ISSN (e): 2250 – 3005 || Volume, 06 || Issue, 10 || October – 2016 ||
International Journal of Computational Engineering Research (IJCER)

The Effects of Crossdock Shapes on Material Handling Costs

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ABSTRACT
Layout design for the cross-docking centers is one of the strategic decision level and critical issue because of its directly effects on material flow efficiency in these areas. At this stage, the size and shapes of the cross-docking center have to be determined by taking into account material handling operations. In this study, the effects of the crossdock shapes on material handling cost from inbound doors to outbound doors are analyzed for different type of cross-docking center layouts. In this content, the shapes of I, L, T, and U for cross-docking centers are considered. In order to identify the best shape of the cross-docking centers, a mathematical model is formulated based on the truck-door assignment problem in cross-docking centers. In computational studies, the proposed mathematical model is performed for different sized problems considering the four building shapes and the best building shape is identified by comparing the total material handling costs.

Keywords:*Cross-docking, material handling, mathematical modelling, layout plan*

I. INTRODUCTION

The efficiency of transportation is one of the most important factor for supply chain management. For this reason, many companies develop various strategies to boost customer satisfaction and bring down the total costs. Cross-docking is one of these strategy and has a great potential to bring considerable reduction in the distribution cost by eliminating the redundant storage [1, 2].

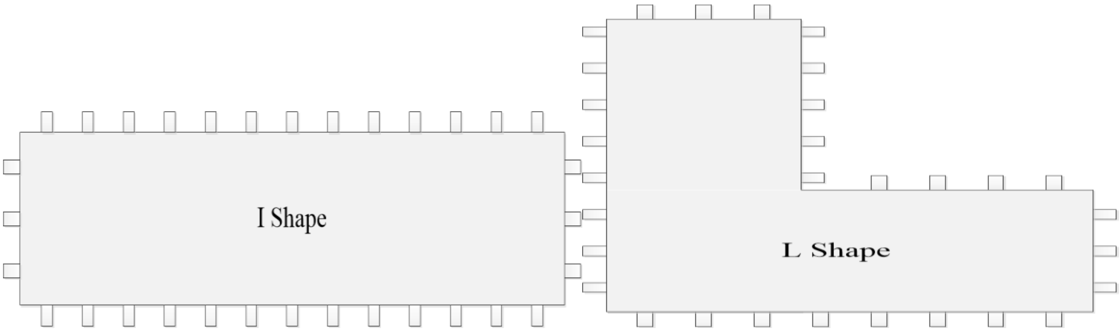
The cross-docking system can be described as the process of moving products from suppliers to customers through cross-docking centers without storing products for a long time. In the cross-docking network, the products are unloaded from incoming trucks at inbound doors and consolidated according to their destination. After the consolidation operations products are reloaded to outgoing trucks at outbound doors for distribution. In short term decision level of the cross-docking system, the operational plans such as transportation, truck-door assignment, consolidation, product placement, scheduling, etc. play an important role to increase efficiency of the system [3, 4]. In order to minimize total material handling costs in cross-docking centers, this study considers the truck-door assignment problem of cross-docking system with product placement operations which is called as truck-door assignment and product placement problem in cross-docking center. The truck-door assignment problem in cross-docking centers can be described as finding the optimal assignment plan of incoming and outgoing trucks to inbound and outbound doors, respectively [1, 4, 5].

The earliest study for the truck-door assignment problem is presented by Tsui and Chang [6] where a bilinear program is proposed for assigning the origins and destinations to dock doors. The authors also proposed a simple heuristic approach to solve problem. The same authors later proposed an improved version of the heuristic approach [7]. Bartz-Beielstein et al. [8] developed a model which is derived from real freight forwarder's data and solved by using an evolutionary multi-objective algorithm. Cohen and Keren [9] expanded the truck-door assignment problem by allowing the freight splitting for capacitated trailers and proposed a heuristic algorithm to solve problem. Oh et al. [10] considered the truck-door assignment problem for a real life case of a mail distribution center. The problem is formulated as a non-linear mathematical model and solved by two heuristic methods proposed by the authors. Bozer and Carlo [11] studied the static and dynamic truck-door assignment problem, in which the outbound doors are fixed over the planning horizon for static door assignment problem while the assignment plans are re-formed every day for dynamic doors assignment problem. The static truck-door assignment problem is also taken into account by Yu et al. [12]. The authors developed two heuristic methods which provide approximately 20% reduction in man-hour requirements. Miao et al. [13] considered the truck-door assignment problem with operational time constraints and proposed a tabu search and a genetic algorithm for the problem. Stephan and Boysen [14] compared the assignment policy of the trucks to the doors and they showed that the mix policy is better than the fixed policy for most of the cases. Luo and Noble [15]

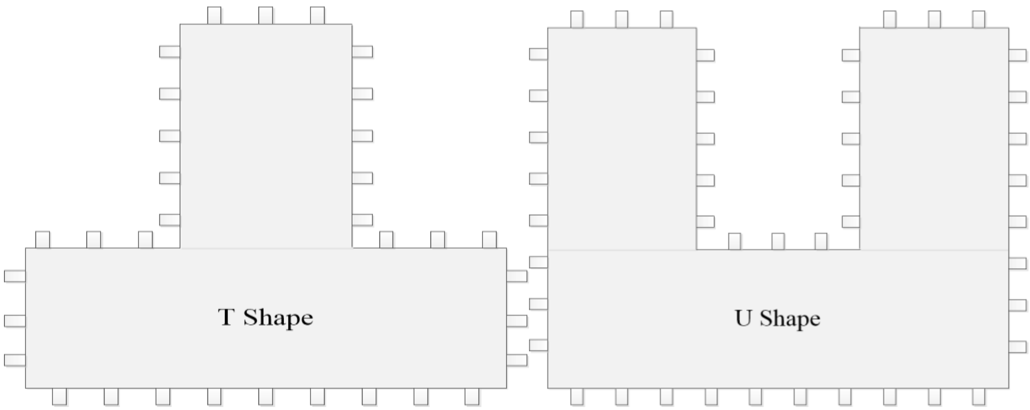
considered the truck-door assignment problem with staging operations where the products are assigned to a lane in cross-docking center for storage. The authors developed a genetic algorithm to solve the large sized problems. Miao et al. [16] proposed an adaptive tabu search algorithm for the similar problem where operational time constraints are considered. Nassief et al. [17] presented a new mixed integer mathematical model for the truck-door assignment problem which is embedded into a Lagrangean relaxation. Fatthi et al. [18] proposed a mixed integer mathematical model for solving a real-time truck-door assignment problem by considering the operational times in cross-docking center where the aim of the model is to minimize total service time of trucks and reduce the waiting time of trucks before the service.
In this paper, the effects of the crossdock shapes on material handling cost from inbound doors to outbound doors are analyzed by considering four different type building shapes. To identify the best shape of the cross-docking centers, a mathematical model is formulated based on the truck-door assignment problem in cross-docking centers which aims to determine best assignment plan of trucks to doors that minimizes the total movement of the products. In this content, the rest of the paper consists of the following parts: problem definition, model formulation, computational results and finally conclusion.

II. PROBLEM DEFINITION

In order to identify the effects of building shapes on material flow efficiency for cross-docking systems, four type of crossdock shapes given in Figure 1 are considered in this study, where Figure 1a, 1b, 1c, and 1d represent I, L, T, and U shape for the buildings, respectively. To evaluate the performance of the building shapes on the basis of material flow from inbound doors to outbound doors, the truck-door assignment problem is taken into account to determine material handling cost in cross-docking centers.



a. I shape for the crossdock layout **b.** L shape for the crossdock layout



c. T shape for the crossdock layout **d.**U shape for the crossdock layout

Figure 1. Considered layout shapes for the crossdocks

In truck-door assignment problem in cross-docking center, the products picked up from suppliers are unloaded from incoming trucks at inbound doors and moved to the temporary storage area after consolidation operations. Subsequently, products are transferred from temporary storage area to outbound doors according to their destinations and loaded into the outgoing trucks for distribution. The objective of the problem is to find best assignment plans in cross-docking center to minimize total travelling distance of the products. In this study, the truck-door assignments plans are taken into account with the following assumptions:

- Each truck can be used for only one location and also each location can be serviced by one incoming/outgoing truck, which means that each supplier/customer location is assigned to a door in cross-docking center.

- Each door can be used by incoming or outgoing trucks.
- For each door at most one truck can be assigned in a planning horizon.
- Material flow in cross-docking center is considered from incoming truck to outgoing truck. The movements from incoming trucks to temporary storage area and from temporary storage area to outgoing trucks are ignored.

III. MODEL FORMULATION

According to the assumptions described above, the truck-door assignment problem of cross-docking center is formulated as a linear mathematical model as follows:

Parameters

M Number of incoming trucks

N Number of outgoing trucks

D Number of doors

P Number of products transported from suppliers to customers

d_p Incoming truck label of product p; $p = 1, \dots, P$

$d_p^{'}$ Outgoing truck label of product p; $p = 1, \dots, P$

c_{ij} Transportation cost of a product between door i and door j; $i, j = 1, \dots, D$

Decision Variables

x_{im} is a binary variable and equal to 1 if incoming truck m is assigned to door i and 0 otherwise; $i = 1, \dots, D; m = 1, \dots, M$

y_{in} is a binary variable and equal to 1 if outgoing truck n is assigned to door i and 0 otherwise; $i = 1, \dots, D; n = 1, \dots, N$

z_{pij} is a binary variable and equal to 1 if product p is moved from door i to door j and 0 otherwise; $i, j = 1, \dots, D; p = 1, \dots, P$

Using the parameters and decision variables described mentioned above, the truck-door assignment problem of cross-docking center is formulated as follows.

$$Min \sum_{p \in P} \sum_{i \in D} \sum_{j \in D} c_{ij} z_{pij} \qquad (1)$$

Subject to:

$$\sum_{i \in D} x_{im} = 1 \qquad \forall m \in M \qquad (2)$$

$$\sum_{i \in D} y_{in} = 1 \qquad \forall n \in N \qquad (3)$$

$$\sum_{m \in M} x_{im} + \sum_{n \in N} y_{in} \leq 1 \qquad \forall i \in D \qquad (4)$$

$$\sum_{i \in D} \sum_{j \in D} z_{pij} = 1 \qquad \forall p \in P (5)$$

$$\sum_{j \in D} z_{pij} \leq x_{id_p} + y_{id_p^{'}} \forall p \in P; \qquad \forall i \in D \qquad (6)$$

$$\sum_{i \in D} z_{pij} \leq x_{jd_p} + y_{jd_p^{'}} \forall p \in P; \qquad \forall j \in D \qquad (7)$$

$$x_{im} \in \{0,1\} \forall i \in D; \qquad \forall m \in M \qquad (8)$$

$$y_{in} \in \{0,1\} \forall i \in D; \qquad \forall n \in N \qquad (9)$$

$$z_{pij} \in \{0,1\} \forall p \in P; \qquad \forall i, j \in D \qquad (10)$$

The objective function (1) aims to minimize total transportation cost of the products in cross-docking center. Constraints (2) and (3) assign each incoming and outgoing truck to a door, respectively. Constraint (4) ensures that the maximum one vehicle can be assigned to a door. Constraints (5) – (7) identify the movement of the products between the doors, where constraint (5) assigns each product to doors and constraints (6) and (7) guarantee that a product can be assigned to a door if it unloaded or loaded at there. Constraints (8) – (10) define the binary decision variables of the model.

IV. COMPUTATIONAL RESULTS

In order to analyze the effects of the layout shapes on material handling costs in cross-docking centers, 15 different sized instance are randomly generated and solved by using the proposed mathematical model. For each instance four layout shapes (I, L, T, U) with equal area and number of doors are respectively considered. Table 1 presents the details of the generated problems and their solutions which are obtained by using the Gurobi 6.0.4 solver with one hour time limitation. The solutions of the instances are identified in Table 1 with their objective function value (OFV) and optimality gap (%Gap) value.

It can be concluded from the computational results that the minimum average cost for the product movements is obtained with the I shape crossdock layout. Although the average number of products for the instances is 61.9, the I shape layout provides a saving according to the other layout shapes, such as 3.90% for L shape, 1.54% for T shape and 1.70% for U shape. Moreover, the results of the instances 1-3, 5-6, 9, whose solutions are optimum for each crossdock shape, indicate that the average savings between the I shape and other shapes shown in Table 2 are 7.18%, 4.95%, and 6.66%. As a result, it should be pointed out that the I shape building for the cross-docking centers provide effective movements according to L, T, and U shape buildings.

Table 1. Problems descriptions and Gurobi solutions

Problem No	Number of Products	I Shape		L Shape		T Shape		U Shape	
		OFV	%Gap	OFV	%Gap	OFV	%Gap	OFV	%Gap
1	59	336	0.0	349	0.0	350	0.0	350	0.0
2	73	494	0.0	535	0.0	538	0.0	538	0.0
3	58	386	0.0	433	0.0	400	0.0	434	0.0
4	52	390	0.0	422	0.0	396	0.0	420	10.0
5	49	336	0.0	366	0.0	352	0.0	356	0.0
6	85	636	0.0	699	0.0	666	0.0	684	0.0
7	31	220	0.0	228	0.0	220	10.3	232	7.2
8	70	606	4.3	636	7.7	622	7.6	610	4.8
9	70	633	0.0	657	0.0	666	0.0	660	0.0
10	64	652	17.4	672	15.0	694	11.1	652	11.5
11	59	574	13.7	591	13.4	580	14.9	554	16.5
12	73	940	13.0	895	19.9	858	14.2	882	19.6
13	60	558	25.4	597	26.7	582	27.0	570	18.3
14	62	662	22.3	680	20.5	670	23.3	666	28.0
15	64	704	29.4	689	24.6	660	22.4	660	22.1
Average	61.9	541.8	8.37	563.8	8.52	550.3	8.72	551.2	9.20

Table 2. Cost savings between the I shape and other shapes (L, T, and U)

Problem No	Saving%		
	I - L Shape	I - T Shape	I - U Shape
1	3.72	4.00	4.00
2	7.66	8.18	8.18
3	10.85	3.50	11.06
5	8.20	4.55	5.62
6	9.01	4.50	7.02
9	3.65	4.95	4.09
Average	7.18	4.95	6.66

$$Saving\% = \left(\frac{OFV_{L,T,or\,U\,Shape} - OFV_{I\,Shape}}{OFV_{L,T,or\,U\,Shape}}\right) \times 100\%$$

V. CONCLUSION

In this study, the effects of the crossdock shapes on material handling cost are analyzed by considering four type of building shapes: I, L, T, and U for cross-docking centers. To identify the best shape of the cross-docking centers, a mathematical model is formulated based on the truck-door assignment problem in cross-docking centers. The performance of the building shapes are tested on a problem set by using the Gurobi 6.0.4 solver. The results show that the I shape for the crossdock buildings provides effective material handling plans from inbound doors to outbound doors with respect to other three building shapes.

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