**266**	**250**	**275**	**266**	**250**	**275**
Space															
Max Area utilization	91%	87%	81%	90%	87%	82%	81%	78.9%	76.1%	78.6%	80.5%	72.1%	0%	0%	0%
Control															
Total Operating-hours/ year	90948			66746			42293			27239			8472		
Total Operation Time / Outbound Trailer (Min)	7291	6270	7427	5766	4476	5161	3496	2835	3429	2235	1960	2091	682	614	659
Avg. Entity Wait Time (Min)	5673	4828	5573	3665	2830	3278	2638	2220	2622	1622	1410	1567	579	511	543
Penalty Cost	**0**	**0**	**0**	**0**	**0**	**0**	**278**	**249**	**270**	**409**	**343**	**445**	**20372**	**16361**	**21111**

Table 8 Performance indicator for crossdock scenario with box dimension range of 2.3 ft – 3.8 ft

	All Staged						Simultaneous						Direct Loading		
	Random			Zoned			Random			Zoned					
	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3	door 1	door 2	door 3
Material Handling															
Avg. Transfer Time/Entity (Min)	4.86	4.7	5.16	4.61	4.48	4.72	3.81	3.92	4.41	3.60	3.70	4.10	3.09	2.97	3.11
Avg. Sorting Time/Entity (Min)	7.87	7.86	7.92	7.45	7.52	7.48	6.4	6.37	6.56	6.07	6.32	6.2	1.5	1.5	1.5
Container Utilization															
Container Volume Utilization	80.4%	79.1%	80.4%	80.4%	79.1%	80.4%	80.4%	79.1%	80.4%	80.4%	79.1%	80.4%	68%	60%	66%
Number of Boxes Missed	0	0	0	0	0	0	0	0	0	0	0	0	12	14	8
Average Total Boxes	35	36	37	35	36	37	35	36	37	35	36	37	35	36	37
Space															
Max Area utilization	44%	43%	43%	44%	43%	43%	34%	34.5%	39.6%	35%	35.8%	40.8%	0%	0%	0%
Control															
Total Operating-hours/ year		4658			4381			2843			2891			1395	
Total Operation Time / Outbound Trailer (Min)	413	324	338	369	308	334	272	172	212	251	165	205	136	96	90
Avg. Entity Wait Time (Min)	235	229	252	220	219	237	123	129	141	116	124	134	72	74	70
Penalty Cost	0	0	0	0	0	0	43	43	41	42	43	46	299	313	387

4.2 Cost and Sensitivity Analysis

To get idea of how the strategies under examination affect the cost and revenue of a crossdock operation, the annual profits generated in each of the above cases are calculated. Parameters such as labor cost, building cost per square foot, and revenues per mile are key inputs in calculating setup and operational cost of a crossdock facility. Sensitivity analysis over a +/-40% range is performed to examine the impact of this variation. This is also helpful in representing business of different sizes in terms of cost and miles covered per year. Parameters assumed during these calculations are representative of the Midwest region. Labor cost is estimated to be $20/hr, including health care and financial add-ons to the basic pay, based on a typical job description of a forklift driver in a warehousing company in the Midwest region (Aerotek, 2005). Number of miles per year and revenue per mile are assumed to be 150,000 and $3.8 per mile respectively (Thompson, 2004 and Hannon, 2005). Annualized capital cost and operating cost for one material handling unit is estimated to be $5460/year and $31/hr respectively (Noble and Tanchoco, 1993). The price per square foot of the building is estimated to be $70 (Charlotte Business Journal, 2005). Total cost of the building is spread over a period of 10 years to find an annualized cost. Table 4 lists the profit calculation for the different scenarios that are considered as the base case for the sensitivity analysis. For the base case value for Slack and Number of Type of boxes is 3 and 10, respectively. Box dimensions for the base case fall in the range of 0.8 ft – 3.8 ft.

Table 9 Annual profit calculation for the base case scenarios

Scenario	Annual Profits
Direct Loading	78342
Case 1 - All Staged – Random Staging	-74958
Case 2 - All Staged – Zoned Staging	11002
Case 3 - Simultaneous Loading – Random	98362
Case 4 - Simultaneous Loading – Zoned	131482

It is observed that inspite of good profit figures for the Direct Loading strategy, Simultaneous Loading with Zoned Staging strategy (Case 4) yields the highest profits. Case 4 strikes a balance between the amount of staging and the container utilization for the environment under consideration. This might not give highest profits if certain parameters are changed such as freight mix or the size and nature of business. Nature of trucking business can be classified based on the distance a shipment is transported: short haul (shipment transported to between 50 – 700 miles) and long haul (shipment transported to between 200 – 1000 miles or more). For example if the nature of business is of short haul type with single destinations, investing time and money on staging and better container utilizations might not justify the returns. It might be more economical to run another trip than doing extra material handling. It can be seen in the case where freight consists of boxes with smaller dimensions (0.8 ft – 2.3 ft) resulting in large material handling time, which offsets the savings due to better utilization. Results in Table 11 show Simultaneous Loading with Zoned strategy loses 7 times more money that the Direct Loading case. Thus later strategy is preferred in this specific case. Results for direct loading can be counter intuitive due to the minimal material handling required in the direct loading case, but increased number of miles and reduced container utilization offsets this saving. Although a direct loading strategy is close to an ideal case of crossdocking, it can be limiting in a real LTL operating environment. LTL requires carrying freight for long distances to multiple destinations on most occasions. Shipment to multiple destinations requires packages to be loaded in a desired sequence. Direct Loading lacks ability to rearrange packages while loading, which might render unloading of required packages at different destinations difficult and costly. A Direct loading strategy can be used effectively for business that involves short hauls to single destinations. The All Staged strategy produced the lowest profits among all strategies studied. This is attributed to increased material handling and total operation time without resulting in better performance than the Simultaneous Loading strategy. However, this strategy can be useful under environments where some value added activities take place during the staging operation such as labeling or consolidation, which requires packages to be staged for longer durations. Table 10 presents the profit calculations for scenarios considered under different conditions. All dimensions presented in Table 10 are in feet.

Table 10 Annual profit figures for all cases studied

Scenario	**Annual Profits**				
	No. of Box Types-20 Dim 0.8-3.8	No. of Box **Types-10** Dim 0.8-3.8	No. of Box **Types-30** Dim 0.8-3.8	No. of Box Types-20 **Dim .08-2.3**	No. of Box Types-20 **Dim 2.3-3.8**
Direct Loading	$234,840	$210,177	$237,440	$55,350	$274,737
Case 1 - All Staged – Random Staging	-$68,610	-$202,489	-$21,666	-$2,380,566	$236,284
Case 2 - All Staged – Zoned Staging	$64,628	$29,639	$73,163	-$1,630,304	$244,871
Case 3 - Simultaneous Loading – Random	$200,036	$147,997	$230,054	-$872,261	$292,549
Case 4 - Simultaneous Loading – Zoned Staging	$251,372	$227,512	$261,767	-$405,587	$297,261

Results show that profits increase with increased variety of boxes as long as the dimension range of boxes remain constant. This is because increased variety reduced number of boxes generated marginally reducing total operation time. The biggest impact and gain is observed with the variation in box size. Freight with large dimension boxes showed higher profits due to very low number of boxes for the same 90% cube volume inspite of drop in container utilization by 10%. Freight with small dimension boxes resulted in loss because of large number of boxes comprising the same 90% cube volume resulting increased material handling time, total operation time and reduced profits. Detailed profit calculations and individual sensitivity graphs for each scenario of base case are produced in Appendix. Annual profits are further analyzed for changes in 3 key variables: revenue/mile, price/square foot of facility cost, and number of miles/year. Table 5 list these input variable varying from +40% to -40%. A pairwise comparison is conducted for each case with respect to the Direct Loading case in order to analyze the impact the variation has on the difference in annual profits generated (Figure 15, 16, 17 and 18).

Table 11 Sensitivity analysis

Deviation	**-40%**	**-30%**	**-20%**	**-10%**	**0%**	**10%**	**20%**	**30%**	**40%**
Revenue/Mile	2.28	2.66	3.04	3.42	3.8	4.18	4.56	4.94	5.32
Labor Cost/hr	12	14	16	18	20	22	24	26	28
$/sq. foot	42	49	56	63	70	77	84	91	98

The sensitivity graphs (Figure 15, 16, 17 and 18) show that revenue/mile is the most sensitive input variable that affects profit. Cube utilization is the key variable that directly impacts revenue. Better utilization means more freight hauled per trailer or the same freight hauled in fewer trips, which directly increases revenues. Revenue/mile is also affected by the various business decisions such as product costing, accounting for varying fuel cost, etc., which are out of the scope of this study. Labor cost/hr is the second most sensitive factor and can directly be related to the total operating hours because the greater the material handling and waiting time for packages before they get loaded results in higher labor cost. Although facility price per square foot is not as sensitive as other variable it can still easily offset profit figures by the sheer size of its number depending on how this fixed cost is dispersed and accounted for in the revenue calculations. It is clearly visible from the sensitivity plots that strategy of Simultaneous Loading with Zoned Staging out performs all other strategies (Figure 18).

Figure 15 Sensitivity analysis - Random Staging with All Staged vs. Direct Loading

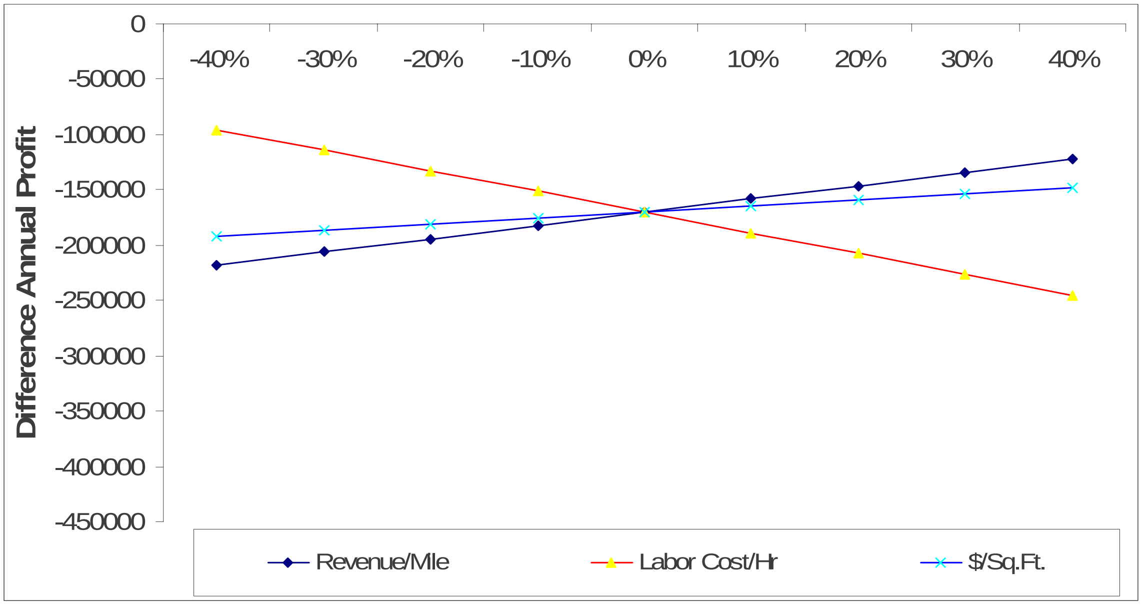

Figure 16 Sensitivity analysis - Zoned Staging with All Staged vs. Direct Loading

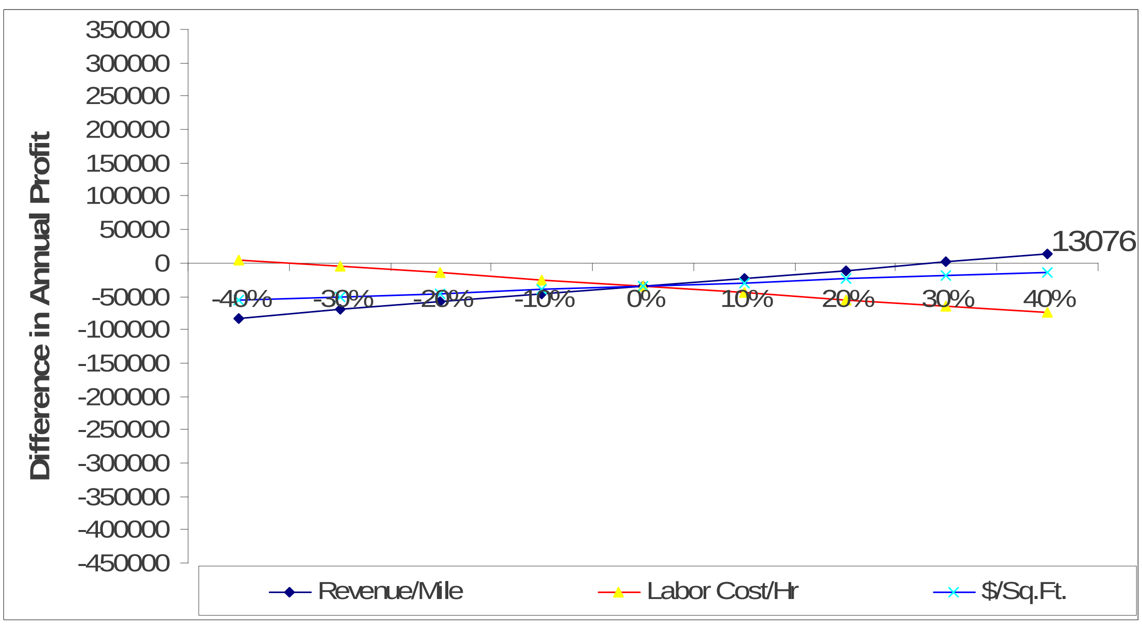

Figure 17 Sensitivity analysis - Random Staging with Simultaneous Loading vs. Direct Loading

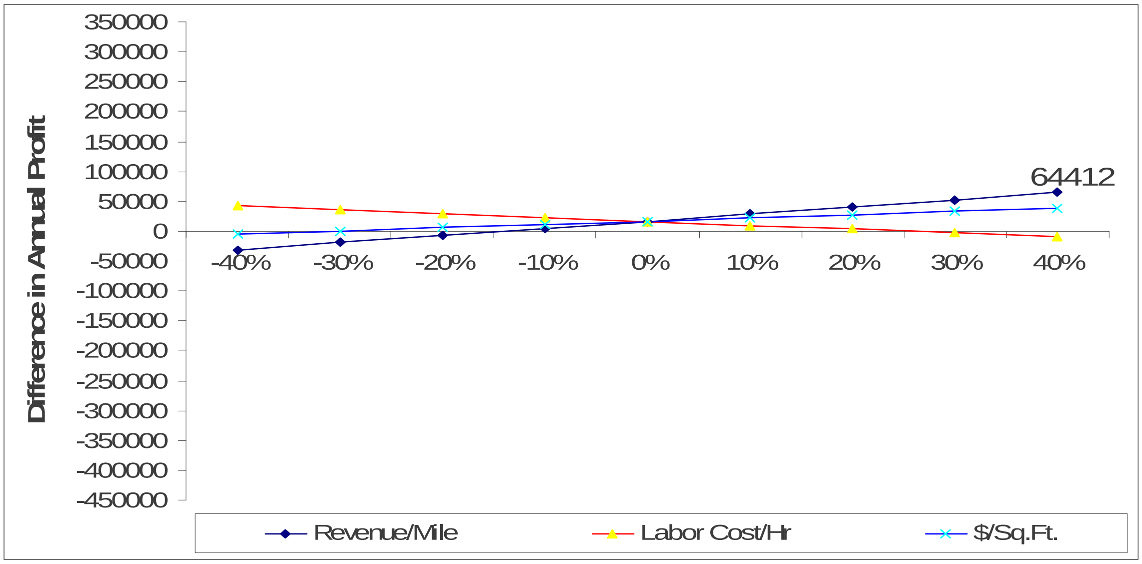

Figure 18 Sensitivity analysis - Zoned Staging with Simultaneous Loading vs. Direct Loading

4.3 Summary

A simulation model was build using Arena® to capture and analyze five different staging scenarios in a Less Than Truckload crossdock environment. Performance of four staging strategies, random and zoned in cases where all freight is staged before loading and/or some freight is loaded while staging was studied. Outbound container volume utilization, staging floor space utilization and material handling time are used as indicators to identify the best possible strategy in the assumed environment. Results are further quantified using a profit function. The Analysis suggests that loading outbound trailer simultaneously while using a zoned staging strategy performs better than any other strategy considered during the study. It was also observed that the freight consisting of larger dimension sized boxes improves profit inspite of lower container volume utilization.

Chapter 5 CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

5.1 Contribution Made by This Research

The contributions made by this research are in three areas:

1. Analysis of staging operations in a LTL crossdock facility

2. Development of simulation model to imitate staging operation

3. Integration of an optimal container loading heuristic with the simulation model.

The most significant contribution is development of model that can simulate the staging floor space of a crossdock facility and also integrates the output of an optimal loading heuristic allowing for different staging strategies to be tested. The simulation model also considers other staging components such as material handling equipment, delays caused due to waiting and vehicle congestion. This can be useful as an off-line tool to plan the staging space and outbound trailer loading operations with already available information about the incoming freight. Results from this research can serve as guidelines for selecting an appropriate staging strategy depending on different conditions.

5.2 Conclusion

The staging of loads in a crossdock environment is a reality that needs to be planned for in order to maximize profits. This research has continued the work of Taylor and Noble (2004) examining specific staging strategies and their impact on overall system performance. The Results support the use of a Zoned Staging strategy to deal with loads that can not be immediately loaded into an outbound trailer. The inevitable need for staging at some point during operations precludes choosing a Direct Loading strategy, even though it reduces material handling to almost half and floor space requirement to the minimum possible. A Random strategy with simultaneous loading is a reasonable good representation of staging strategy in practice, except that the strategy uses loading heuristic for loading outbound trailer. A Zoned strategy with simultaneous loading utilizes the freight information already in hand to organize and cut down by almost 21% of total operation time from the current staging practices. Zoned Strategy also helps utilizing the optimal loading heuristic with reduced handling and operating time, to increase container utilization to around 90% in contrast to 69% in case of direct loading, thus sharply increasing revenues. In terms of container utilization Direct Loading closely represent the container utilization in current practice. 69% container utilization can be considered quite liberal in current practices considering in the majority of cases loading is based on human judgment. Results also showed that freight with larger dimension boxes reduced total operation time due to fewer number of boxes accounted for the same cube volume of 90%, inspite of decrease in container utilization by 10%.

5.3 Area of Future Extensions

There are many opportunities to expand this research.

1. The staging strategies need to be further examined for bigger crossdock having more number of doors. Crossdocks with around 40 – 120 doors should be considered to build on these conceptual staging strategies and to study their impact in a more complex environment. Testing these strategies for more than one pair of door in combination can results in effective space utilization and material handling.

2. Out bound demand scenarios of High Demand/Close (Assumes that some outbound trailers have much more flow than others and places these trailers at the best dock doors) and High Demand/Disbursed (Assumes that some outbound trailers have much more flow than others but places these trailers at disbursed outbound locations) by Taylor and Noble (2004) are another factors to be considered.

3. Different freight mix should be considered and ways in which the available staging space should be allocated to accommodate it. For example staging areas of two outbound doors can be depending on the freight mix and demand flow.

4. A constraint with respect to the number of trailers and their size should be considered as part of the objective function to represent the fleet size and composition. Variable can be useful in deciding on an optimal fleet size and composition for a specific business size and set up.

5. Multivariate analysis should be used as a decision making tool to set key identified operating parameters.
6. Dock vehicles should be allowed to carry more than one freight unit when it is advantageous.
7. Allowing for the stacking of freight on top of one another is another desirable capability to explore.

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APPENDIX

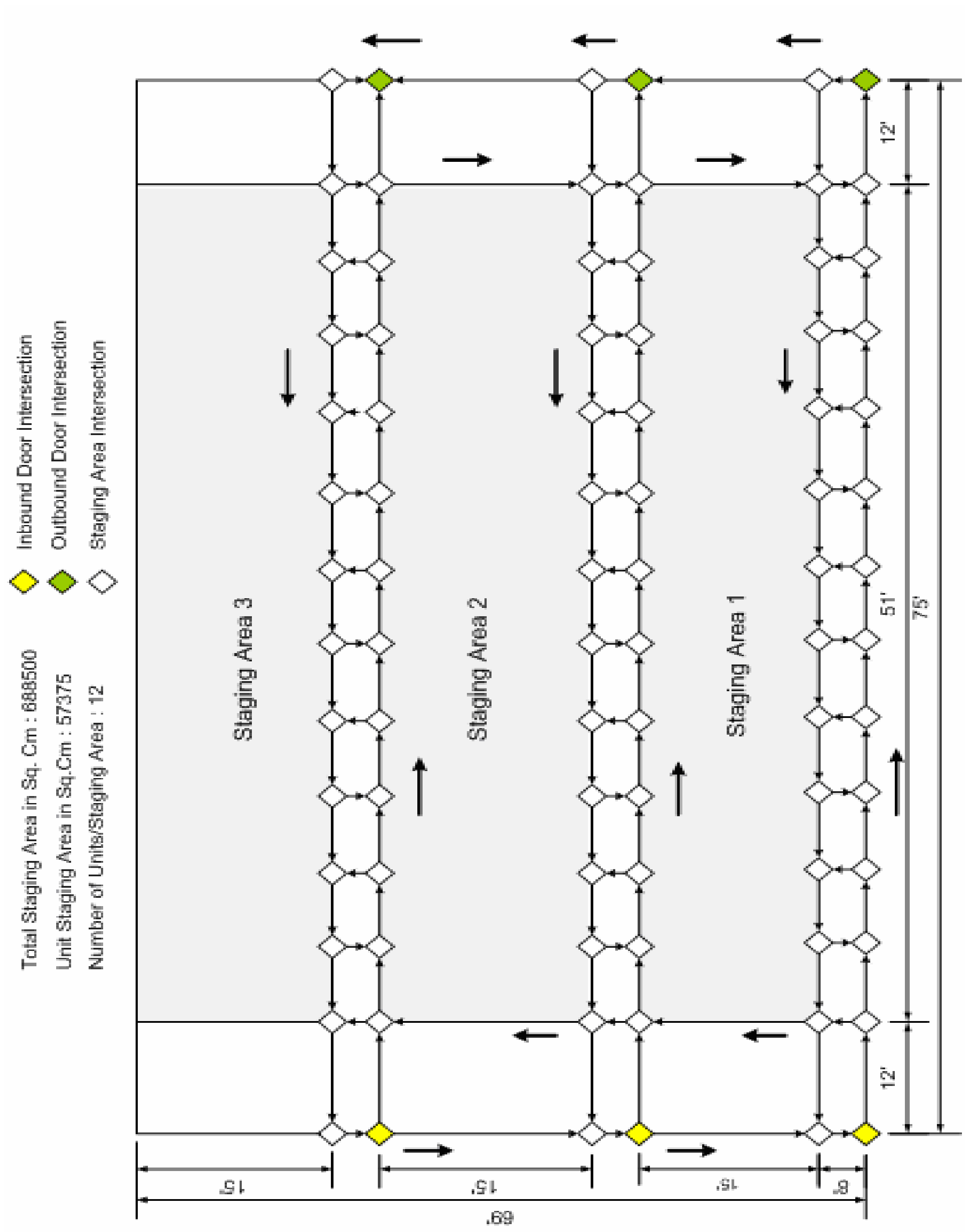

Figure 19 Guided network for transporting vehicles

forklit utilization = 1

Annualized capital cost(spread over 10 yrs)

	Profit	=	Cube Utilization	x	Revenue/Mile	x	Number of miles/Yr.	-	(MH Equip. operating Cost	+	Equip. Fixed Cost	+	MH Operating (hrs)	x	Labor cost/hr)	-	($/Sq Ft.	x	Dock area)	Annuity
									11											
Case - Direct	234840	=	0.69	x	3.8	x	150000	-	29502	+	16380	+	2682	x	20	-	70	x	5175	58938
Case - 1	-68610	=	0.9	x	3.8	x	150000	-	179652	+	16380	+	16332	x	20	-	70	x	5175	58938
Case - 2	64628	=	0.9	x	3.8	x	150000	-	132374	+	16380	+	12034	x	20	-	70	x	5175	58938
Case - 3	200036	=	0.9	x	3.8	x	150000	-	84326	+	16380	+	7666	x	20	-	70	x	5175	58938
Case - 4	251372	=	0.9	x	3.8	x	150000	-	66110	+	16380	+	6010	x	20	-	70	x	5175	58938

Avg. Miles/Wk	=	2308 miles/wk	Case - Direct Loading
Avg. Revenue/Mile	=	$2.4/Mile	Case - 1: All Staged - Random Staging
Labor Cost	=	$20/hr	Case - 2: All Staged - Zoned Staging
Annualized MH equipment cost	=	5460/yr	Case - 3: Simultaneous Loading - Random Staging
MH equipment operating cost	=	$11/hr	Case - 4: Simultaneous Loading - Zoned Staging
Land cost per square foot	=	$70/Sq.Ft.	

Figure 20 Profit Calculations for the base case of each scenario

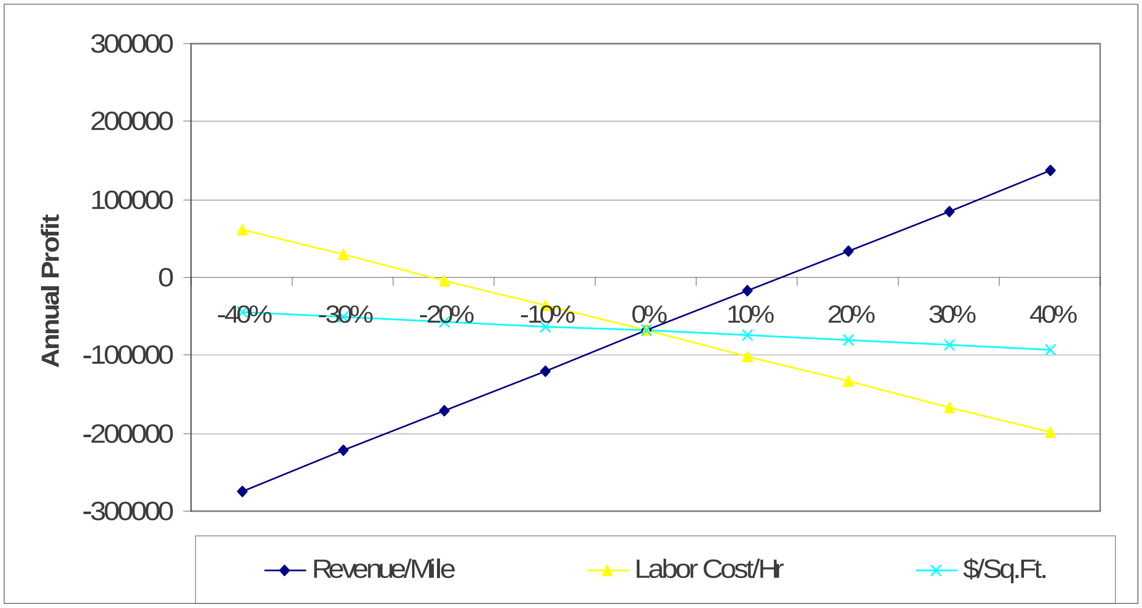

Figure 21 Sensitivity analysis for case – All Staged with Random Staging

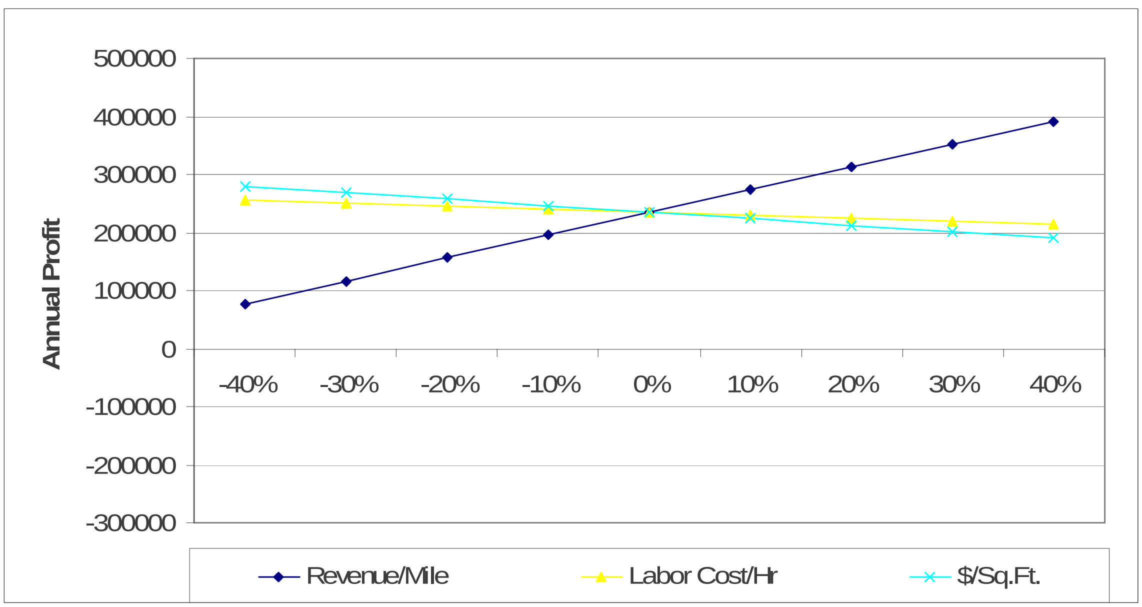

Figure 22 Sensitivity analysis for case – Direct Loading

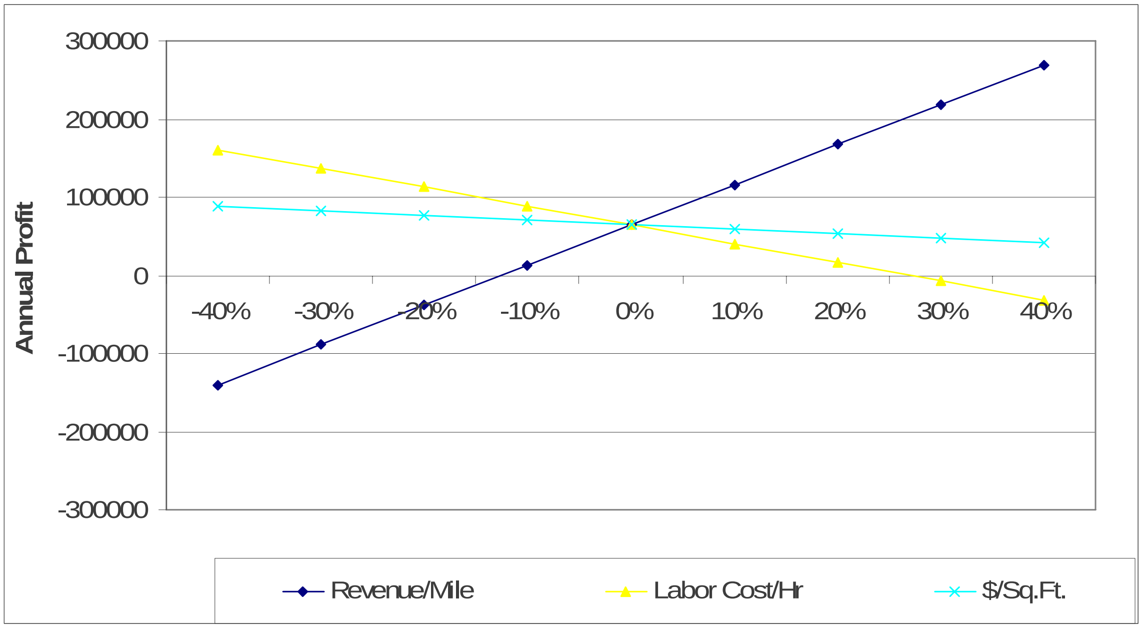

Figure 23 Sensitivity analysis for case - All Staged with Zoned Staging

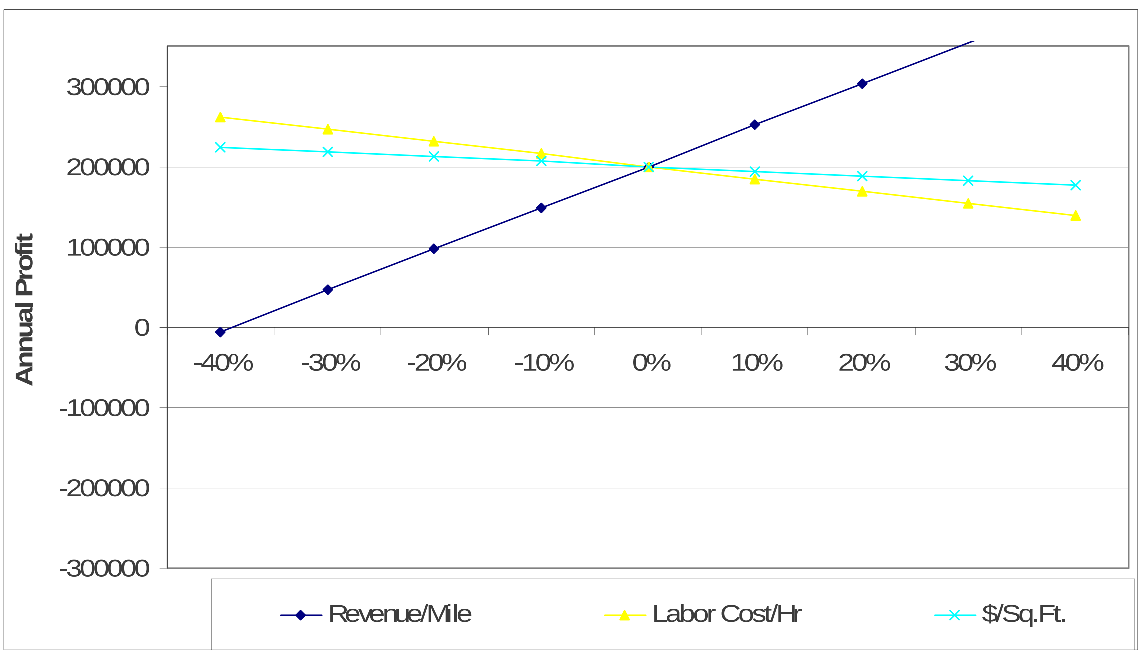

Figure 24 Sensitivity analysis for case - Simultaneous Loading with Random Staging

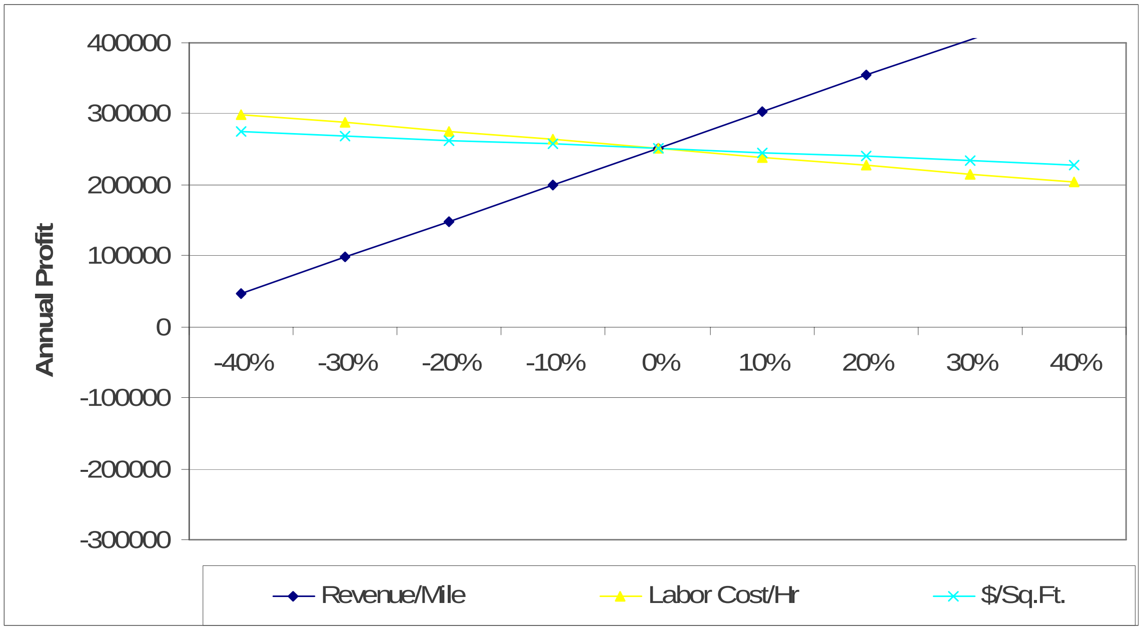

Figure 25 Sensitivity analysis for case – Simultaneous Loading with Zoned Staging

Half-width at 95% confidence interval

For Case-4: Simultaneous Loading with Zoned Strategy

Transfer Time:

1. Door 1 entity: 0.12
2. Door 2 entity: 0.06
3. Door 3 entity: 0.07

Material Handling Time:

4. Door 1 entity: 0.89
5. Door 2 entity: 1.19
6. Door 3 entity: 0.98

Staging Area Utilization:

7. Door 1 area: 0.01
8. Door 2 area: 0.00
9. Door 3 area: 0.01

Total Time:

10. Door 1 entity: 37.20
11. Door 2 entity: 35.20
12. Door 3 entity: 32.37