A Mathematical Model for Outbound Truck Scheduling with Multiple Trips in Multi-Door Cross Docking System

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Abstract

This paper presents the novel mathematical model which considered the outbound scheduling problem in the multi-door cross docking system. The proposed model is different from other truck scheduling models due to the characteristic of the outbound trucks in which each outbound truck can make multiple trips to deliver products to different sets of customers. In addition, it is desired that outbound trucks leave the dock doors as close to their predetermined due time to ensure customer satisfaction. To determine optimal solutions for this problem, the problem is formulated as a Mixed Integer Programming (MIP) model. The objectives are to minimize the total tardiness and the total earliness of all outbound trucks. The model is solved using the exact method of LINGO programming solver. The experimental results are executed in two phases. First, the optimal truck schedules are obtained by optimizing two objectives separately. Then, the multi-objective approach is used to find a set of solutions so that the decision makers can make a decision based on their preferences. The numerical results illustrate that, the model can only find optimal solutions for the small-size problems, however; it could not find optimal solutions for the large size problems within reasonable time.

Keywords

Multi-door cross docking, Truck scheduling, Outbound truck, Total Earliness, Total Tardiness

1. Introduction

Nowadays the organization has a focus on speed in responding to customer's demand, which is extremely important in competition with other companies. Cross docking is a logistic strategy in which inbound trucks deliver products from suppliers and transfer their loads into outbound trucks to customers directly. Cross docking function as a distribution centers. The typical operations in a distribution consist of five main operations: receiving, sorting, storage, order picking, and shipping. The most expensive and resource consuming processes are storage and order picking activities. Cross docking functions as a distribution centers with elimination of these two expensive activities as much as possible. As a result, the inventory is held at the minimum level and the delivery lead time is shortened. Therefore, the aim of cross docking system is to minimize inventory management cost while achieving customer satisfaction with fast delivery. Many industries adopt the concept of cross docking to eliminate high cost activities. However, the completed coordination of the inbound and outbound trucks is difficult to achieve because an organization should have a decent plan and well synchronize schedule. It requires specific technologies, which would lead to higher initial investment in the basic structure than that of traditional distribution centers (Belle et al., 2012).

Truck scheduling problem is one of crucial problems in cross docking operational activities that has been studies extensively. Miao et al. (2009) presented an application of Tabu search (TS) and Genetic algorithm (GA) for solving truck scheduling problems in cross docking. Two objectives; minimization of the operational cost and minimization of total number of unfulfilled shipments, were considered. They used ILOG CPLEX in order to find optimum solutions and compared solutions derived from the two metaheuristics. The computational experiment showed that the metaheuristics, especially TS, outperformed the CPLEX solver in nearly all test cases adapted from industrial applications. Soltani and Sadjadi (2010) presented an application of two hybrid metaheuristic algorithms named as

Hybrid Simulated Annealing and Hybrid Variable Neighborhood Search to solve truck scheduling problem in a cross docking with the objective to minimize the total flow time. The proposed algorithms were compared with Tabu Search (TS), and the results showed that their proposed metaheuristics were better than TS. Alpan et al. (2011) proposed the Dynamic Programming (DP) and three metaheuristics for the purpose to compare the quality of solutions in truck scheduling problem. It was found that the results obtained from DP yielded higher solution quality but consumed higher computational time compared to the metaheuristics. Arabani et al. (2011) studied proposed five metaheuristics for solving truck scheduling problem by aiming to minimize the total makespan. They also investigated the effects of using simulation on the success of a multi-door cross docking. Agustina et al. (2014) studied cross docking operations to ensure that food can be delivered just-in-time at minimum cost of delivery, including inventory holding and transportation costs, and the penalty costs of early or tardy deliveries. This study focused on the integration of truck scheduling and vehicle routing problems. The problem was modeled as a mixed integer linear program in CPLEX. The problems were solved in a reasonable time only for small sized instances. However, in large sized instances, they recommended that the size of the solution space should be reduced by modifying the customer zones and using hard-instead of soft-time windows. Amini et al. (2014) addressed a truck scheduling problem, in which a position-based learning effect was taken into consideration for unloading and loading tasks done by human labors in several related environments. The mathematical model was proposed with the objective to minimize the mean completion time of outbound trucks. Four heuristics were developed based on a simulated annealing (SA) algorithm to deal with the complexity of large-sized problems. Wisittipanich and Hengmeechai, (2015) presented the door assignment and truck scheduling problem in cross docking terminals with multi-door according to Just-In-Time concept. This study presented an implementation of a multi-objective differential evolution (MODE) in order to obtain a Pareto frontier, with the objective function of minimizing total earliness and total tardiness of all inbound and outbound trucks. Vincent et al. (2015) proposed a multi period vehicle routing problems in the cross docking with the consideration of multiple products, consolidation of customer orders and time windows of multiple periods. The development of the proposed algorithm was based on the concept of GLNPSO. The proposed algorithm demonstrated its superior performances to CPLEX in terms of solution quality and computational time. Keshtzari et al. (2016) proposed the improved version of the mixed integer programming model for solving small-size truck scheduling problems in the cross docking terminals. The new model showed that it was more effective than the previous ones. In addition, the novel metaheuristics based on Particle Swarm Optimization was also proposed for solving the larger size truck scheduling problems, and the new algorithm outperformed the other two state-of-the-art metaheuristics. Mohammad Taghi Assadi and M. Bagheri, (2016) formulated a mixed integer programming model to solve the truck scheduling problem in small-sized instances using ILOG CPLEX solver, and presented two metaheuristics; differential evolution and simulated annealing to deal with the large sized instances. The computational results showed the efficiency of the proposed meta-heuristics. Arkat et al. (2016) considered the inbound and outbound trucks scheduling problem in which inbound trucks entered the system according to their release times. A mathematical model was developed to determine the truck scheduling at multiple doors and the loading sequence for each of the outbound trucks. A simulated annealing (SA) algorithm was then adapted to find the near-optimal solutions, as the mathematical model is not applicable to solve real-world problems.

Most of researches on truck scheduling problem in cross docking only consider the single assignment of each truck to the door and sequence each assigned truck for a single delivery. However, in practice, it is often the case that each truck travels multiple rounds to deliver products to a different set of customers. Thus, the assignment and sequencing of trucks needs to be made for each delivery. The characteristics of this problem are similar to operations of flexible job shop scheduling problem (FJSP) in which an operation (each truck delivery) is allowed to be processed on any machine from a set of alternative machines (outbound doors). The aim of FJSP is to find a job sequence on each machine regarding to the given objective function. Demir Y., et al. (2013) proposed the mathematical programming formulation for solving FJSP, and then developed an effective heuristic to deal with large problem sizes. Most of the mathematical formulations of FJSP proposed in literatures include the similar patterns to the sequence and assignment conditions of jobs to the machine. Karimi S., et al. (2016) proposed two Mixed Integer Linear Programing (MILP) models of sequence-based and position-based to efficiently solve FJSP in small-sized instances.

This study presented the novel mathematical model which considers the outbound truck scheduling problem in the multi-door cross docking system. The proposed model is different from other scheduling models due to the characteristic of the outbound trucks in which each outbound truck can make multiple trips to deliver products to different sets of customers. In addition, it is desired that outbound trucks leave the dock doors as close as their predetermined due time to ensure customer satisfaction. The problem was formulated as a Mixed Integer Programming (MIP) model with the objective to minimize the total tardiness and the total earliness of all outbound trucks.

2. Problem Description

This paper studies the problem of outbound truck scheduling in multi-door cross docking system by considering two important criteria. First, each outbound truck is expected to leave the dock door at its predetermined due time as close as possible in order to deliver products to the customers on time. Second, each outbound truck can make multiple delivery trips to different sets of customers due to the limitation of truck capacity. To find the optimal solution of this problem, the problem is formulated as a mixed integer programming (MIP) model with the objective to minimize the total tardiness and minimize the total earliness of all outbound trucks. The scheduling problem composes of two sub-problems; the assignment of all trucks to dock doors and the sequencing of trucks at each door. When outbound trucks with different load capacities come to the outbound doors, the products are loaded either to the full truck capacity or subjected to customer demand. The proposed mathematical model for the problem is formulated using the following assumptions:

- There are two sizes of trucks with different capacities.
- The total loading time of products to an outbound truck was set according to the truck capacity.
- The delivery routing of each truck is predetermined in advance.
- The numbers of delivery trips for all trucks are assumed to be equal

Parameters and decision variables used in formulating the model are defined as follows.

Indices

I : A set of delivery round i , where $i \in I$, $i = 1, 2, ..., I$
K : A set of outbound truck k, where $k \in K$, $k = 1, 2, ..., K$
H : A set of outbound door h, where $h \in H$, $h = 1, 2, ..., H$

Parameters

LT_{ik} : Loading time of outbound truck k round i
UT_{ik} : Unloading time an outbound truck k round i to customers
TV_{ik} : Travel time of an outbound truck k round i
due_{ik} : Due time of an outbound truck k round i
M : Big Number

Decision variables

et_{ik} : Arrival time of an outbound truck k round i
dt_{ik} : Departure time an outbound truck k round i

$$X_{ii'kk'} : \begin{cases} 1, & \text{if an outbound truck k delivering for round i is assigned to the dock door after an} \\ & \text{outbound truck k' delivering for round i'} \\ 0, & \text{otherwise} \end{cases}$$

$$P_{ikh} : \begin{cases} 1, & \text{if an outbound truck k delivering for round i is assigned to an outbound door h} \\ 0, & \text{otherwise} \end{cases}$$

The mathematical model of the problem can be formulated as follows.

Objective function

This study considers two objective functions which are minimization of the total earliness and minimization of the total tardiness of outbound trucks as shown in equation (1) and (2), respectively.

$$\text{Min } z_1 = \sum_{i=1}^{I}\sum_{k=1}^{K} \max(0, er_{ik}) \tag{1}$$

$$\text{Min } z_2 = \sum_{i=1}^{I}\sum_{k=1}^{K} \max(0, ta_{ik}) \tag{2}$$

Where

er_{ik} : Earliness time of outbound truck k traveling round i
ta_{ik} : Tardiness time of outbound truck k traveling round i

Constraints

Door assignment: Constraint (3) ensures that each outbound truck is assigned to an outbound door.

$$\sum_{h=1}^{H} P_{ikh} = 1; \forall_{i,k} \{i = 1, 2, ..., I; k = 1, 2, ..., K\} \tag{3}$$

Truck sequences: Constraints (4) - (5) represent the conflict constraints to ensure that each outbound door can operate only one outbound truck at a time.

$$\begin{aligned} & et_{ik} \geq et_{i'k'} - M(3 - X_{ii'kk'} - P_{ikh} - P_{i'k'h}); \forall_{i,i',i\neq i',k,k',k\neq k',h} \\ & \{i = 1, 2, ..., I; k = 1, 2, ..., K; h = 1, 2, ..., H\} \end{aligned} \tag{4}$$

$$\begin{aligned} & et_{i'k'} \geq et_{ik} - M(X_{ii'kk'} + 2 - P_{ikh} - P_{i'k'h}); \forall_{i,i',i\neq i',k,k',k\neq k',h} \\ & \{i = 1, 2, ..., I; k = 1, 2, ..., K; h = 1, 2, ..., H\} \end{aligned} \tag{5}$$

Arrival time of truck to the dock door: Constraint (6) states that the arrival time of an outbound truck k, round i must be greater than or equal to the departure time of its previous round (an outbound truck k, round i-1).

$$\begin{aligned} & et_{ik} \geq dt_{i-1k} + TV_{i-1k} + UT_{i-1k;} \forall_{i,i>1,k} \\ & \{i = 1, 2, ..., I; k = 1, 2, ..., K\} \end{aligned} \tag{6}$$

Departure time of truck from the dock door: Constraint (7) states that the departure time of truck k must be greater than or equal to its arrival time plus loading time.

$$\begin{aligned} & dt_{ik} \geq et_{ik} + LT_{ik;} \forall_{i,k} \\ & \{i = 1, 2, ..., I; k = 1, 2, ..., K\} \end{aligned} \tag{7}$$

Earliness and tardiness conditions: Constraint (8) and (9) specify the earliness time (er_{ik}) and tardiness time (ta_{ik}) of outbound truck k traveling round i, respectively.

$$er_{ik} \geq due_{ik} - dt_{ik}; \forall_{i,k} \{i = 1, 2, ..., I; k = 1, 2, ..., K\} \tag{8}$$

$$ta_{ik} \geq dt_{ik} - due_{ik}; \forall_{i,k} \{i = 1, 2, ..., I; k = 1, 2, ..., K\} \tag{9}$$

Constraint (10) states that all variables are non-negative variables.

$$\text{All variable} \geq 0 \tag{10}$$

3. Computational Experiment

3.1 Experimental setup

In the experiments, the due dates for each outbound truck are set using equation (11) and (12).

$$due_{1k} = 1.1 * LT_{1k} \tag{11}$$

$$due_{ik} = due_{i-1k} + 1.1 * (TV_{i-1k} + UT_{i-1k} + LT_{ik}) \tag{12}$$

For each truck k, the due date for the first round of delivery was set with allowable 10% increase from the truck loading time. Then, the due date of the next delivery is set as equal to it previous round's due date plus an allowable 10% increased from its operational time. Fifteen instances were generated with different sets of parameters I, K and H, which are the number of delivery rounds, the number of outbound trucks, and the number of outbound doors, respectively. The mathematical model was implemented on the LINGO optimization program version 5. The computational experiment was executed using a personal computer of Intel® Core™ i7-4700HQ CPU 2.40 GHz processor with 8GB RAM memory.

The problem is solved in two phases. First, the objective of minimizing the total earliness and minimizing the total tardiness are optimized separately. Second, the problems were solved using multi-objective approach to determine a set of solutions. Thus, instead of minimize each individual objective, the weighted sum method is used to combined two objectives into one objective so that the decision makers can make a decision based on their preferences.

3.2 Experimental results

To evaluate the efficiency of the proposed mathematical model, 15 instances were generated. Each instance is characterized by its variables I, K, H which are the numbers of rounds, the number of outbound trucks, and the number of outbound door, accordingly. An example of data set used for instance 8 is shown in Table 1.

Table 1. Data set for instance 8

Instance 8			Time setting (Minute)			
I	K	H	Loading Time (LT_{ik})	Unloading Time (UT_{ik})	Travel Time (TV_{ik})	Due Time (due_{ik})
1	1	3	30	30	60	33
1	2	3	45	45	110	50
1	3	3	45	45	100	50
1	4	3	30	30	75	33
2	1	3	30	30	0	165
2	2	3	45	45	0	270
2	3	3	45	45	0	259
2	4	3	30	30	0	182

As shown in Table 1, in the instance 8, the number of delivery rounds is equal to 2, the number of outbound trucks is equal to 4, and the number of outbound doors is equal to 3. The loading time (LT) and unloading time (UT) are determined from two different truck capacities (LT and UT for small truck = 30 and LT and UT for large truck = 45). Since the delivery routing of each truck is predetermined in advance, the travel time is derived according to that route. It is noted that the travel time of each truck in the last round is not considered in model because the problem focuses only on the departure time of each delivery from the outbound door.

Table 2 and 3 illustrated the experimental results in the cases where the total earliness and the total tardiness were minimized separately, respectively.

Table 2. The results of minimizing total earliness

Instance	Test Problem			Objective		Computational Time (h:m:s)
	I	K	H	Earliness	Tardiness	
1	2	2	2	0	0	0:00:01
2	3	2	2	0	0	0:00:01
3	2	3	2	0	131	0:00:01
4	2	3	3	0	0	0:00:01
5	3	3	2	0	104	0:00:01
6	3	3	3	0	0	0:00:01
7	2	4	2	0	287	0:00:01
8	2	4	3	0	50	0:00:01
9	2	4	4	0	0	0:00:01
10	3	4	2	0	248	0:00:01
11	3	4	3	0	300	0:11:53
12	3	4	4	0	48	0:00:01
13	2	5	3	0	206	0:00:01
14	2	6	3	0	300	0:00:09
15	2	7	3	0	N/A	24:00:00

Table 3. The results of minimizing total tardiness

Instance	Test Problem			Objective		Computational Time (h:m:s)
	I	K	H	Earliness	Tardiness	
1	2	2	2	48	0	0:00:01
2	3	2	2	121	0	0:00:01
3	2	3	2	47	30	0:00:01
4	2	3	3	77	0	0:00:01
5	3	3	2	165	30	0:03:44
6	3	3	3	225	0	0:00:01
7	2	4	2	23	61	0:00:31
8	2	4	3	48	30	0:16:26
9	2	4	4	97	0	0:00:01
10	3	4	2	N/A	N/A	24:00:00
11	3	4	3	N/A	N/A	24:00:00
12	3	4	4	N/A	N/A	24:00:00
13	2	5	3	N/A	N/A	24:00:00
14	2	6	3	N/A	N/A	24:00:00
15	2	7	3	N/A	N/A	24:00:00

According to the results obtained in Table 2 and 3, it was clearly seen in the case of minimizing the total earliness that the model was able to find solutions easily. This could be simply explained that, in this case, the departure time of each outbound truck can be scheduled at any time and any door as long as it was not allocated prior to its due time. Thus, the final truck schedule can be generated more flexible without difficulty. On the other hand, in the case total tardiness minimization, the final schedule was optimized under the objective of minimizing the delay of truck departure times, and this makes the problems more complex. In addition, the computational time increased as the problem sizes increased in both objective functions. However, for the case of minimization of the total tardiness criterion, the use of current LINGO version could not find solutions for the large-size problems within acceptable time. Figure 1 and Figure 2 illustrate the optimal schedules of instance 8 generated in the case of minimizing the total earliness and minimizing the total tardiness, respectively.

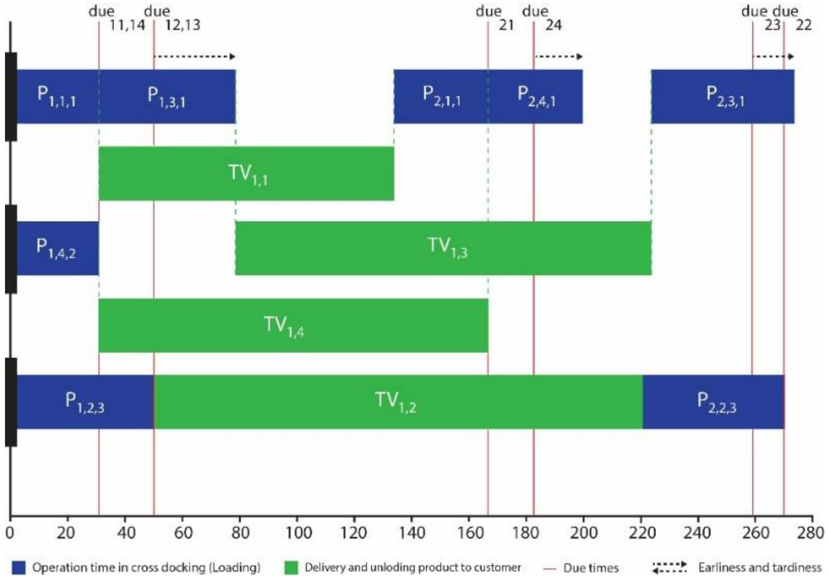

Figure 1. The generated schedule for minimizing the total earliness (instance 8)

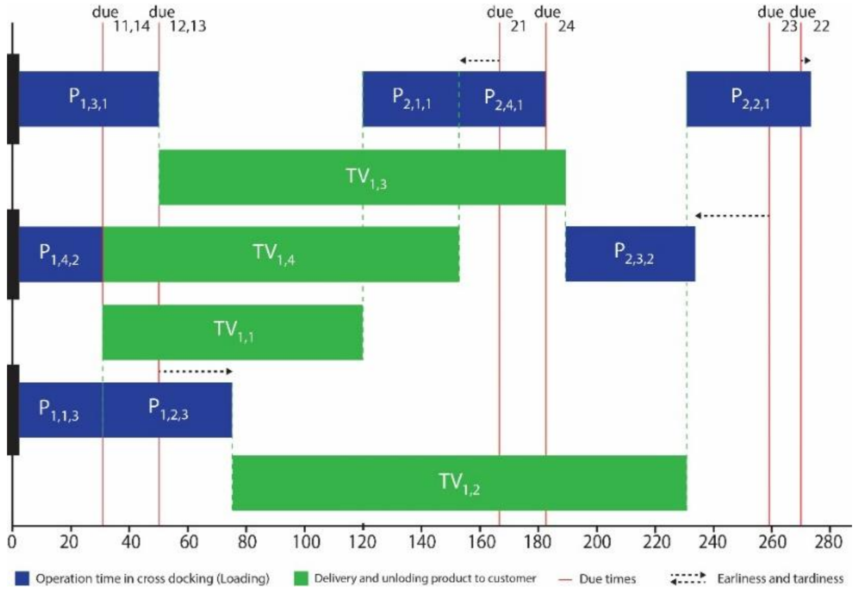

Figure 2: The generated schedule for minimizing the total tardiness (instance 8)

In the second phase, the outbound truck scheduling problems are solved by multi-objective approach. Instead of minimize each individual objective, the weighted sum method was used to combined two objectives into one objective as shown in equation (13).

$$W_1 * \left[\sum_{i=1}^{I} \sum_{k=1}^{K} \max(0, er_{ik}) \right] + W_2 * \left[\sum_{i=1}^{I} \sum_{k=1}^{K} \max(0, ta_{ik}) \right] \tag{13}$$

Where W_1 and W_2 are important weights of the earliness and tardiness respectively in which $W_1 + W_2 = 1$.

In this phase, the combinations of weight (C1- C11) are set with the weight values varying from 0.0 to 1.0, and therefore, a set of solutions were generated according to different weight combinations for each instance. Table 4 shows the results of instance 3, 7 and 8 in which the weighted sum approach for the total earliness and total tardiness minimization were used. Figure 3, 4, and 5 illustrate a set of solution according to the different combination of objective weights. Therefore, in real-world practices, decision makers can see all possible solution and make a decision based on their preferences.

Table 4. The results of weighted sum approach for the total earliness and total tardiness minimization

Instance	Combination	Weight		Total Earliness (Minute)	Total Tardiness (Minute)	Objective (Minute)
		Earliness	Tardiness			
Instance 3	C1	0.0	1.0	47	30	30
	C2	0.1	0.9	3	30	27.3
	C3	0.2	0.8	3	30	24.6
	C4	0.3	0.7	3	30	21.9
	C5	0.4	0.6	3	30	19.2
	C6	0.5	0.5	3	30	16.5
	C7	0.6	0.4	3	30	13.8
	C8	0.7	0.3	0	36	10.8
	C9	0.8	0.2	0	36	7.2
	C10	0.9	0.1	0	36	3.6
	C11	1.0	0.0	0	80	0
Instance 7	C1	0.0	1.0	23	61	61
	C2	0.1	0.9	6	61	55.5
	C3	0.2	0.8	6	61	50
	C4	0.3	0.7	6	61	44.5
	C5	0.4	0.6	6	61	39
	C6	0.5	0.5	6	61	33.5
	C7	0.6	0.4	6	61	28
	C8	0.7	0.3	0	73	21.9
	C9	0.8	0.2	0	73	14.6
	C10	0.9	0.1	0	73	7.3
	C11	1.0	0.0	0	358	0
Instance 8	C1	0.0	1.0	48	30	30
	C2	0.1	0.9	3	30	27.3
	C3	0.2	0.8	3	30	24.6
	C4	0.3	0.7	3	30	21.9
	C5	0.4	0.6	3	30	19.2
	C6	0.5	0.5	3	30	16.5
	C7	0.6	0.4	3	30	13.8
	C8	0.7	0.3	0	36	10.8
	C9	0.8	0.2	0	36	7.2
	C10	0.9	0.1	0	36	3.6
	C11	1.0	0.0	0	50	0

According to results in Table 4, the solutions obtained from different sets of weights provide the decision maker with good insights into possible alternative for the final decision. When more weight is given to total earliness, the schedule is generated with smaller value of total earliness. On the other hand, when more weight is given to total tardiness, the schedule is generated with smaller value of total tardiness. In fact, appropriated weights of different objectives are designed individually by decision makers which may be different from one another. However, in most cases, the penalty cost according to the tardiness is higher that the penalty cost of the earliness. Thus, it is recommended that the decision makers should put more weights on the tardiness objective.

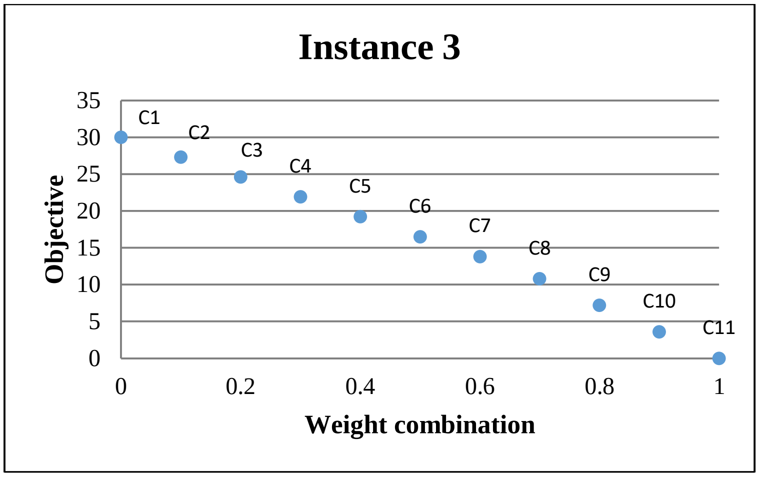

Figure 3. Multi-objective solutions in instance 3

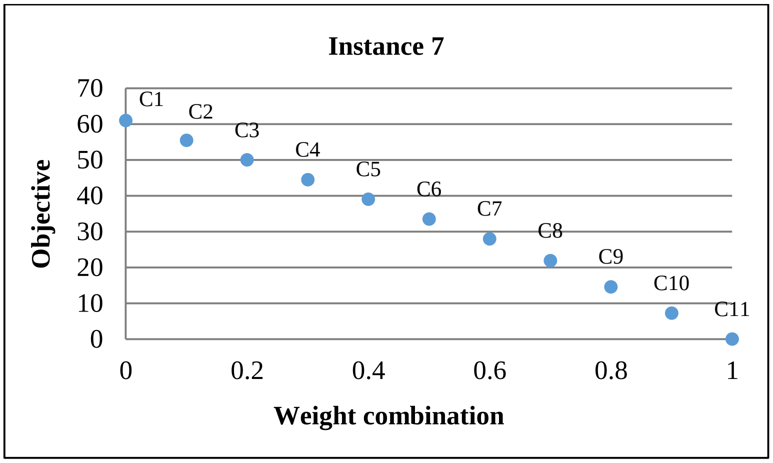

Figure 4. Multi-objective solutions in instance 7

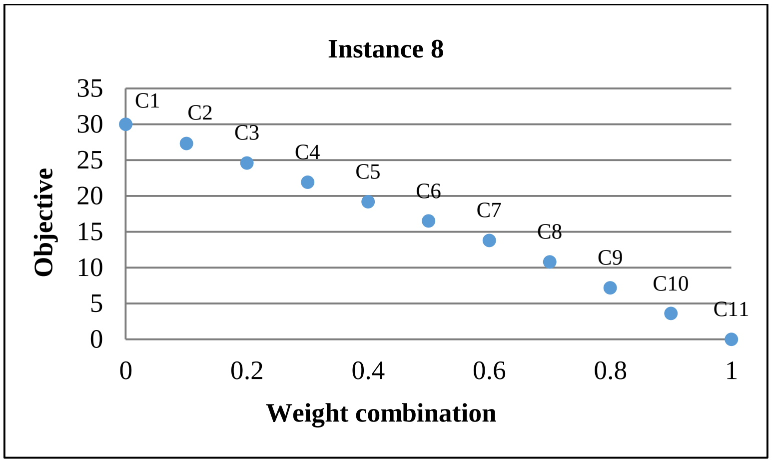

Figure 5. Multi-objective solutions in instance 8

4. Conclusion

This paper considers the scheduling problem of outbound trucks in the multi-door cross docking system. Each outbound truck can make multiple trips to deliver products to different sets of customers. In addition, it is desired that outbound trucks leave the dock doors as close as their predetermined due time to ensure customer satisfaction. To determine optimal solutions for this problem, the outbound truck scheduling is formulated as a Mixed Integer Programming (MIP) model. The objective of the model is to minimize the total tardiness and the total earliness of all outbound trucks. The model is solved using the exact method of LINGO programming solver. The experimental results are executed in two phases. First, the optimal truck schedules are obtained by optimizing two objectives separately. Then, in the second phase, the multi-objective approach based on the weighed sum method is used in order to find a set of solutions according to the different combination of objective weights. Therefore, the decision makers can make a decision based on their preferences. Since the problem is NP-Hard, the numerical results illustrate that the proposed mathematical model is able to find optimal solutions only for the small-size problems. However; it cannot find optimal solutions for the large size problems within reasonable time.

The further works include the improvement of the mathematical model to take into account of more complex constraints to represent real-world practices. Moreover, for highly complicated problems consisting of many trucks and many doors, other solution tools such as heuristic and meta-heuristic models could be used instead.

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Biographies

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