IJE TRANSACTIONS B: Applications Vol. 32, No. 2, (February 2019) 296-305

International Journal of Engineering

Journal Homepage: www.ije.ir

Truck Scheduling in a Cross-Docking Terminal by Using Novel Robust Heuristics

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PAPER INFO

Paper history:
Received 27 October 2018
Received in revised form 27 November 2018
Accepted 03 January 2019

Keywords:
Cross-docking
Scheduling
Optimization
Heuristic

ABSTRACT

Nowadays, one of the major goals of the distribution environment is to reduce lead times and inventories. Cross-docking is a logistics technique which removes the storage and picking up the functions of a warehouse. The term cross-docking refers to moving products directly from incoming to outgoing trailers with little or no storage in between. According to the recent related papers, the truck scheduling problem is one of the objectives for cross-docking systems which is divided into smaller parts. The first stage is about the assignment of the trucks to the dock doors while the second stage aims to sequence all inbound and outbound trucks, in an effective way. Therefore, for dealing with the truck scheduling problem in a cross-docking system, this paper develops five heuristics. The obtained results are compared with those from the previous works. We use many test problems in the literature that were created in different sizes to study the performance of the novel heuristics. In small and medium dimensions the minimum value which found is related to one of the methods CDH3 (Cross Dock Heuristic) which has been proposed in this paper beside in all scales the method CDH4 is the best among others. The numerical results show that the developed heuristics are able to find quick good solutions with fast convergence.

doi: *10.5829/ije.2019.32.02b.15*

NOMENCLATURE

R	Number of inbound trucks in the set (i=1, …, R)
S	Number of outbound trucks in the set (j=1, …, S)
N	Number of product types in the set (k=1, …, N)
r_{ik}	Number of k-type units that were primarily loaded on the inbound truck i
s_{jk}	Number of k-type units that were needed primarily for the outbound truck j
D	Truck changeover time
V	moving time of products from the receiving dock to the shipping dock
M	big number
Parameters	
P_{ij}^{RS}	Number of products shipped directly from the inbound truck i to the outbound truck j if scheduling has been taken for both of them.
P_{ij}^{RT}	Number of products shipped to the temporary storage via the inbound truck i if the outbound truck j does not need them.
$p_{ij}{}^{S}{}_{/T}$	The proportion of the number of products that sent directly to the outbound truck j (P_{ij}^{RS}) to the number of products that will be sent to the temporary storage via the inbound truck i (P_{ij}^{RT})
S'_{jk}	Number of products type k that has not yet been met in this iteration of the algorithm for the outbound truck j.
$p_{j}{}^{T}{}_{S}$	Number of products that outbound truck j supplies its required products from the temporary storage
$P_{ij}{}^{S}{}_{/M}$	The proportion of the number of products that were sent directly to the outbound truck j by the inbound truck (P_{ij}^{RS}) to the number of products that the outbound truck needs to leave the shipping dock S_{jk}
Decision Variables	
T	Makespan
C_i	Time at which inbound truck i enters the receiving dock
F_i	Time at which inbound truck i leaves the receiving dock
D_j	Time at which outbound truck j enters the shipping dock
L_j	Time at which outbound truck j leaves the shipping dock
x_{ijk}	Number of units of product type k that transfer from inbound truck i to outbound truck j

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Please cite this article as: I. Seyedi, M. Hamedi, R. Tavakkoli-Moghaddam, Truck Scheduling in a Cross-Docking Terminal by Using Novel Robust Heuristics, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 32, No. 2, (February 2019) 296-305

P_j^{AT}	Number of products sent from the inbound truck sequences related to the outbound truck *j* to the temporary storage.	v_{ij}	1; If any products transfer from inbound truck i to outbound truck j; 0; Otherwise;
$P_{ij}^{T/S}$	The proportion of the number of products that will be sent to the temporary storage via the inbound truck *i* (P_{ij}^{RT}) to the number of products that sent directly to the outbound truck *j* (P_{ij}^{RS})	p_{ij}	1; If inbound truck i preceeds inbound truck j in the inbound truck sequence; 0; Otherwise;
P_j^{TRS}	Number of products that outbound truck *j* supplies its required products from the storage and the next inbound truck	q_{ij}	1; If outbound truck i preceeds outbound truck j in the outbound truck sequence; 0; Otherwise;

1. INTRODUCTION

In today's competitive environment, the use of new technologies for the perpetuation of the business environment appears necessary. Business organizations are trying to find suitable methods to control their materials flow efficiently. So organizations focus on supply chain processes, that this concept plays an effective role in creating the value of real economic goods and services due to environmental considerations [1]. Procurement, manufacturing, and distribution are three main stages that are common in each supply chain. The most important role in the distribution stage is played by distribution centers. One of the innovative warehousing strategies in logistics management is the cross-docking system in which items are distributed directly from a supplier to clients with the least displacement and less than twenty four hours of storage time. In warehousing operations, the maximum costs are related to storage and retrieval that cross-docking has the potential to eliminate them [2]. Besides, reducing inventory as well as reducing handling costs are the other benefits of cross-docking operation that can be useful for companies with little or no warehouse. Therefore, it can simplify supply chains by helping them deliver products faster and more efficient to the market. The most well-known place in implementing cross-docking operations is Wal-Mart. This strategy has aided Wal-Mart to increase the market share of its business and eventually its profitability [3].

For a comprehensive review of the concept of cross-docking and instructions for successful implementation, we can mention the works presented by Boysen and Fliedner [4], Stephan and Boysen [5], Van Belle *et al*. [6] and Ladier and Alpan [7] which reviewed and classified cross dock problems.

Generally, several decision problems are studied in cross-docking operations. One of these reviews about cross-docking classified works in three categories based on the level of decision making: strategic, tactical and operational level [6]. Strategic level is concern about decisions with effects on a long-term planning process such as cross-dock locations, optimal shape of the cross-dock facilities and cross-dock layout. The cross-docking networks and how products are distributed, are related to the Tactical level. Operational level is to deal with short-term decisions, such as truck scheduling and vehicle routing in a cross-dock.

This paper on hand deals with the category of cross-docking problems at the operational level, and particularly the truck scheduling problem. Generally, in a cross-docking system, there are two sub-problems that the truck scheduling problem encounter them, the assignment of trucks to dock doors and the determination of an overall docking schedule for all trucks and doors.

2. LITERATURE REVIEW

Rohrer [8] introduced one of the first scientific activities on cross-docking systems. He has been described cross-docking systems modeling and issues. The various cross-docking operations in manufacturing, transportation, distribution and retailing were described by Napolitano [9]. All of these operations have common features, such as integration and short-cycle times that made possible by pre-defined delivery and delivery times. Bartholdi and Gue [10] had also one of the early works in this research area, and they considered minimizing labor costs in shipping terminals by appropriate assigning inbound and outbound trucks to doors. Also in this paper, they considered types of congestion and some other intra-terminal factors which affect costs.

In recent years, many studies on cross-dock terminal scheduling problem have been carried out with different assumptions. This topic has recently attracted by most industrial practitioners and academia. In the following, some of the most relevant works to this paper are pointed. Probably the most important paper which studied trucks scheduling in cross-docking systems were proposed by Yu and Egbelu [2]. They presented the most famous mixed integer programming model in a cross-docking system with the goal of minimizing the total operation time (makespan). They employed nine heuristic algorithms for this problem to schedule trucks. The presented model by Yu and Egbelu [2] was used by many researchers such as Vahdani and Zandieh [11].

Shakeri et al. [12] studied the truck scheduling in a resource-constrained cross-dock. For this goal, a heuristic algorithm with two-phase was proposed. The first phase creates a viable sequencing of trucks, and the second phase uses a rule-based heuristic to assign properly each truck in the sequence to the dock doors. The results showed that their heuristic algorithm was robust in finding feasible solutions with respect to the characteristics of the input data. Madani-Isfahani *et al*. [13] presented a mixed-integer programming model for minimizing total operation time in a multiple cross dock system with a limited capacity. To solve the presented model, they proposed two meta-heuristics, namely Simulated Annealing (SA) and Firefly Algorithms (FA) and they obtained and compared the final solutions from these two algorithms.

Mohtashami [14] for the truck scheduling in a cross-docking system utilized a new approach in GA. the objective of the model aims to minimize the total operation time. He assumed that a temporary storage is available in shipping dock and for inbound vehicles frequently enter and leave to unload their products is permissible. In his proposed dynamic genetic algorithm different kinds of chromosome for inbound and outbound trucks are suggested. Amini and Tavakkoli-Moghaddam [15] considered the breakdown possibility of a truck in the truck scheduling problem. The numerical results have illustrated the high-quality performance of the proposed factor.

Golshahi-Roudbaneh et al. [16] used the presented model by Yu and Egbelu [2]. They employed some metaheuristics and two heuristics which got better solutions compared to Yu and Egbelu [2]. Later Molavi *et al.* [17] considered a truck scheduling problem at a two-touch cross-docking center with due dates for outbound trucks as a hard constraint. To minimize total cost a mixed integer programming model was developed. This cost includes the delivery and penalty cost of delayed loads at the end of the planning period. Results illustrate that the outcome will be better if the process of sorting shipments is done due to ascending unloading times and nearest due dates.

Lately in another research Mohammadzadeh *et al.* used three recent nature-inspired metaheuristics in this area. These three novels nature-inspired are Red Deer Algorithm (RDA), Virus Colony Search (VCS) and Water Wave Optimization (WWO). The outputs of the proposed algorithms demonstrate that RDA showed a competitive performance compared with mixed other existing algorithms [18]. Heidari *et al.* address the problem of scheduling incoming and outgoing trucks at a cross-dock facility, when vehicle arrival times are unknown, through a cost-stable scheduling strategy [19]. Some of the latest work in this field are addressed in literature [20-22].

This paper for solving truck scheduling problem in a cross-docking system introduces innovative heuristic methods. The goal of this paper is to find an optimal sequence for both receiving and shipping trucks to minimize total completion times. We use many test problems in small, medium, and large dimensions in the literature that were produced for testing of new heuristics efficiently.

The structure of this paper is organized as follows. Section 2 presents the literature review of the problem. Section 3 describes research methodology and proposed powerful heuristics. Experimental results are presented in section 4. Finally, in section 5 conclusion of the research is provided.

3. RESEARCH METHODOLOGY

As stated before Yu and Egbelu [2] presented the most famous mixed integer programming model in this area. Therefore this paper the same as vahdani and zandeh [10], golashahi et al. [15] and Boloori Arabani *et al.* [23] succeeds the survey of Yu and Egbelu [2] model.

3. 1. Mathematical Modeling In the following the mixed integer programming model developed by Yu and Egbelu [2]. The objective function of the model is minimizing the total completion time (makespan) as shown in equation (1). Constraint (2) indicates that the total completion time is greater than or equal to the time when the last shipping truck leaves the sending platform. Constraints (3 and 4) show that the total number of items received by the receiving trucks is equal to the total amount of items sent by the shipping trucks. Constraint (5) shows the relationship between the variables X_{ijk} and v_{ij}. Constraints (6, 7, and 8) specify the time of arrival and departure of receiving trucks according to their order in the inbound truck sequence. Constraint (9) ensures that no inbound truck surpasses itself in sequence. Constraints (10, 11, and 12) specify the time of arrival and departure of shipping trucks based on their order in the sequence. Constraint (13) is related to that no shipping truck cannot surpass itself in the outbound truck sequence. Constraint (14) if any product sent from the receiving truck to the shipping truck, make a communication between the departure time for each shipping truck and arrival time of each receiving truck.

$$\text{Min Z} = T \qquad \forall j \tag{1}$$

$s.t.$

$$T \geq L_j \qquad \forall j \tag{2}$$

$$\sum_{j=1}^{S} X_{ijk} = r_{ik} \qquad \forall\ i,k \tag{3}$$

$$\sum_{i=1}^{R} X_{ijk} = S_{jk} \qquad \forall\ j,k \tag{4}$$

$$X_{ijk} \leq Mv_{ij} \qquad \forall\ i,j,k \tag{5}$$

$$F_i \geq c_i + \sum_k r_{ik} \qquad \forall i \tag{6}$$

$$C_j \geq F_i + D - M(1 - P_{ij}) \qquad \forall i,j \quad and\ i \neq j \tag{7}$$

$$C_i \geq F_j + D - MP_{ij} \qquad \forall i,j \quad and\ i \neq j \tag{8}$$

$$P_{ii} = 0 \qquad \forall i \qquad (9)$$

$$L_j \geq d_j + \sum_k s_{jk} \qquad \forall i,j \quad and\ i \neq j \qquad (10)$$

$$d_j \geq L_i + D - M(1 - q_{ij}) \qquad \forall i,j \quad and\ i \neq j \qquad (11)$$

$$d_i \geq L_j + D - Mq_{ij} \qquad \forall i,j \quad and\ i \neq j \qquad (12)$$

$$q_{ii} = 0 \qquad \forall j \qquad (13)$$

$$L_j \geq c_i + V + \sum_k X_{ijk} - M(1 - v_{ij}) \qquad \forall i,j \qquad (14)$$

$$All\ variables \geq 0 \qquad (15)$$

3. 2. Heuristic Methods In this section, to solve the IP model that was introduced in the previous section, five algorithms are proposed. Yu and Egbelu [2] presented a heuristic method to solve their mixed integer programming model. They introduce some strategies for inbound and outbound trucks selection. The heuristic combines these selection strategies and obtains nine combinations. In this paper, new selection strategies for selecting inbound and outbound trucks is presented. This algorithm consists of two steps. In the first step, a sequence of inbound trucks is formed for each unplanned outbound truck. This sequence is obtained using one of the selection strategies. This sequence includes trucks that are capable to meet the needs of the corresponding outbound truck. Therefore, there may be more than one sequence for an outbound truck.

In the second step, we choose the next outbound truck using the strategy of choosing outbound trucks. This selected truck will be located in the sequence of the outbound trucks, and the corresponding sequence of inbound trucks will be placed in the final sequence of the inbound trucks. After scheduling of this outbound truck and sequences of the corresponding inbound trucks, the set of unplanned inbound and outbound trucks will be updated. The acquired sequence's makespan is computed at each iteration of algorithms. Finally, the sequence with the least makespan is selected. As long as all trucks are not scheduled, these processes are continued. In developing the heuristics approaches the notations at the beginning of the paper are used. Some of the above notations were presented by Yu and Egbelu [2].

In the following the steps of the heuristic algorithm are presented, and they are common between all heuristics:

Step 1. Select one of the outbound trucks (the first one for the first time).

Step 2. According to inbound trucks selection strategies, one of the unplanned inbound trucks is selected for the desired outbound truck. The selection strategies are presented in each heuristic method.

Step 3. For each inbound truck firstly the number of transferred products from inbound truck to the outbound truck is calculated. After this calculation, the remaining products that should be shipped to the temporary storage is computed.

Step 4. If there is still an unmet demand, according to inbound trucks selection strategies assign other unscheduled inbound trucks until all demands of the outbound truck have been met.

Step 5. Place the selected outbound truck at first place in the sequence of outbound trucks and the corresponding selected inbound trucks at first position of the inbound trucks sequence.

Step 6. For the selected outbound truck the number of products which have not been sent directly to that outbound truck from the associate inbound trucks is calculated. In fact, this is the number of products in the temporary storage.

Step 7. For the selected outbound truck elapsed time for loading at the shipping is determined.

Step 8. For the next outbound truck in the sequence is selected according to one of the outbound truck selection strategies. The outbound truck selection strategies are presented in each heuristic method.

Step 9. Assign unscheduled inbound trucks until all demands of the outbound truck have been met.

Step 10. If there are unscheduled outbound trucks go to Step 8.

Step 11. The makespan of a cross-docking operation relevant to these sequences will be calculated. Then we select the minimum makespan and the corresponding sequence.

Step 12. Do these steps for all outbound trucks.

These steps are followed in the following heuristic methods. Generally, heuristic methods which are presented here used five strategies to find a sequence of inbound trucks and also two outbound truck selection strategies to find a sequence of outbound trucks. By combining these truck selection strategies five heuristic algorithms are obtained. In these approaches at each iteration of algorithms, the inbound and outbound truck sequence, as well as the amount of transshipment product from inbound trucks to outbound trucks, is obtained. Then, the makespan relevant to these outputs will be available. The heuristic methods, which have been derived from combining the strategies for selecting inbound and outbound trucks are as follows:

CDH1:

Inbound trucks selection strategy:

In this method for each inbound truck, the number of products that will be shipped directly to the outbound truck (P_{ij}^{RS}) is calculated.

$$P_{ij}^{RS} = \sum_{k=1}^{N} [\min\{\acute{r}_{ik}, \acute{s}_{jk}\}]. \tag{16}$$

After calculating this value for all unplanned inbound trucks, the truck with the largest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_{ij}^{RT}) will be selected.

Outbound trucks selection strategy:
In this method for shipping trucks sequence, each outbound truck that supplies the highest amount of its required products from the temporary storage is placed in the sequence. This value is calculated as follows:

$$P_j^{TS} = \sum_{k=1}^{N} W - S_{jk} \tag{17}$$

After calculating this value for all outbound trucks, the truck with the lowest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_j^{AT}) will be selected.

CDH2:
Inbound trucks selection strategy:
In this strategy for each inbound truck, by using equation 18 the proportion of the number of products that were sent to the temporary storage(P_{ij}^{RT}) to the number of products that sent directly to the outbound truck (P_{ij}^{RS}) is calculated.

$$P_{ij}^{T/S} = \frac{P_{ij}^{RT}}{P_{ij}^{RS}} \tag{18}$$

After calculating this value for all unplanned inbound trucks, the truck with the lowest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_{ij}^{RT}) will be selected.

Outbound trucks selection strategy
In this method for shipping trucks sequence, each outbound truck that supplies the highest amount of its required products from the storage is placed in the sequence. This value is calculated with Equation (17). After calculating this value for all outbound trucks, the truck with the lowest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_j^{AT}) will be selected.

CDH3:
Inbound trucks selection strategy:
In this method for each inbound truck, the number of products that will be shipped directly to the outbound truck (P_{ij}^{RS}) is calculated with Equation (16). After calculating this value for all unplanned inbound trucks, the truck with the largest value will be selected. If this value is equal for two trucks, a truck with the smaller amount of (P_{ij}^{RT}) will be selected.

Outbound trucks selection strategy:
In this method for shipping trucks sequence, each outbound truck that supplies most of its required products from the storage and the next inbound truck is placed in the sequence. This value is calculated as follows:

$$P_j^{TRS} = \sum_{k=1}^{N} (S_{jk} - W) + \sum_{k=1}^{N} (S_{jk} - r_{ik}) \tag{19}$$

After calculating this value for all outbound trucks, the truck with the highest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_j^{AT}) will be selected.

CDH4:
Inbound trucks selection strategy:
In this strategy for each inbound truck, by using equation 20, the proportion of the number of products that sent directly to the outbound truck (P_{ij}^{RS}) to the number of products that were sent to the temporary storage (P_{ij}^{RT}) is calculated.

$$P_{ij}^{S/T} = \frac{P_{ij}^{RS}}{P_{ij}^{RT}} \tag{20}$$

After calculating this value for all unplanned inbound trucks, the truck with the largest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_{ij}^{RT}) will be selected.

Outbound trucks selection strategy:
In this method for shipping trucks sequence, each outbound truck that supplies most of its required products from the storage and the next inbound truck is placed in the sequence. This value is calculated with equation 19.
After calculating this value for all outbound trucks, the truck with the highest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_j^{AT}) will be selected.

CDH5:
Inbound trucks selection strategy:
In this strategy for each inbound truck, the ratio of the number of products that were sent directly to the outbound truck by the inbound truck (P_{ij}^{RS}) to the number of products that the outbound truck needs to leave the shipping dock $(\acute{S}_{jk})$is calculated.

$$P_{ij}^{S/H} = \frac{P_{ij}^{RS}}{\acute{S}_{jk}} \tag{21}$$

After calculating this value for all unplanned inbound trucks, the truck with the largest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_{ij}^{RT}) will be selected.

Outbound trucks selection strategy:
In this method for shipping trucks sequence, each outbound truck that supplies most of its required products from the storage and the next inbound truck are placed in the sequence. This value is calculated with equation 19.

After calculating this value for all outbound trucks, the truck with the highest value will be selected. If this value is equal for two trucks, a truck with a smaller amount of (P_j^{AT}) will be selected.

4. NUMERICAL RESULTS AND ANALYSIS

The previous section studied heuristic methods for scheduling problem in a cross-docking system. In this section, In order to investigate the performance of our proposed heuristic, twenty sets of test problems that were randomly generated by Yu [24] are employed.

The scale of these twenty test problems is small and moderate because the number of inbound and outbound trucks are within three to six and total numbers of products are between 890 and 2030 units. Fifteen test problems in medium and large scales are also used which are generated by Golshahi-Roudbaneh et al. [16]. The number of inbound and outbound trucks are within eight to twenty and total numbers of products are between 2254 and 8367 units. Details of these test problems can be found in Yu [24] and Golshahi-Roudbaneh et al. [16].

For representing the effectiveness of algorithms, makespan is used as a measure, and in each run for each algorithm, the related makespan is recorded.

Table 1 presents problem size and the makespan obtained from nine heuristic solutions offered by Yu and Egbelu [2] as well as two heuristics presented by Golshahi-Roudbaneh et al. [16].

TABLE 1. Best makespan found.

set	Best value	Founded by Golshahi [16]	Founded by Yu and Egbelu [2]
1	**1562**	(H1 & H2)	
2	**1577**	(H2)	R1S1 & R1S2
3	**1372**	(H1 & H2)	R1S1 & R2S1
4	**1789**		R3S1
5	**1579**	(H1 & H2)	
6	**1546**		R2S1 & R3S1
7	**1535**	(H1 & H2)	R2S2 & R3S2
8	**1525**	(H1 & H2)	R1S1 & R1S2& R2S1 & R2S2& R3S1& R3S2
9	**1473**	(H1 & H2)	R2S1 & R3S1
10	**1452**	(H1 & H2)	(R1S1 & R1S3 & R2S1 & R2S3 & R3S1 & R3S3
11	**2232**		(R1S1 & R1S3 & R2S1 & R2S3 & R3S3
12	**2833**	(H2)	
13	**2403**	(H2)	
14	**2413**		R2S1
15	**2762**		R1S1 & R1S3 & R3S1 & R3S3
16	**2407**		R1S1
17	**1885**		(R1S1 & R2S2 & R2S3& R3S1)
18	**2642**	(H1 & H2)	(R1S2 & R2S2 & R3S2
19	**2553**	(H1 & H2)	
20	**2926**	(H2)	

Among these 11 heuristic methods, H2 presented by Golshahi-Roudbaneh et al. [16] had a better performance. In Table 2, the makespan which is obtained by the algorithms presented in this paper, as well as the best value, is presented. The best value demonstrates the minimum makespan which found by all algorithms.

Totally, 11 heuristics are presented in the literature review, and five heuristics are presented in this paper. Heuristics that presented in this paper outperform in eighteen cases out of twenty problem sets. In most cases, two of these heuristics, named CDH3 and CDH4 performed the best among other algorithms. As can be seen, in fifteen problem sets they found the best solutions. Generally in all cases, heuristics that presented in this paper outperform than heuristic algorithms presented in the literature review.

As presented in Table 3, the average gap between the best makespan found among all algorithms and the makespan obtained through each heuristic solutions is noticeable. This gap is calculated based on the equation (22). Among sixteen heuristic methods, CDH3 and CDH4 had a better performance as can be seen in Table 3. The remarkable point is that both of these techniques use the same strategy to select the outbound trucks in the sequence. This outbound trucks selection strategy is based on providing its required products from the storage and the next inbound truck.

$$Gap(\%) = \frac{Heuristic\ solution\ makespan - the\ best\ makespan}{the\ best\ makespan} \times 100 \qquad (22)$$

Figure 1 shows the average gap acquired by each heuristic solution. This figure indicates the fewest rate is related to one of the methods (CDH3) proposed in this paper with the average gap of 0.01. Because of the small scale of test problems which have been tested so far, we test extra 15 problems in medium and large scale that are generated by Golshahi-Roudbaneh et al. [16].

TABLE 2. Makespan obtained in small and medium scale by this paper's proposed algorithms.

Problem set	Best value	Our heuristic solutions CDH1	CDH2	CDH3	CDH4	CDH5
1	1495	1557	1566	**1495**	**1495**	**1495**
2	1609	1694	1694	**1609**	**1609**	**1609**
3	1355	**1355**	1372	1372	1372	1372
4	1789	1840	**1789**	1830	1830	1830
5	1579	1646	**1579**	**1579**	**1579**	**1579**
6	1538	1552	1607	**1538**	**1538**	**1538**
7	1431	**1431**	1636	1535	1535	1535
8	1507	1556	1571	**1507**	**1507**	**1507**
9	1473	1473	1500	**1473**	**1473**	**1473**
10	1352	**1494**	**1494**	1352	1352	1352
11	2232	2311	2311	**2232**	2270	**2232**
12	2833	**2833**	**2833**	**2833**	**2833**	**2833**
13	2378	2386	2481	**2378**	**2378**	**2378**
14	2413	2441	2466	**2413**	**2413**	**2413**
15	2734	2795	**2734**	2753	**2734**	2753
16	2510	2528	2646	**2510**	**2510**	**2510**
17	1885	**1885**	**1885**	**1895**	**1895**	**1895**
18	2600	**2600**	2653	2642	2642	2642
19	2538	**2538**	2612	2553	2553	2553
20	2926	3101	3064	**2926**	**2926**	**2926**

TABLE 3. Average gap for 20 test problems in small and medium sizes.

Author	Heuristic Name	Average
	RS1SS1	0.034
	RS1SS2	0.064
	RS1SS3	0.085
	RS2SS1	0.032
Yu and Egbelu [2]	RS2SS2	0.082
	RS2SS3	0.073
	RS3SS1	0.033
	RS3SS2	0.082
	RS3SS3	0.087
Golshahi et al. [16]	H1	0.034
	H2	0.027
	CDH1	0.026
	CDH2	0.039
	CDH3	0.01
This paper	CDH4	0.011
	CDH5	0.021

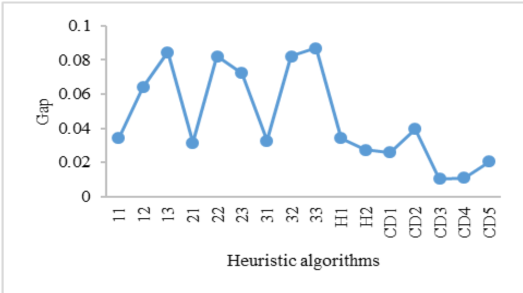

Figure 1. Average of the gap obtained by heuristics for small size problems

Table 4 compares the makespans which acquired with heuristic methods in this paper and Heuristics solutions presented by Golshahi-Roudbaneh et al. [16] in medium and large sizes.

TABLE 4. Makespan obtained in medium and large scale by algorithms

Set	Best value	Golshahi et al. [16] H1	H2	heuristic solutions in this paper CDH1	CDH2	CDH3	CDH4	CDH5
21	3188	3344	**3188**	3365	3295	3305	3305	3305
22	3565	3627	3847	3627	**3565**	3592	3616	3592
23	5245	5457	5345	5337	**5245**	5264	5338	5264
24	3903	4060	4035	4006	4079	3946	**3903**	3946
25	5192	5646	5312	5567	5337	5381	5602	5622
26	8100	8306	8131	8416	8394	8306	**8100**	8306
27	7091	7550	7225	7545	7512	**7091**	7143	7091
28	7677	7820	**7677**	8094	7876	7741	7680	7741
29	6279	6623	6363	**6279**	6473	6623	6377	6623
30	5482	5849	**5482**	5796	5842	5892	5687	5892
31	8528	9026	**8528**	8836	8877	8816	8547	8827
32	8215	8665	8429	8541	8518	8574	**8215**	8574
33	9405	9850	**9405**	10144	9826	9828	9440	9828
34	11126	11720	11129	11255	11322	**11126**	11167	11126
35	9301	9835	**9301**	10191	9712	10134	9386	10104

Table 5 shows the average gap between the makespan acquired through heuristic solutions and the best solution in medium and large scale. Additionally, the last row (average) demonstrates the average gap acquired via each heuristic methods. To compare the performance of algorithms, the gap average obtained through heuristics solutions are shown in Figure 2. Obviously, the method CDH4 is the best among other.

In this method the inbound trucks selection strategy is according to the ratio of the number of products that sent directly to the outbound truck to the number of products that sent to the temporary storage and its outbound trucks selection strategy is based on providing its required products from the storage, and the next inbound truck.

TABLE 5. Gap average for 15 test problems in medium and large sizes

set	Golshahi et al. [16]		Heuristic solutions in this paper				
	H1	**H2**	**CDH1**	**CDH2**	**CDH3**	**CDH4**	**CDH5**
1	0.045	0.045	0.041	0.047	0.000	0.000	0.000
2	0.020	0.000	0.074	0.074	0.020	0.020	0.024
3	0.013	0.013	0.000	0.013	0.013	0.013	0.013
4	0.070	0.075	0.033	0.004	0.028	0.028	0.028
5	0.000	0.000	0.042	0.000	0.000	0.000	0.000
6	0.065	0.051	0.009	0.045	0.000	0.000	0.000
7	0.073	0.073	0.000	0.143	0.073	0.073	0.073
8	0.012	0.012	0.033	0.042	0.000	0.000	0.000
9	0.000	0.000	0.000	0.018	0.000	0.000	0.000
10	0.074	0.074	0.105	0.105	0.000	0.000	0.157
11	0.035	0.057	0.035	0.035	0.000	0.017	0.017
12	0.066	0.000	0.000	0.000	0.000	0.000	0.000
13	0.011	0.011	0.003	0.043	0.000	0.000	0.033
14	0.079	0.083	0.012	0.022	0.000	0.000	0.000
15	0.031	0.019	0.022	0.000	0.007	0.000	0.000
16	0.043	0.006	0.050	0.099	0.043	0.043	0.043
17	0.005	0.005	0.000	0.000	0.005	0.005	0.005
18	0.016	0.016	0.000	0.020	0.016	0.016	0.016
19	0.006	0.006	0.000	0.029	0.006	0.006	0.006
20	0.021	0.000	0.060	0.047	0.000	0.000	0.000
21	0.049	0.000	0.056	0.034	0.037	0.037	0.037
22	0.017	0.079	0.017	0.000	0.008	0.014	0.008
23	0.040	0.019	0.018	0.000	0.004	0.018	0.004
24	0.040	0.034	0.026	0.045	0.011	0.000	0.011
25	0.087	0.023	0.072	0.028	0.036	0.079	0.083
26	0.025	0.004	0.039	0.036	0.025	0.000	0.025
27	0.065	0.019	0.064	0.059	0.000	0.007	0.000
28	0.019	0.000	0.054	0.026	0.008	0.000	0.008
29	0.055	0.013	0.000	0.031	0.055	0.016	0.055
30	0.067	0.000	0.057	0.066	0.075	0.037	0.075
31	0.058	0.000	0.036	0.041	0.034	0.002	0.035
32	0.055	0.026	0.040	0.037	0.044	0.000	0.044
33	0.047	0.000	0.079	0.045	0.045	0.004	0.045
34	0.053	0.000	0.012	0.018	0.000	0.004	0.000
35	1.363	0.763	1.090	1.254	0.591	0.438	0.842
Ave	**0.078**	**0.044**	**0.062**	**0.072**	**0.034**	**0.025**	**0.048**

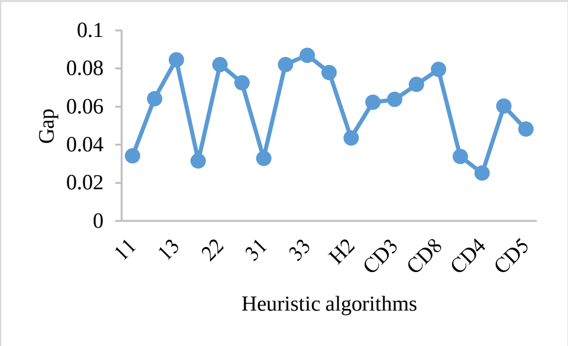

Figure 2. Gap Average obtained by heuristics for medium and large size problems

5. CONCLUSION

In this paper, five new heuristic algorithms namely: CDH1, CDH2, CDH3, CDH4, and CDH5 were applied to schedule the inbound and outbound trucks in a cross-docking system. The objective of the study is to find the best sequence of receiving and shipping trucks with the aim of minimizing makespan. To compare the proposed heuristic algorithms with other heuristics presented in the literature, twenty small-scale test problems were employed. Also to increase the efficiency, fifteen test problems in medium and large scales were used.

In small scales, the best rate is related to methods CDH3, CDH4, CDH5 and CDH1 which are presented in this paper, respectively. After them, H2, presented in previous works, finds a better solution. In medium and large scales, the developed heuristics in this paper showed superior results too. Also in these scales, CDH4, CDH3, H2, and CDH5 had better performance, respectively. The gap average for both small-medium and medium-large are lower than the two main previous works. All in all, the obtained results from the developed heuristics in all small, medium and large sizes demonstrated a better performance among all algorithms in previous works.

However, for further works on this problem, the proposed algorithms can be modified to be useful for multiple doors cross-docking systems. Besides, to assess the capability of heuristics, the problem assumptions can be changed. Moreover, meta-heuristic methods can be utilized to gain better solution.

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Truck Scheduling in a Cross-Docking Terminal by Using Novel Robust Heuristics

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PAPER INFO

Paper history:
Received 27 October 2018
Received in revised form 27 November 2018
Accepted 03 January 2019

Keywords:
Cross-docking
Scheduling
Optimization
Heuristic

چکیده

امروزه یکی از مهمترین اهداف محیط های توزیع، کاهش زمان انجام کار و موجودی کالا است. سیستم انبار های متقاطع یک روش تدارکاتی است که عملیات ذخیره سازی و برداشت کالا از انبار را حذف می کند. اصطلاح انبار های متقاطع اشاره به انتقال مستقیم محصولات از کامیونهای ورودی به کامیون های خروجی با کمترین و یا بدون ذخیره سازی آنها است. با توجه به مقالات اخیر این حوزه، یکی از اهداف سیستم های انبار متقاطع، مسئله برنامه ریزی کامیون است که به دو بخش تخصیص کامیون ها به درب های بارگیری و ترتیب کامیون های ورودی و خروجی تقسیم می شود. بنابراین، برای حل مسئله برنامه ریزی کامیون ها در یک سیستم انبار متقاطع، این مقاله پنج راه حل ابتکاری را ارائه می کند و نتایج حاصل از آنها با آنچه که در مقالات قبلی ارائه شده، مقایسه شده است. در این مقاله ما از مسائل نمونه موجود در ادبیات موضوع استفاده نمودیم که در ابعاد کوچک، متوسط و بزرگ برای آزمایش تاثیر روش های ابتکاری جدید تولید شده اند. در ابعاد کوچک و متوسط حداقل مقداری که بدست آمده است مربوط به CDH3 است که یکی از روش هایی است که در این مقاله پیشنهاد شده است. علاوه بر این در همه مقیاس ها نیز روش CDH4 بهترین در میان دیگران است. نتایج عددی نشان می دهد که روش های ابتکاری توسعه یافته در این مقاله می توانند پاسخ های خوب با همگرایی سریع پیدا کنند.

doi: *10.5829/ije.2019.32.02b.15*