Minimizing Product Damage through Optimal Truck Schedule in a Cross Docking System

- 크로스도킹 시스템 하에서의 최적 트럭 일정계획 수립에 따른 제품 손상의 최소화에 대한 연구 -

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Abstract

크로스도킹은 물류센터의 운영 개념으로써 입고트럭에 의해 배달된 물품이 재고로써 보관됨이 없이 즉시 고객의 수요에 따라 재분류되어 출고트럭에 적재되어 고객에게 배달되는 프로세스로 구성된다. 본 연구에서는 임시보관 장소를 보유한 크로스도킹 시스템의 총 운영시간을 최소화하기 위한 입고 트럭과 출고 트럭의 일정계획 수립을 위한 수학적 모델을 개발하였다. 본 연구에서 개발한 모델의 적용으로 물류센터 내에서의 자재 취급 빈도 및 시간이 감소하여 제품 손상을 최소화 시키는 효과가 기대된다.

Keyword : Distribution Center, Cross Docking, Optimization, Minimization, Total Operation Time, Truck, Scheduling, Product Damage.

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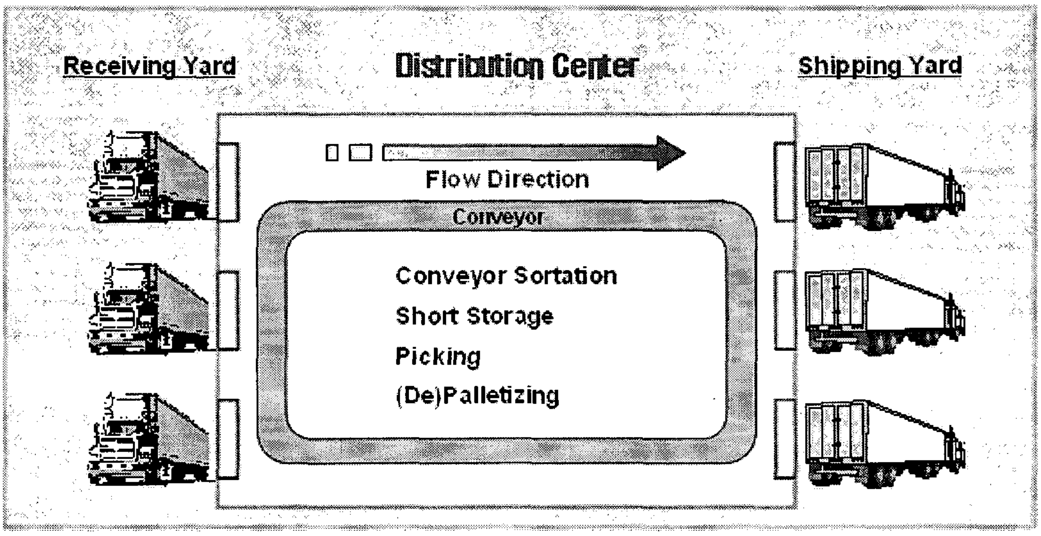
1. Introduction

Cross docking is a material handling and distribution concept in which items move directly from receiving dock to shipping dock, without being stored in a warehouse or distribution center. < Figure 1 > shows the typical cross docking distribution facility. The advantages of cross docking systems include reduced inventory, increased inventory turn, better control of the distribution operation, and increased customer satisfaction.

Cross docking systems have two characteristics: hardware and software. Since cross docking systems are highly automated, it is necessary to have appropriate equipment. Meanwhile, software keeps the cross docking system running smoothly. This includes truck scheduling system, product tracking systems, and information transfer with vendors.

Both hardware and software are important for cross docking success. Hardware such as material handling devices, sortation systems and computers has been continuously developed. Therefore, most of the required hardware for a cross docking system is available today. Meanwhile, software is relatively less developed, though it is as important as hardware to cross docking success.



< Figure 1 > Typical Cross Docking Distribution Facility

To prevent the lack of operational management from becoming a barrier to successful cross docking implementation, the appropriate software should be implemented simultaneously. In this research, one of operational management areas was studied. The objective of this research is to find the best truck spotting

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sequence for both receiving and shipping trucks in order to minimize total operation time where a temporary storage area is available in a distribution center. The allocations of the items from receiving trucks to shipping trucks are decided simultaneously as well as the spotting sequence of the receiving and shipping trucks.

2. Literature Review

In many warehouses or distribution centers, cross docking systems are implemented successfully. Nevertheless, relatively few research papers or articles are published on cross docking systems. The first technical paper found on cross docking systems was presented by Rohrer[1]. He discussed modeling methods and issues as they apply to cross docking systems. His paper also described how simulation helps ensure success in cross docking systems by determining optimal hardware configuration and software control, as well as establishing failure strategies before cross docking problems are encountered.

Yu[3] presented two solution approaches in order to find the best truck spotting sequence for both receiving and shipping trucks to minimize total operation time of the cross docking system. The first approach was the branch and bound method. For the branch and bound approach, the new branching strategy was developed in order to make the receiving truck sequence and the shipping truck sequence. The second approach was the tabu search method. He found that the tabu search solutions were close to the optimal solutions.

Another Yu's paper[4] developed two mathematical models in order to find the best truck spotting sequence for both receiving and shipping trucks where a temporary storage area is not available in a distribution center. The objective of the first mathematical model is to minimize makespan. For this model, the number of variables and constraints grow exponentially as the number of receiving trucks, number of shipping trucks, and number of product types increase. Computationally, the approach is not effective for solving the test problems, including the smallest one. A different view point to the problem led to the development of a second integer program model. The objective of the second mathematical model is to minimize the number of matching pairs of the receiving and shipping trucks. A receiving truck and a shipping truck are said to form a matching pair if there is item exchange between them. With the objective of minimizing the number of matching pairs, the number of variables and constraints are dramatically decreased.

3. Model Description

The cross docking system of this study is assumed to have only one receiving dock and one shipping dock, respectively. In the distribution center, there is a temporary storage area in front of the shipping dock. If a product that arrives at the shipping dock does not need to be loaded into shipping truck currently at the dock, the product can be stored in the temporary storage until the appropriate shipping truck comes into the shipping dock. In this model, it is also assumed that both the receiving and the shipping trucks must stay in docks until they finish their task once they come into docks. Therefore, a receiving truck cannot leave the receiving dock until all of its products are unloaded onto the receiving dock. Similarly, a shipping truck cannot leave the shipping dock until all of its needed products are loaded.

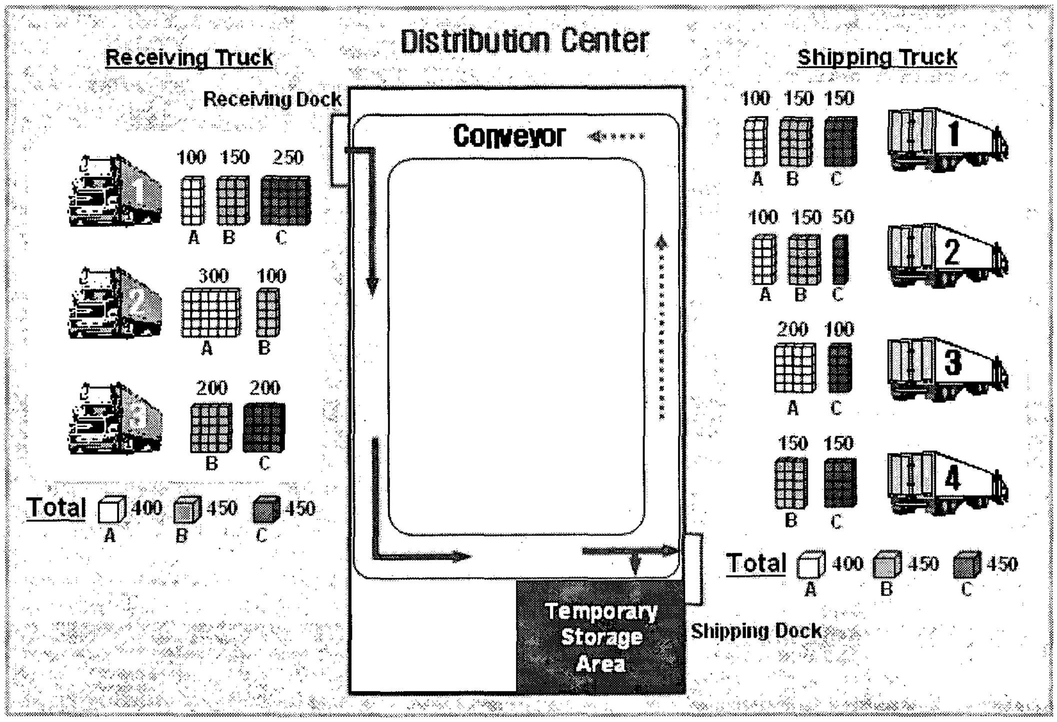
The cross docking system of this study is assumed to operate as follows:

1. Receiving trucks arrive at the receiving docks and unload products onto the receiving dock.
2. Products move from the receiving dock to the shipping dock on a conveyor.
3. Shipping trucks load products from shipping docks and leave shipping docks.

In addition to the operation conditions above, the following assumptions are applied to the model.

1. All receiving and shipping trucks are available at time zero.
2. The total number of receiving products for each type of products is the same as the total number of shipping products for each type of products.
3. The capacity of temporary storage is unlimited.
4. The operations inside the distribution center such as scanning and sorting operations are not considered.
5. The following information is assumed to be previously known.
   - i) Product types and the number of products loaded in a receiving truck.
   - ii) Product types and the number of products needed for a shipping truck.
   - iii) Loading and unloading times for the products.
   - iv) Moving times of products from a receiving dock to a shipping dock.
   - v) Truck change time of receiving trucks and shipping trucks, respectively.

< Figure 2 > shows the example of the cross docking system studied in this research. In this example, there are three receiving trucks, four shipping trucks and three types of products.



< Figure 2 > Example of Cross Docking System studied in This Research

4. Model Development

For the mathematical model of the cross docking problem, it is assumed that unloading time from a receiving truck and loading time into a shipping truck are the same for all products and that it takes one unit of time in duration to unload or load one unit of product. Additionally, it is assumed that all operations can be carried out simultaneously. In other words, unloading operations from a receiving truck, loading operations into a shipping truck, or receiving and shipping truck changes can be carried out at the same time. With the above assumptions, the following mathematical model was developed for the problem with the objective of minimizing total operation time of a cross docking operation.

<u>Notations</u>

Continuous Variables:

T = Total operation time,
c_i = Time at which receiving truck i enters the receiving dock,
F_i = Time at which receiving truck i leaves the receiving dock,
d_j = Time at which shipping truck j enters the shipping dock,
L_j = Time at which shipping truck j leaves the shipping dock,

Integer Variables:

x_{ijk} = Number of units of product type k which transfer from receiving truck i to shipping truck j,

Binary Variables:

$$v_{ij} = \begin{cases} 1, & \text{If any product transfer from receiving truck } i \text{ to shipping truck } j \\ 0, & \text{Otherwise} \end{cases},$$

$$p_{ij} = \begin{cases} 1, & \text{If receiving truck } i \text{ precedes receiving truck } j \text{ in the receiving truck sequence} \\ 0, & \text{Otherwise} \end{cases},$$

$$q_{ij} = \begin{cases} 1, & \text{If shipping truck } i \text{ precedes shipping truck } j \text{ in the shipping truck sequence} \\ 0, & \text{Otherwise} \end{cases},$$

Data:

R = Number of receiving trucks in the cross docking model,

S = Number of shipping trucks in the cross docking model,

N = Number of product types in the cross docking model,

r_{ik} = Number of units of product type k that is initially loaded in receiving truck i,

s_{jk} = Number of units of product type k that is initially needed for shipping truck j,

D = Truck change time,

V = Moving time of products from the receiving dock to the shipping dock,

M = Big number.

Mathematical Model for Cross Docking System

Min $\quad T$

Subject to

$$T \geq L_j, \quad \textit{for all } j \qquad (1)$$

$$\sum_{j=1}^{S} x_{ijk} = r_{ik}, \quad \textit{for all } i, k \qquad (2)$$

$$\sum_{i=1}^{R} x_{ijk} = s_{jk}, \quad \textit{for all } j, k \qquad (3)$$

$$x_{ijk} \leq M v_{ij}, \quad \textit{for all } i, j, k \qquad (4)$$

$$F_i \geq c_i + \sum_{k=1}^{N} r_{ik}, \quad \textit{for all } i \qquad (5)$$

$$c_j \geq F_i + D - M(1 - p_{ij}), \quad \textit{for all } i, j \textit{ and where } i \neq j \qquad (6)$$

$$c_i \geq F_j + D - Mp_{ij}, \quad \text{for all } i, j \text{ and where } i \neq j \tag{7}$$

$$p_{ii} = 0, \quad \text{for all } i \tag{8}$$

$$L_j \geq d_j + \sum_{k=1}^{N} s_{jk}, \quad \text{for all } j \tag{9}$$

$$d_j \geq L_i + D - M(1 - q_{ij}), \quad \text{for all } i, j \text{ and where } i \neq j \tag{10}$$

$$d_i \geq L_j + D - Mq_{ij}, \quad \text{for all } i, j \text{ and where } i \neq j \tag{11}$$

$$q_{ii} = 0, \quad \text{for all } i \tag{12}$$

$$L_j \geq c_i + V + \sum_{k=1}^{N} x_{ijk} - M(1 - v_{ij}), \quad \text{for all } i, j \tag{13}$$

$$\text{all variables} \geq 0.$$

Constraint (1) makes total operation time equal the time the last scheduled shipping truck leaves the shipping dock. *Constraint (2)* ensures that the total number of units of product type k that transfer from receiving truck i to all shipping trucks is exactly the same as the number of units of product type k that was initially loaded in receiving truck i. Similarly, *constraint (3)* ensures that the total number of units of product type k that transfer from all receiving trucks to shipping truck j is exactly the same as the number of units of product type k needed for shipping truck j. *Constraint (4)* just enforces the correct relationship between the x_{ijk} variables and the v_{ij} variables.

Constraints (5) to *(7)* make a valid sequence for arriving and departing times for the receiving trucks based on their order. *Constraint (8)* ensures that no receiving truck can precede itself in the receiving truck sequence. Similar to *constraints (5)* to *(7)* for receiving trucks, *constraints (9)* to *(11)* function in a similar manner for the shipping trucks. Similar to *constraint (8)*, *constraint (12)* ensures that no shipping truck can precede itself in the shipping truck sequence. *Constraint (13)* connects the leaving time for a shipping truck to the arriving time of a receiving truck if any products or items are transferred between the trucks.

The number of decision variables for this mathematical model is $RS(N+3)+2(R+S)+1$. The decision variables consist of $3RS$ of binary variables, RSN of integer variables and $2(R+S)+1$ of continuous variables. The number of constraints is $2(R^2+S^2)+R(S+N)+S(RN+N+1)$, including $2(R^2+S^2)+R(S-1)$ of inequality constraints and $(R+S)(N+1)+RSN$ of equality constraints.

5. Implementation and Results

Example set presented in < Figure 2 > was applied to the mathematical model and solved by LINDO software. As mentioned in Section 3, the example problem has three receiving trucks, four shipping trucks, and three product types. < Figure 2 > was summarized and represented in < Table 1 > and detailed information about each receiving truck and shipping truck can be found in < Table 1 >.

< Table 1 > Example Set to Illustrate Mathematical Programming Model

Receiving Truck

Truck	Product	Quantity
1	A	100
	B	150
	C	250
2	A	300
	B	100
3	B	200
	C	200

Shipping Truck

Truck	Product	Quantity
1	A	100
	B	150
	C	150
2	A	100
	B	150
	C	50
3	A	200
	C	100
4	B	150
	C	150

For this example problem, there are a total of 87 variables and 123 constraints. In order to apply the mathematical model to the problem, it is assumed that truck change time(i.e. D in a mathematical model notation) takes 100 time units and moving time of products from the receiving dock to the shipping dock(i.e. V in a mathematical model notation) takes 150 time units. The solution obtained for the example problem is presented in < Figure 3 >. As shown in < Figure 3 >, total operation time for this problem is 1750 time units. The best receiving truck sequence is 1→2→3 and the best shipping truck sequence is 1→3→2→4. Detailed information about product assignments from receiving trucks to shipping trucks as well as docking times and leaving times of receiving and shipping trucks are also represented in < Figure 3 >.

For this example problem if the receiving truck sequence is 1→3→2 and shipping truck sequence is 3→1→2→4, then total operation time becomes 2650 time units. In this case, total operation time takes 51% more than the optimal solution.

Optimal Solution

Total Operation Time : 1750 Truck Schedule: Receiving Truck 1→2→3
Shipping Truck 1→3→2→4

◆ Product Assignment

Receiving Truck	Shipping Truck	Product	Quantity
1	1	A	100
		B	150
		C	150
1	3	C	100
2	3	A	200
2	2	A	100
		B	100
3	2	B	50
		C	50
3	4	B	150
		C	150

◆ Receiving Truck Schedule Time

Receiving Truck	Docking Time	Leaving Time
1	0	500
2	600	1000
3	1100	1500

◆ Shipping Truck Schedule Time

Receiving Truck	Docking Time	Leaving Time
1	0	550
3	650	950
2	1050	1350
4	1450	1750

< Figure 3 > Optimal Solution of the Example Problem

Therefore, it is evident that scheduling receiving and shipping truck sequences affects to total operation time greatly and therefore scheduling good receiving and shipping truck sequences is important to enhance the cross docking operation efficiency.

6. Conclusion

Although both hardware and software are important for cross docking success, software is relatively less developed. In this research, one of cross docking software areas was studied. The objective of this research is to find the best truck spotting sequence for both receiving and shipping trucks in order to minimize total operation time where a temporary storage area is available in a distribution center.

In this research, a mathematical model was developed to solve the cross docking problem. The developed mathematical model is able to find the global optimal solution, but is not effective for solving large size problem because of its computational intensity. However, the developed mathematical model can be used as a benchmarking solution if heuristic methods are developed for a cross docking problem in the future.

7. References

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