

## Truck-to-door sequencing in multi-door cross-docking system with dock repeat truck holding pattern

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### ABSTRACT

Cross-docking is a logistics strategy that consolidates the products of different inbound trucks according to their destinations in order to reduce the inventory, order picking, and transportation costs. It requires a high level of collaboration between inbound trucks, internal operations, and outbound trucks. This article addresses the truck-to-door sequencing problem. Truck-to-door sequencing has been studied by some researchers in different titles such as scheduling and sequencing of inbound and outbound trucks of the cross-dock center. However, previous studies have not considered repeat truck holding pattern. Therefore, it is important to determine the doors and the sequence of the inbound and outbound trucks that should be assigned in a cross-dock center. This paper focuses on optimizing truck-to-door sequencing with consideration of repeat truck holding pattern in inbound trucks in order to minimize makespan. Two methods are considered to solve this problem, including mathematical modeling and a heuristic algorithm. In the first method, a mixed integer-programming model is developed to minimize the makespan. Then, GAMS software is used to solve small-scale problems. In the second approach, a heuristic algorithm is developed to find near-optimal solutions within the shortest time possible and the algorithm is used to solve large-scale problems. The results of the mathematical model and the heuristic algorithm are slightly different and show the good quality of the presented heuristic algorithm.

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## 1. Introduction

Cross-docking is considered as a logistics strategy and has drawn great attention from many large companies. These companies seek to reduce their costs by reducing inventory and storage time through applying this strategy. The basic idea of cross-docking is to transfer goods from inbound trucks to outbound trucks without using the storage step. In traditional warehouses, goods are received, classified, and finally stored. When a customer orders a product, workers load the product from dock and ship to a particular destination. Cross-docking intends to remove the storage and order picking steps. This is because they are among the most costly stages of distribution. For instance, storage cost includes the cost of storage of goods and labor.

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Cross-docking is divided into three-decision levels, which are strategic (Long term), tactical (mid-term), and operational levels (short term). Different research questions have been raised in these decision levels, but the operational level is the most attractive part for scholars and has been developed into the five research areas (Boysen & Fliedner, 2010; Van Belle et al., 2012). *Dock-door assignment* or *Truck-to-door assignment* tries to allocate trucks to doors optimally, and the time is considered not important. *Truck scheduling* includes the time dimension but does not take into account the order of trucks. *Truck sequencing* only considers the sequence of trucks. *Truck-to-door scheduling* only takes into account at which door and at what time the truck should be docked. *Truck-to-door sequencing* tries to address which door and in which order the truck should be docked when an inbound truck arrives at the cross-dock center (Ladier & Alpan, 2016; Van Belle et al., 2012).

When the problem of truck-to-door sequencing is mentioned, two different questions should be answered: at which door and in which order the trucks should be docked. Several scholars only answered the first question which has been called as truck-to-door assignment (Nassief et al., 2016; Yu & Egbelu, 2008), while others answered the second question, which has been considered as truck sequencing (Dondo & Cerdá, 2013; Fazel Zarandi et al., 2016; Larbi et al., 2009; Yazdani et al., 2015). Most studies tried to solve the cross-docking problems with one inbound and outbound door (Bolori Arabani et al., 2011; Cóccola et al., 2015; Liao et al., 2012; Maknoon & Baptiste, 2009; Yu & Egbelu, 2008), which is impractical in the real world (Wisittipanich & Hengmeechai, 2017). In general, the literature on truck-to-door sequencing focuses on the order or sequence of trucks and the doors which trucks should be assigned. In order to simulate real cross-dock operations, scholars should consider planning and scheduling problems with a realistic number of trucks and doors (Dondo & Cerdá, 2014; Shahin Moghadam et al., 2014; Wisittipanich & Hengmeechai, 2017). Li et al. (2004) presented research as a two-phase parallel machine scheduling problem with earliness and tardiness in an integer programming model. In this model, the jobs were trucks and doors were machines. This research aimed to process the trucks close to their due date and minimize the total deviation. McWilliams and his co-authors presented several studies related to truck-to-door sequencing (McWilliams, 2005, 2009, 2010; D. L. McWilliams, 2009; McWilliams. et al., 2005, 2008) in Parcel industry that included the scheduling of inbound trucks which after unloading, the products were transferred to the outbound trucks with conveyors. The research aimed to minimize the period with different assumptions. As a method, the author used a Genetic Algorithm (GA) in the simulation. In another study, McWilliams (2005) used a Simulated Annealing (SA) to solve the same problem. In continue of their research, they relaxed the assumption of the same size parcel and unloading time for all the inbound trucks, but the objective was the same (McWilliams et al., 2008).

Furthermore, McWilliams (2009) presented a minimax model to solve the parcel hub scheduling problem to minimize the timespan. In this study, the author used a decomposition method that relied on a combination of time and resource-based decomposition because simulation optimization is expensive in the application. In the five installments, McWilliams (2010) solved the model presented in the previous study but relaxed the assumption of same size inbound trucks and equal unloading time. In order to solve the problem, the simulated annealing and local search algorithm were presented. In addition to the presented articles by McWilliams (2010), another study has been presented by McWilliams (2009) to solve the static balance of the output station. Thus, a dynamic load balancing algorithm was developed to reduce the congestion of conveyor network flow. The result of the research was 8.6% better than the results of the static environment. All studies conducted by McWilliams and his co-authors only focused on inbound trucks (McWilliams, 2005, 2009, 2010; McWilliams, 2009; McWilliams. et al., 2005, 2008). Lim et al. (2006) presented an integer programming (IP) model to sequence and assigned the truck to doors, and the aim of the study was minimizing the total shipping distances inside the cross-dock center with consideration of the time window and capacity constraint. Following the same model, Miao et al. (2009) considered the sequencing of trucks where the number of trucks exceeded the number of doors. This problem was impacted by three factors, which were arrival and departure time, operational time for

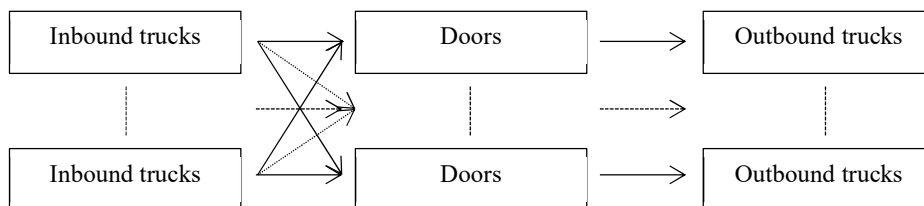
cargo shipment, and total capacity at the cross-dock center. This paper aimed to find the optimal sequence of trucks in order to minimize the operational cost of shipments and unfulfilled shipments.

Konur and Golias (2013) presented a bi-level optimization problem for pessimistic and optimistic approaches. The arrival time of inbound trucks are unknown, and in order to sequence the inbound trucks Genetic algorithm was proposed. Kuo (2013) developed a model intending to solve the sequencing and assignment of the inbound and outbound trucks simultaneously. In order to minimize the makespan, a variable neighborhood search algorithm was used. Madani-Isfahani et al. (2014) conducted a study with multiple cross-dock, assuming that each truck could be assigned only to one door, and there was one temporary storage with unlimited capacity. The aim was to minimize the makespan. The metaheuristic algorithm, such as simulated annealing and firefly algorithms was used to solve the problem. In continue, Wisittipanich and Hengmeechai (2017) proposed a truck scheduling problem in the multi-door cross-docking terminal. They presented a Mixed Integer Programming (MIP) model for minimizing the makespan and then solved the model with a modified PSO Meta-heuristic algorithm. In continue, Molavi et al. (2018) presented a truck scheduling model in a cross-docking area with consideration of fixed due dates. The proposed model was a MIP model, and in order to solve, they considered a hybrid genetic algorithm-reduced variable neighborhood search. The objective of the research was minimizing the delayed shipments and delivery cost of retained products.

To the best of our knowledge with reviewing the literature and according to the literature provided by Ladier and Alpan (2016), Wisittipanich and Hengmeechai (2017), and Ye et al. (2018) on truck-to-door sequencing, this paper is the first study that focuses on truck-to-door sequencing problem with consideration of pre-emption and continues the research presented by Wisittipanich and Hengmeechai (2017). A truck holding pattern can help managers have freedom in changing the sequence of trucks when they are faced with an uncertain environment. The paper is organized as follows. The problem is described in details in the next section, after which a section related to assumptions has been presented. A Mixed integer model is proposed and solved with GAMS software. Also, because the problem is NP-hard in a strong sense, a heuristic algorithm is developed. Finally, numerical result, conclusion, and future research are presented.

## 2. Problem Description

This study has been carried out to make a model according to the problem suggested by Yu (2002). Makespan refers to the time when the first product is unloaded from an inbound truck to the time when the last product is loaded in an outbound truck in cross-dock center. It must also be noted that secondary activities, such as labeling, and preparation, are not considered in this model. When inbound trucks enter the cross-dock center, all their products are unloaded. Then, products are transferred to outbound doors by the transfer system (conveyers or workers) and loaded in the outbound trucks. Here, there are several doors in the cross-dock center (Fig. 1). The inbound trucks enter the cross-dock center are assigned to inbound doors. Inbound trucks can move between doors, but the outbound doors are fixed. When assigned to outbound doors, each outbound truck stays in the same door until its capacity becomes full. Then, products are shipped to their respective destination. There is no space in the model for temporary storage.



**Fig. 1.** Assignment of inbound and outbound trucks to doors

### 2.1. Assumptions

The following assumptions are considered in this model:

1. Inbound and outbound trucks are presented in a cross-dock at a certain time  $t=0$ . They can be assigned to various doors simultaneously.
2. All inbound products must be transferred to outbound trucks without storage. This transfer is usually applied to fresh or frozen food products requiring temperature control.
3. The number of receiving products equals the number of shipping products.
4. There is no priority for products regarding loading and unloading.
5. It is also possible to unload receiving products as much as outbound trucks capacity. In other words, inbound truck 1 has 100 units of product 2 and 30 of product 3. The outbound truck only needs 80 units of product 1. Only the same 80 units are transferred, and the inbound truck leaves the doors and waits for the next assignment.
6. Inbound trucks stay at entrances only when the outbound trucks' needs are satisfied. Outbound trucks have no time limit for staying at exits.
7. No time is considered for secondary operations like product identification and labeling. Hence, it is assumed that immediately after the entrance of inbound truck, it can transfer its load to the dock and outbound truck.
8. Loading and unloading time of all products are the same for inbound and outbound trucks.
9. Delay time for changing all inbound and outbound trucks is the same and constant.
10. Constant time is considered for transferring products from an inbound truck to the outbound equal to one unit of time.
11. If trucks are displaced between two doors, docks change considered rather than truck change. Its value is different from the trucks changes.

### 3. Mathematical Modelling

The above assumptions were used for modeling the problem. Also, it was assumed that the number of inbound and outbound trucks must be more than the number of doors to simulate a real-world problem.

#### 3.1. Parameters

$n$	Number of products
$m$	Number of doors
$q$	Number of inbound trucks
$u$	Number of outbound trucks
$k$	Index for products where $k = \{1, 2, \dots, n\}$
$l, l'$	Index for doors where $l, l' = \{1, 2, \dots, m\}$
$i, h$	Index for inbound trucks where $i = \{1, 2, \dots, q\}$
$j, e$	Index for outbound trucks where $j = \{1, 2, \dots, u\}$
$r_{i,k}$	Number of units of product $k$ loaded in the inbound truck $i$
$s_{j,k}$	Number of units of product $k$ needed for outbound truck $j$
$t_{l,l'}$	Transportation time from door $l$ to door $l'$ .
$d$	Truck changeover time
$v$	Transportation time of products from inbound doors to outbound doors

#### 3.2. Binary Variables

$Y_{i,j,l}$	Binary variable taking value 1 if any product transferred from inbound truck $i$ to outbound truck $j$ at the door $l$ ; and Otherwise 0.
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- $Z_{i,h,l}$  Binary variable taking value 1 if inbound truck  $i$  precedes inbound truck  $h$  at the door  $l$ , and 0 otherwise.  $i \langle q, h \rangle i$
- $W_{j,e}$  Binary variable taking value 1 if outbound truck  $j$  precedes outbound truck  $e$ ; and 0 otherwise.  $j \langle u, e \rangle j$
- $H_{i,l}$  Binary variable taking value 1 if inbound truck  $i$  visits door  $l$ ; and 0 otherwise.
- $L_{j,l}$  Binary variable taking value 1 if the outbound truck  $j$  is assigned to the door  $l$ , and 0 otherwise.
- $G_{i,l,l'}$  Binary variable taking value 1 if inbound truck  $i$  visit door  $l$  before the door  $l'$ ; and 0 otherwise.  $l \langle m, l' \rangle l$ .

### 3.3. Continuous Variables

- $E_{i,l}^1$  Continuous variable for starting time of unloading the inbound truck  $i$  at the door  $l$ .
- $E_{i,l}^2$  Continuous variable for finishing time of unloading the inbound truck  $i$  at the door  $l$ .
- $F_j^1$  Continuous variable for starting time of loading outbound truck  $j$ .
- $F_j^2$  Continuous variable for finishing time of loading outbound truck  $j$ .
- $C_{max}$  Continuous variable for makespan

### 3.4. Integer Variables

- $X_{i,j,k,l}$  Integer variable for the number of units of product  $k$  transferred from inbound truck  $i$  to outbound truck  $j$  at the door  $l$ .  $X_{i,j,k,l} \in \mathbb{Z}$ .

### 3.5. Mixed Integer Programming Model

In this section, the mathematical model is presented:

$$\min C_{max} \quad (1)$$

subject to:

$$\sum_{j=1}^u \sum_{l=1}^m X_{i,j,k,l} = r_{i,k} \quad \forall_{i,k} \quad (2)$$

$$\sum_{i=1}^q \sum_{l=1}^m X_{i,j,k,l} = s_{j,k} \quad \forall_{j,k} \quad (3)$$

$$\sum_{k=1}^n X_{i,j,k,l} \leq M * Y_{i,j,l} \quad \forall_{i,j,l} \quad (4)$$

$$\sum_{j=1}^u Y_{i,j,l} \leq M * H_{i,l} \quad \forall_{i,l} \quad (5)$$

$$\sum_{l=1}^m L_{j,l} = 1 \quad \forall_j \quad (6)$$

$$\sum_{i=1}^q Y_{i,j,l} \leq M * L_{j,l} \quad \forall_{j,l} \quad (7)$$

$$E_{i,l}^2 \geq E_{i,l}^1 + \sum_{j=1}^u \sum_{k=1}^n X_{i,j,k,l} \quad \forall_{i,l} \quad (8)$$

$$E_{i,l}^1 \geq E_{i,l'}^2 + t_{i,l'} - M(3 - G_{i,l,l'} - H_{i,l} - H_{i,l'}) \quad \forall_{i,l \langle m,l' \rangle l} \quad (9)$$

$$E_{i,l'}^1 \geq E_{i,l}^2 + t_{i,l'} - M(2 + G_{i,l,l'} - H_{i,l} - H_{i,l'}) \quad \forall_{i,l \langle m,l' \rangle l} \quad (10)$$

$$E_{i,l}^1 \geq E_{h,l}^2 + d - M(3 - Z_{i,h,l} - H_{i,l} - H_{h,l}) \quad \forall_{i \langle q,h \rangle i,l} \quad (11)$$

$$E_{h,l}^1 \geq E_{i,l}^2 + d - M(2 + Z_{i,h,l} - H_{i,l} - H_{h,l}) \quad \forall_{i \langle q,h \rangle i,l} \quad (12)$$

$$F_j^2 \geq F_j^1 + \sum_{i=1}^q \sum_{k=1}^n \sum_{l=1}^m X_{i,j,k,l} \quad \forall_j \quad (13)$$

$$F_j^1 \geq F_e^2 + d - M(3 - W_{j,e} - L_{j,l} - L_{e,l}) \quad \forall_{j \langle u,e \rangle j,l} \quad (14)$$

$$F_e^1 \geq F_j^2 + d - M(2 + W_{j,e} - L_{j,l} - L_{e,l}) \quad \forall_{j \langle u,e \rangle j,l} \quad (15)$$

$$F_j^2 \geq E_{i,l}^1 + v + \sum_{k=1}^n X_{i,j,k,l} - M(1 - Y_{i,j,l}) \quad \forall_{i,j,l} \quad (16)$$

$$C_{max} \geq F_j^2 \quad \forall_j \quad (17)$$

The objective, as presented by Eq. (1), is to minimize makespan. Constraint (2) states that the total number of product  $k$  transferred from inbound truck  $i$  to all outbound trucks at door  $l$  is the same as the number of product  $k$  first loaded in inbound truck  $i$ . Similarly, constraint (3) states that total number of product  $k$  transferred from all inbound trucks to each outbound truck  $j$  at door  $l$  is the same as the number of product  $k$  required for each outbound truck  $j$ . Constraint (4) establishes proper relationship between transfer variable  $Y_{i,j,l}$  and decision variable  $X_{i,j,k,l}$ . Constraint (5) states that a product will be transferred from the truck  $i$  to truck  $j$  at door  $l$  if inbound truck  $i$  is assigned to door  $l$ . Constraint (6) states that each outbound truck  $j$  is only assigned to a door and stays in the same station until it is fully loaded. Constraint (7) states that if outbound truck  $j$  is assigned to door  $l$ , it will be possible to load product to the outbound truck. Constraints (8), (9), and (10) control the assignment and entering and leaving time of inbound trucks. It should also be mentioned that constraints (9) and (10) indicate the repeat truck holding pattern in inbound trucks. Constraint (11) and (12) control the sequence and entering and leaving time for inbound trucks. Constraints (13) to (15) control the sequence and leaving time for the outbound trucks. Constraint (16) shows the relationship between the leaving time of outbound trucks and entering time of inbound trucks if a product is transferred. Constraint (17) considers the completion time as the same as the time of the last outbound trucks leaving outbound doors.

#### 4. Solution method

##### *Heuristic Algorithm*

In order to solve a large model, a heuristic algorithm is presented. Similar assumptions of the model were considered for developing the heuristic algorithm. However, the number of inbound and outbound trucks must be larger than the number of doors. The most important strategy is to consider the maximum capacity of product transfer in all presented methods. The heuristic method is to minimize makespan. The basic idea of the heuristic methods has been derived from the study of Yu (2002) with the main differences being considering repeat truck holding pattern and sequencing of inbound and outbound trucks. The outbound truck stays in the dock until the loading of the truck completes. In the first step, a sequence of inbound and outbound trucks is obtained. Then, the makespan is calculated. Three selection criteria (SC) are presented in the first step, and the second step, these conditions will be added and tested. In each reiteration, the number of inbound trucks is selected to match the number of doors. In the first reiteration, outbound trucks are selected for doors. They stay in docks until capacity completion. This is different for inbound trucks. After the selection of trucks based on the number of doors, the information about the process of assignment is updated. The number of products remains constant in the inbound trucks, and the empty capacity for outbound trucks is determined. The process of transferring inbound

trucks and updating the table is carried out to the satisfaction of inbound and outbound trucks. Heuristic algorithms with six SC are as follow:

1. SC1: maximum products transfer
2. SC2: maximum ratio between products transfer
3. SC3: maximum fit between products transfer
4. SC4: maximum products transfer regarding priority condition
5. SC5: maximum products transfer ratio regarding priority condition
6. SC6: maximum fit between products transfer regarding priority condition

SC 1, 2, and 3 comply with the same trend except for the time when the algorithm seeks for selecting the same number of trucks as doors. In each reiteration, the most suitable trucks are selected based on selection criteria. SC 4, 5, and 6 are partially changed versions of SC 1, 2, and 3. They follow the same rules as SC 1, 2, and 3 but have a priority condition regarding the assignment. In reiterations of this algorithm, if there is a set of trucks meeting priority condition, SC 1, 2, and 3 will be computed for the trucks. Then, the best trucks are selected among them. Otherwise, in reiterations, the algorithm will automatically change into algorithms 1, 2, and 3. It should be noted that our study considers a different problem based on the presented method by Yu (2002). The main difference is in the selection of each pair as we have more than one door, so we need to select trucks according to the number of doors. The method for updating the trucks as we have repeat truck holding pattern. Finally, in order for calculating the makespan because it is completely related to a penalty that will pay for changing trucks.

#### *Priority conditions*

In priority condition, assume that a certain type of product is only placed along with the sequences of an algorithm in an inbound truck. This indicates that all outbound trucks requiring that product are paired with the inbound truck carrying that product. For instance, assume that we have four inbound trucks, four outbound trucks, and two doors. In algorithm reiterations, product 3 is only loaded on inbound truck 4. Trucks 1, 2, and 3 do not carry product 3. Outbound trucks 2 and 3 need product 3. Outbound truck 1 and 4 do not need product 3. Hence, outbound trucks 2 and 3 must be paired with inbound truck 4. The same rules must also be considered for outbound trucks. Assume that an outbound truck receives only one type of product. Other outbound trucks do not need that product, however. All inbound trucks with that particular product are paired with that outbound truck needing that product.

#### *4.1. SC 1 -maximum products transfer*

For the heuristic algorithm, we calculate the total number of products which can be transferred from inbound trucks to outbound trucks for all pairs. Then, we select the pair with a maximum number of products transferred from inbound trucks to outbound trucks. It must be noted that the number of inbound trucks is selected based on the number of existing doors. For instance, if we have three doors, three trucks must also be selected in each reiteration unless there is no inbound or outbound truck to be selected. Upon the selection of the best set of trucks, the number of products remained in inbound trucks and the number of products required for outbound trucks is updated for the following reiterations. These reiterations will continue until the satisfaction of inbound and outbound trucks.

#### *Heuristic Algorithm with SC 1*

**Step 1:** For each pair of inbound truck  $i$  and outbound truck  $j$ , the number of products transferred from receiving trucks to outbound trucks is computed.

$$\mu_{ij} = \sum_{K=1}^N \min(r_{i,k}, s_{j,k}) \quad (18)$$

$\mu_{ij}$ : Total product units transferred from an inbound truck  $i$  and outbound truck  $j$

$r_{i,k}$ : Total units of product  $k$  loaded in the inbound truck  $i$  in algorithm reiterations

$s_{j,k}$ : Total units of product  $k$  required in outbound truck  $j$  in algorithm reiterations

**Step 2:** If all  $\mu_{ij}$  equal 0, the algorithm is stopped. A response is obtained for the model. Otherwise, if there is any non-zero  $\mu_{ij}$ , those pairs (as the same number as doors) with maximum  $\mu_{ij}$  are selected. If some cases have the same amount, the most suitable pairs are selected after calculation.

**Step 3:** The number of products remained for inbound and outbound trucks is updated and then go back to Step 1.

#### 4.2. Heuristic Algorithm with SC 2 -Maximum Ratio between Products Transfer

Here, the between-pair ratio  $\theta_{ij}$  is expanded for selecting pairs. The ratio  $\theta_{ij}$  for inbound trucks  $i$  and outbound truck  $j$  is defined as follow:

$$\theta_{ij} = \frac{\sum_{K=1}^N \min(r_{i,k}, s_{j,k})}{\sum_{K=1}^N \max(r_{i,k}, s_{j,k})} \quad (19)$$

$r_{i,k}=0 \text{ or } s_{j,k}=0$        $r_{i,k}=0 \text{ or } s_{j,k}=0$

$\theta_{ij}$ : Ratio for inbound trucks  $i$  and outbound truck  $j$  pair

$r_{i,k}$ : Total units of product  $k$  loaded in the inbound truck  $i$  in algorithm reiterations

$s_{j,k}$ : Total units of product  $k$  required in outbound truck  $j$  in algorithm reiterations

Given that if the denominator is 0, the total term will be considered 0.

Pairs ratio  $\theta_{ij}$  can be considered as the correlation between inbound trucks  $i$  and outbound truck  $j$ .  $\theta_{ij}$  ratio interval is between 0 and 1.  $\theta_{ij}=0$  indicates that there is no relationship between inbound and outbound trucks. On the other hand, the outbound truck needs no product from the inbound truck. Yet,  $\theta_{ij}=1$  indicates that the number and type of products are the same for inbound and outbound trucks.

#### Heuristic Algorithm with SC 2

**Step 1:** For each pair of inbound trucks  $i$  and outbound truck  $j$ , inbound trucks  $i$  and outbound truck  $j$  ratio is calculated by Eq. (19).

**Step 2:** If all  $\theta_{ij}=0$ , the algorithm is stopped. A response is obtained for the model. Otherwise, if there is any non-zero  $\theta_{ij}$ , those pairs (as the same number as doors) with maximum  $\theta_{ij}$  are selected. If some cases have the same value, the best pairs are selected after calculating the problems.



**Step 3:** The number of products remained for inbound and outbound trucks is updated and then go back to Step 1.

#### 4.3. Heuristic Algorithm with SC 3 -Maximum Fit between Products Transfer

Pairs fit  $\lambda_{ij}$  was established for SC 3. It can be considered as a correlation between inbound and outbound trucks. Yet, it differs from SC 2 in that  $\lambda_{ij}$  provides the same weight from the type of products regardless of number of products loaded.

$\lambda_{ij}$  ratio interval is between 0 and 1.  $\lambda_{ij}=0$  indicates that there is no relationship between inbound and outbound trucks. On the other hand, the outbound truck needs no product from the inbound truck. Yet,  $\lambda_{ij}=1$  indicates that the number and type of products are the same for inbound and outbound trucks.  $\lambda_{ij}$  fit for inbound and outbound pairs is stated as follow:

$$\lambda_{ij} = \frac{\sum_{k=1}^N \frac{\min(r_{i,k}, s_{j,k})}{\max(r_{i,k}, s_{j,k})}}{\sum_{k=1}^N 1} \quad (20)$$

$\lambda_{ij}$ : Inbound truck  $i$  and outbound truck  $j$  pair fit

$r_{i,k}$ : Total units of product  $k$  loaded in the inbound truck  $i$  in algorithm reiterations

$s_{j,k}$ : Total units of product  $k$  required in outbound truck  $j$  in algorithm reiterations

Denominator indicates a number of products loaded in the inbound truck  $i$  and outbound truck  $j$ .

Given that if the denominator is 0, the total term will be considered 0.

#### Heuristic Algorithm with SC 3

**Step 1:** For each pair of inbound truck  $i$  and outbound truck  $j$ , inbound truck  $i$  and outbound truck  $j$  fit is calculated by Eq. (20).

**Step 2:** If all  $\lambda_{ij}=0$ , the algorithm is stopped. A response is obtained for the model. Otherwise, if there is any non-zero  $\lambda_{ij}$ , those pairs (as the same number as doors) with maximum  $\lambda_{ij}$  are selected. If some cases have the same amount, we will calculate this problem and select the best result.

**Step 3:** We update the number of products remained for inbound and outbound trucks and went back to Step 1. As also mentioned in previous sections, heuristic algorithms 1, 2, and 3 follow the same trends. Yet, they apply different rules for selecting the best pairs. Fig. 2 illustrates a heuristic algorithm function in a stepwise manner in a flowchart.

#### Heuristic Algorithm with SC 4

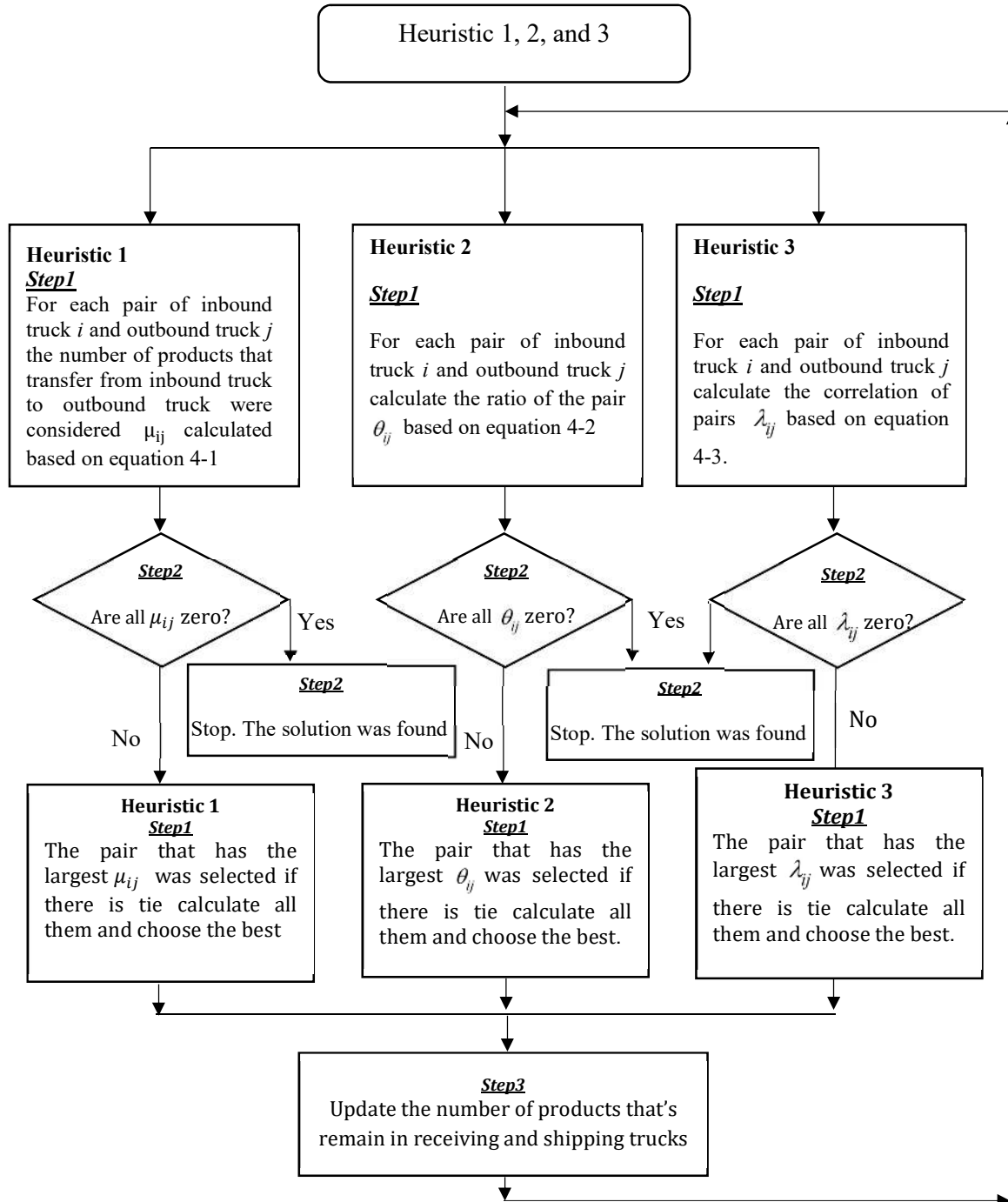
**Step 1:** We identify all pairs meeting priority condition. That is, if a certain product exists in only one truck, we identify all pairs requiring that product for loading and if a product is received by a truck, all trucks can be unloaded to that truck.

**Step 2:** If a pair satisfying priority condition is identified, we go to 2-a. Otherwise, we go to 2-b.

**2-a:** We use a heuristic algorithm with SC 1 on pairs satisfying priority condition. Then, we go to section 1. Also, it should also be noted that if you have to select three pairs and three doors, yet you have two pairs based on priority condition, you obtain the third pair from 2-b.

**2-b:** We use a heuristic algorithm with SC 1.

**Step 3:** We update the number of products remained for inbound and outbound trucks. Then, we go to step 1.



**Fig. 2.** Flowchart of the heuristic algorithm with SC 1, 2, and 3 adopted from (Yu & Egbelu, 2008)

#### 4.5. Heuristic Algorithm with SC 5-Maximum Products Transfer Ratio in Priority Condition

It is precisely the same heuristic algorithm with SC 2; except pairs satisfying priority condition in algorithm reiterations. Priority conditions are considered for these pairs. They are executed in heuristic algorithm 2 for pairs. Otherwise, a heuristic algorithm with SC 5 changes into heuristic algorithm 2 in that reiteration.

##### *Heuristic Algorithm with SC 5*

**Step 1:** We identify all pairs meeting priority condition. That is, if only a certain product exists in only one truck, we identify all pairs requiring that product for loading and if a product is received by a truck, all trucks able to load to that truck.

**Step 2:** If a pair satisfying priority condition is identified, we go to 2-a. Otherwise, we go to 2-b.

**2-a:** We use a heuristic algorithm with SC 1 on pairs satisfying priority condition. Then, we go to section 1. Yet, it must also be noted that if, say, you have to select three pairs and three doors yet you have two pairs based on priority condition, you obtain the third pair from 2-b.

#### 4.6. Heuristic Algorithm with SC 6-Maximum Products Transfer regarding Priority Condition

It is exactly the same heuristic algorithm with SC 3; except pairs satisfying priority condition in algorithm reiterations. Priority conditions are considered for these pairs. They are executed in a heuristic algorithm with SC 3 for pairs. Otherwise, a heuristic algorithm with SC 6 changes into heuristic algorithm 3 in that reiteration.

##### *Heuristic Algorithm with SC 6*

**Step 1:** We identify all pairs meeting priority condition. That is, if only a certain product exists in only one truck, we identify all pairs requiring that product for loading and if a product is received by a truck, all trucks able to shipload to that truck.

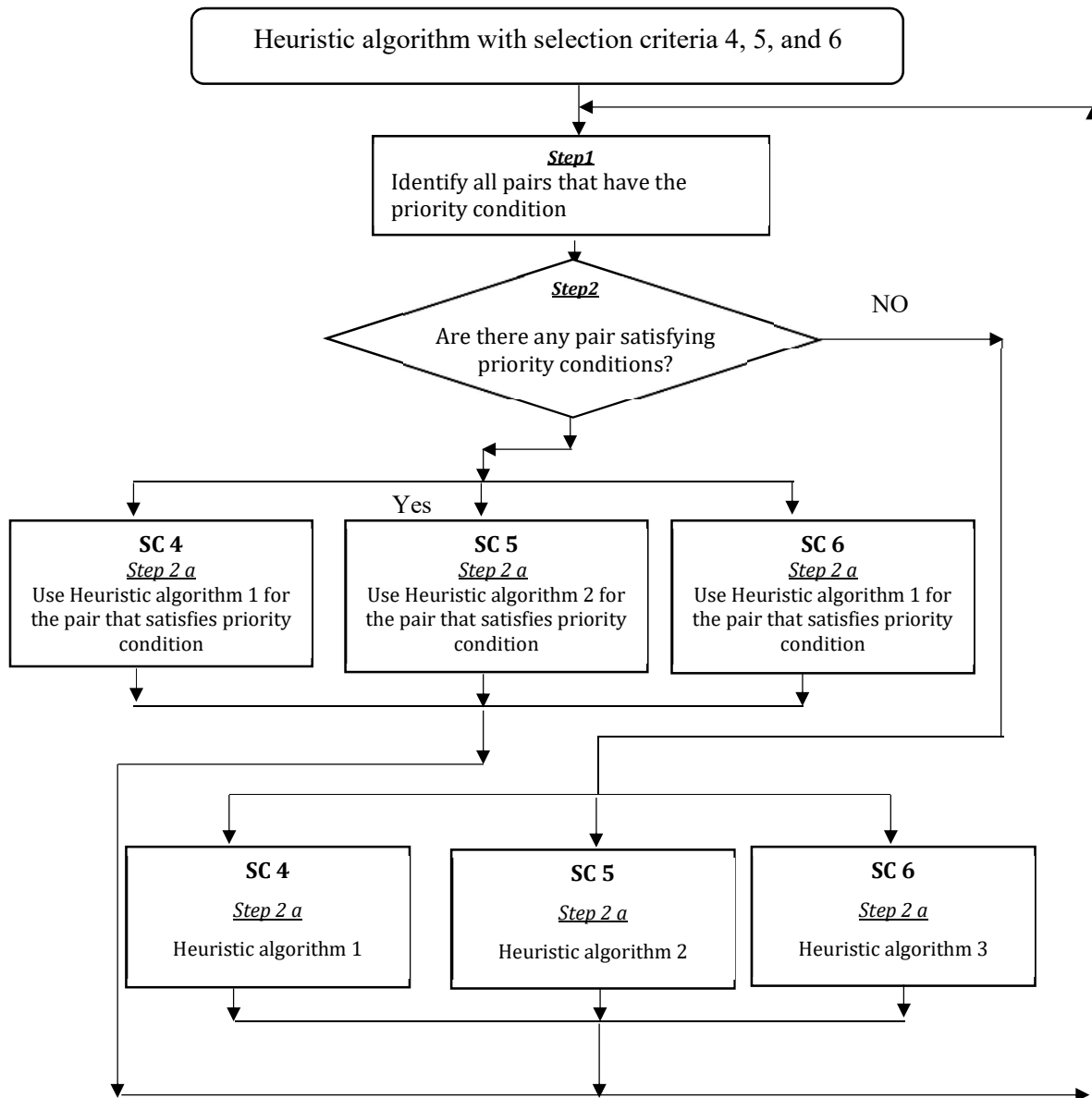
**Step 2:** If a pair satisfying priority condition is identified, we go to 2-a. Otherwise, we go to 2-b.

**2-a:** We use a heuristic algorithm with SC 1 on pairs satisfying priority condition. Then, we go to section 1. It must also be noted that if, say, we have to select three pairs and three doors yet we have two pairs based on priority condition and we obtain the third pair from 2-b.

Fig. 3 illustrates a heuristic algorithm with selection criteria 4, 5, and 6 functions in a stepwise manner in a flowchart.

## 5. Makespan

Based on the Heuristic algorithm with six SC presented above, a response includes the sequence of inbound and outbound trucks, their assignment to each door, and the total number of products transferred from inbound trucks to outbound trucks is obtained. Based on this information, the makespan of the cross-dock center is calculated. Besides, due to the dynamic nature of the cross-dock center, we cannot obtain makespan by an equation. Accordingly, one method is developed for setting the makespan based on Yu and Egbelu (2008). Hence, the entry time of inbound trucks into inbound doors until unloading as well as the movement of outbound trucks toward leaving doors until loading is calculated. In this section, it is assumed that loading and unloading time is the same; it equals to a time unit.



**Fig. 3.** Flowchart of the heuristic algorithm with SC 4, 5, and 6 adopted from (Yu & Egbelu, 2008).

### 5.1. Notation

$T$ :	Makespan
$E_{[i],t}^2$ :	When inbound truck $i$ in the inbound truck sequence leaves the receiving door.
$F_j^2$ :	When outbound truck $j$ in the outbound truck sequence leaves the outbound door.
$n$ :	Number of products
$m$ :	Number of doors.
$q$ :	Number of Inbound trucks.
$u$ :	Number of outbound trucks.
$r_{i,k}$ :	Number of units of product $k$ loaded in the inbound truck $i$ .
$s_{j,k}$ :	Number of units of product $k$ needed for outbound truck $j$ .
$d$ :	Truck changeover time.
$v$ :	Transportation time of products from inbound doors to outbound doors

$t_{l,l'}$ : Transportation time from door  $l$  to door  $l'$ .

### 5.1.1. Variables

$C$ : Binary variable taking value 1 if an inbound truck moves between doors; and 0 otherwise.

$X_{i,j,k,l}$ : Integer variable for the number of units of product  $k$  transferred from inbound truck  $i$  to outbound truck  $j$ .

$Y_{i,j}$ : Binary variable taking value 1 if any product transferred from inbound truck  $i$  to outbound truck  $j$  at door  $l$ ; and 0 otherwise.

### 5.2. Makespan Calculation

Makespan is obtained by finding the leaving time for inbound and outbound trucks. Stepwise computation method is explained in the following.

**Step 1.** The leaving time for inbound trucks is calculated based on the sequence of inbound trucks. The leaving time for the first scheduled inbound truck  $i$  from door  $l$  is determined as follow:

$$E_{[1],l}^2 = \sum_{K=1}^N r_{[1]k} \quad (21)$$

The leaving time of the scheduled truck  $E_{[1],l}^2$  from door  $l$  is precisely the same as the time taken to unload the first inbound truck.

**Step 2.** The leaving time for inbound trucks is calculated based on the sequence of inbound trucks. The leaving time for the first scheduled inbound truck  $i$  from door  $l$  is determined as follow:

$$E_{[i],l}^2 = E_{[i-1],l}^2 + d \times (1-C) + t_{l,l'} \times C + \sum_{K=1}^N r_{[i]k} \quad 2 < i < q \quad (22)$$

The leaving time of the scheduled truck  $E_{[i],l}^2$  from door  $l$  is exactly the same as the time taken to unload next trucks as well as the leaving time of the first truck and the time of movement between doors and trucks changeover.

The leaving time for outbound trucks is related to the sequence of trucks leaving the doors. To calculate the departure time of  $j$ -th outbound trucks scheduled, equations 23, 24 and 25 are used.

$$F_j^2 = \max \{ \alpha_1, \alpha_2 \} \quad (23)$$

$$\alpha_1 = \max_{1 \leq i \leq R} \{ Y_{[i][j]} \times (E_{[i],l}^2 + V) \} \quad (24)$$

$$\alpha_2 = E_{[i-1],l}^2 + d + \sum_{K=1}^N s_{[j]k} \quad (25)$$

After calculating the above cases,  $F_j^2$  with the highest value is selected.

### 5.3. Numerical results

We randomly generated 60 test sets according to those generated by Yu (2002), 20 test sets for the small size problem and 40 test sets for the large size problem. In the small size problem, the proposed mathematical model was codified in GAMS. This software was used for solving the model. Then we ran the model in this software for 20 test sets, and the results are presented in Table 1. Then the heuristic

algorithm solved these 20 test sets, and the results are presented in the same table. These problems were used to evaluate the performance of the mathematical models. We also evaluated the performance of the heuristic algorithm and compared the results. Accordingly, numerical tests were applied to evaluate performance in Table 1. As seen in Table 1, the minimum deviation as compared to the optimal software response is 2.19%, and the maximum is 11.34%.

The second test includes problems in a larger size. Results regarding their performance are presented in Table 2. As it can be seen in Table 2, in instance number five, a total number of the sequence are equal to  $(m!) \times (n!) \times (q!) \times (u!) = 6! \times 5! \times 4! \times 3! = 12441600$  that shows the problem is NP-HARD. Based on the results of evaluating the mathematical model, we realized that as the problem size increases, the software is no longer capable of solving these problems.

Consequently, the software was given the 2000s with smaller sizes to solve the respective problems. Finally, test problems were in the largest size that could be solved by GAMS, but responses provided in the 2000s were not optimum. It is also noteworthy that the heuristic algorithm provided results in less than 10s. Results of Table 2 include the optimal response presented by GAMS as well as a heuristic algorithm. In addition, the deviation percentage of results obtained from the best heuristic algorithm or optimal software result is reported in Table 2. The heuristic algorithm was also executed by MATLAB programming language and by a computer with the processing power of 2.4GHz Intel Core i7 and 6GB RAM.

In the next step, we solved problems which could not be solved by GAMS. In this section, 40 problems were generated. The performance index used for comparing the algorithm results is Relative Percentage Difference (RPD). In calculating this index, each problem was solved by a heuristic algorithm with six SC. Since the target function value was different for each problem, it could not be directly compared. Hence, the relative deviation percentage was applied for problem-solving. After solving all problems for each size, the best response obtained for each problem (i.e. the least makespan.) was computed as  $Min_{sol}$ . Then, the relative deviation percentage was computed by the following formula. Results are presented in Table 2.

$$RPD = \frac{Alg_{sol} - Min_{sol}}{Min_{sol}} \times 100 \quad (26)$$

To obtain more accurate results, ANOVA was also used. Regression analysis was done, i.e. analyzing and modeling the relationship between a response variable and one or more independent variables. It differs from the regression in two terms: 1) independent variables are qualitative (classified), and 2) there is no assumption about the nature of the relationship. That is, the model does not guarantee any indices for variables.

ANOVA is applied to compare group means. To do so, we consider  $H_0$  and  $H_1$ .  $H_0$  represents equal means between more than two groups.  $H_1$  represents the constraint of at least one of them with others. Based on  $H_0$ , the respective factor does not create a significant difference between the mean and distribution place of data. When  $H_0$  is rejected (and, as a result,  $H_1$  is approved), it can be concluded that the respective factor is effective and can create a significant difference between the least mean of a group and other groups (Tables 3 and 4).

ANOVA's capability in MINITAB includes approaches for analysis of models and one-way variance fit with data from various designs. Also, multivariate models in MINITAB fit with designs having several responses, special diagrams for testing variances equality, confidence intervals diagrams, and main and opposite effects diagrams. Therefore, we carried out this analysis using MINITAB 16. Further analysis has been done using the Least Significant Difference (LSD). This test has also been carried out by MINITAB 16. Test results have been presented in Tables 5 and 6.

**Table 1**  
Examples results in small size

PB	Inbound Trucks	Outbound Trucks	Products Type	Number of Doors	Total Number Products	Final solve	Cpu time Gams	Best Possible	explanation	HSC1	HSC2	HSC3	HSC4	HSC5	HSC6	Compound	Percentage Deviation of Makespan
1	3	5	7	2	890	562	3 sec	562	optimal	610	741	641	714	661	641	610	7.87
	3	5	7	2	1352	813	29	813	optimal	860	993	967	1030	869	967	860	5.47
	3	5	7	2	1396	876	18	876	optimal	923	1251	1103	988	1105	1105	923	5.09
	3	5	7	2	1712	1091	45	1091	optimal	1163	1137	1351	1163	1199	1148	1137	4.05
	3	5	7	2	2156	1236	84	1236	optimal	1666	1539	1319	1586	1390	1319	1319	6.29
2	4	3	7	2	1150	600	97	600	optimal	670	690	780	630	639	620	620	3.23
	4	3	7	2	2022	1151	280	1151	optimal	1203	1397	1406	1321	1442	1387	1203	4.3
	4	3	7	2	2387	1389	320	1389	optimal	1442	1663	1731	1512	1702	1680	1442	3.67
	4	3	7	2	1474	892	255	892	optimal	1012	1387	912	1012	1087	912	912	2.19
	4	3	7	2	1814	982	269	982	optimal	1101	1074	1060	1164	1114	1198	1060	7.36
3	5	4	6	2	980	571	1888	571	optimal	606	792	779	754	759	674	606	5.77
	5	4	6	2	1287	755	1970	755	optimal	849	966	939	799	911	949	799	5.5
	5	4	6	2	1291	731	1977	731	optimal	898	792	994	950	994	994	792	7.7
	5	4	6	2	1384	827	1958	827	optimal	990	1074	937	990	1154	890	890	8.07
	5	4	6	2	1460	837	1978	837	optimal	929	913	941	929	913	941	913	8.32
4	4	4	5	2	1020	649	1809	649	optimal	801	685	776	801	801	776	685	5.25
	4	4	5	2	1304	720	1885	720	optimal	748	826	751	764	826	770	748	3.7
	4	4	5	2	1274	753	1863	753	optimal	809	956	926	803	971	1007	803	6.23
	4	4	5	2	1401	798	1903	798	optimal	917	970	860	1066	1019	1010	860	7.21
	4	4	5	2	962	614	1780	614	optimal	782	838	653	798	819	788	653	5.97

**Table 2**  
Examples results in large size

PB	Inbound Trucks	Outbound Trucks	Products Type	Number of Doors	Total Number Products	HSC1	HSC 2	HSC 3	HSC 4	HSC 5	HSC 6	Compound	RPD HSC 1	RPD HSC 2	RPD HSC 3	RPD HSC 4	RPD HSC 5	RPD HSC 6
5	6	5	4	3	2030	932	990	1123	1155	1340	1361	932	0.00	6.22	20.49	23.93	43.78	46.03
	6	5	4	3	1456	749	815	698	749	1127	866	698	6.81	16.76	0.00	7.31	61.46	24.07
	6	5	4	3	1697	1141	952	789	1003	900	692	692	39.35	37.57	14.02	44.94	30.06	0.00
	6	5	4	3	1549	959	780	949	1122	858	989	780	18.67	0.00	21.67	43.85	10.00	26.79
	6	5	4	3	1246	642	794	720	776	813	778	642	0.00	23.68	12.15	20.87	26.64	21.18
6	5	5	5	3	1033	502	643	530	526	681	519	502	0.00	28.09	5.58	4.78	35.66	3.39
	5	5	5	3	2128	912	1070	1049	1168	1231	1190	912	0.00	17.32	15.02	28.07	34.98	30.48
	5	5	5	3	1574	863	1051	897	804	1018	1148	804	6.84	30.72	11.57	0.00	26.62	42.79
	5	5	5	3	1122	509	572	655	711	683	679	509	0.00	12.38	28.68	39.69	34.18	33.40
	5	5	5	3	1489	787	973	707	798	1053	993	707	10.17	37.62	0.00	12.87	48.94	40.45
7	5	6	4	4	1371	700	596	559	738	620	752	559	20.14	6.62	0.00	32.02	10.91	34.53
	5	6	4	4	1399	729	595	698	725	629	707	595	18.38	0.00	17.31	21.85	5.71	18.82
	5	6	4	4	1151	473	591	515	412	593	515	412	12.90	43.45	25.00	0.00	43.93	25.00
	5	6	4	4	1312	601	699	600	605	536	618	536	10.82	30.41	11.94	12.87	0.00	15.30
	5	6	4	4	1226	530	559	606	544	520	585	520	1.89	7.50	16.54	4.62	0.00	12.50
8	6	6	6	4	1703	657	794	801	912	756	797	657	0.00	20.85	21.92	38.81	15.07	21.31
	6	6	6	4	1848	810	841	847	851	993	1010	810	0.00	3.83	4.57	5.06	22.59	24.69
	6	6	6	4	1912	766	790	856	607	700	836	607	20.76	30.15	41.02	0.00	15.32	37.73
	6	6	6	4	2069	648	843	960	648	919	1120	648	0.00	30.09	48.15	0.00	41.82	72.84
	6	6	6	4	1599	696	972	873	627	827	895	627	9.91	55.02	39.23	0.00	31.90	42.74
9	6	7	4	4	1563	568	854	733	636	759	729	568	0.00	50.35	29.05	11.97	33.63	28.35
	6	7	4	4	1620	695	834	770	709	1090	804	695	0.00	20.00	10.79	2.01	56.83	15.68
	6	7	4	4	1402	514	651	591	529	539	726	514	0.00	26.65	14.98	2.92	4.86	41.25
	6	7	4	4	1695	628	730	541	676	797	667	541	13.85	34.94	0.00	24.95	47.32	23.29
	6	7	4	4	1798	654	870	746	825	865	900	654	0.00	33.03	14.07	26.15	32.26	37.61
10	7	7	4	4	2623	813	1122	1153	798	1220	1145	798	1.85	40.60	44.49	0.00	52.88	43.48
	7	7	4	4	1785	705	795	675	639	869	652	639	9.36	24.41	5.63	0.00	35.99	2.03
	7	7	4	4	1946	712	958	883	723	791	933	712	0.00	34.55	24.02	1.54	11.10	31.04
	7	7	4	4	1617	700	764	830	794	998	867	700	0.00	9.14	18.57	13.43	42.57	23.86
	7	7	4	4	1505	710	892	727	693	845	935	693	2.39	28.72	4.91	0.00	21.93	34.92
11	8	7	4	4	1658	674	851	803	812	953	793	674	0.00	26.26	19.14	20.47	41.39	17.66
	8	7	4	4	1911	779	918	799	687	861	903	687	11.81	33.62	16.30	0.00	25.33	31.44
	8	7	4	4	1275	487	709	743	523	702	662	487	0.00	45.59	52.57	7.39	44.15	35.93
	8	7	4	4	1311	504	564	543	490	699	673	490	2.78	15.10	10.82	0.00	42.65	37.35
	8	7	4	4	1741	637	801	660	795	823	676	637	0.00	25.75	3.61	24.80	29.20	6.12
12	8	8	4	5	1693	597	680	712	558	685	892	558	6.53	21.86	27.60	0.00	22.76	59.86
	8	8	4	5	1482	505	587	686	559	666	729	505	0.00	16.24	35.84	10.69	31.88	44.36
	8	8	4	5	1677	554	644	690	591	586	909	554	0.00	16.25	24.55	6.68	5.78	64.08
	8	8	4	5	1161	472	587	461	431	640	600	431	8.69	36.19	6.96	0.00	48.49	39.21
	8	8	4	5	1614	563	544	777	516	618	753	516	8.35	5.43	50.58	0.00	19.77	45.93



**Table 3**  
ANOVA results

Source	DF	SS	MS	F	P
Algorithm	5	19591	3918	20.10	0.000
Error	234	45605	195		
Total	239	65196			

**Table 4**  
Individual 95% CIs For Mean Based on Pooled StDev and grouping Information

Level	N	Mean	StDev	Grouping
HSC1	40	6.06	8.49	A
HSC2	40	24.67	13.76	D
HSC3	40	18.45	14.19	C
HSC4	40	12.36	13.92	B
HSC5	40	30.86	16.04	E
HSC6	40	31.92	15.99	E

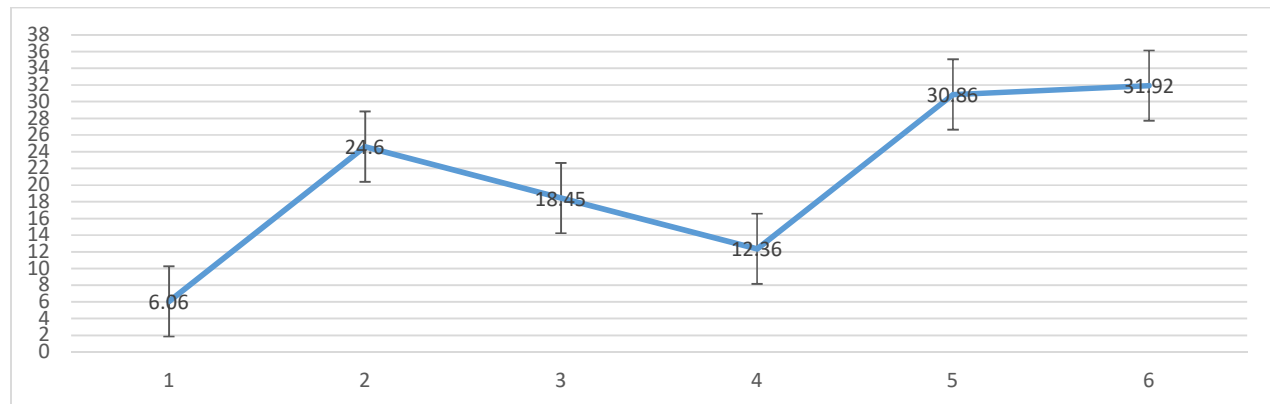
**Table 5**  
Fisher 90% Individual confidence intervals all pairwise comparisons

Algorithms	Lower	Center	Upper
HSC1 and HSC2	13.36	18.52	23.67
HSC1 and HSC3	7.24	12.39	17.55
HSC1 and HSC4	1.15	6.31	11.46
HSC1 and HSC5	18.55	23.70	28.86
HSC1 and HSC6	19.71	24.86	30.02
HSC2 and HSC3	-11.28	-6.12	-0.97
HSC2 and HSC4	-17.37	-12.21	-7.06
HSC2 and HSC5	0.03	5.18	10.34
HSC2 and HSC6	1.19	6.34	11.50
HSC3 and HSC4	-11.24	-6.09	-0.93
HSC3 and HSC5	6.15	11.31	16.46
HSC3 and HSC6	7.31	12.47	17.62
HSC4 and HSC5	12.24	17.39	22.55
HSC4 and HSC6	13.40	18.55	23.71
HSC5 and HSC6	-4.00	1.16	6.31

Based on the results of the algorithms, we found that  $P\text{-value} < \alpha$  in Table 3. Hence,  $H_0$  representing equal samples' means is rejected. We used the Least Significant Difference (LSD) for further examination. This method is applied to the paired comparison of factor levels' means. As compared to other methods, the advantage of this method is that it includes all states. First, we conducted LSD calculations and the paired comparison of algorithms.

$$LSD = t_{\frac{\alpha}{2}, N-a} \times \sqrt{MSE \times \left( \frac{1}{n_i} + \frac{1}{n_j} \right)} = 6.18$$

Before determining LSD, the diagram of means' heuristic algorithms with six SC is displayed in Fig. 2.

**Fig. 2.** Means comparison

This diagram shows the mean difference in the heuristic algorithm.

Now, we conduct a paired comparison. According to the results in Table 6, SC1 is the best compared to other SCs, and after that, SC4 is better than the others.

**Table 6**

**A Paired comparison**

<i>Algorithms</i>	<i>Lower</i>
<i>HSC1 and HSC2</i>	24.67-6.06=18.61 > 6.18
<i>HSC1 and HSC3</i>	18.45-6.06=12.45 > 6.18
<i>HSC1 and HSC4</i>	12.36-6.06=6.3 > 6.18
<i>HSC1 and HSC5</i>	30.86-6.06=24.8 > 6.18
<i>HSC1 and HSC6</i>	31.92-6.06=25.86 > 6.18
<i>HSC2 and HSC3</i>	24.67-18.45=6.22 > 6.18
<i>HSC2 and HSC4</i>	24.67-12.36=12.31 > 6.18
<i>HSC2 and HSC5</i>	30.86-24.67=6.19 > 6.18
<i>HSC2 and HSC6</i>	31.92-24.67=7.25 > 6.18
<i>HSC3 and HSC4</i>	18.45-12.36=6.09 < 6.18
<i>HSC3 and HSC5</i>	30.86-18.45=12.41 > 6.18
<i>HSC3 and HSC6</i>	31.92-18.45=13.47 > 6.18
<i>HSC4 and HSC5</i>	30.86-12.36=18.5 > 6.18
<i>HSC4 and HSC6</i>	31.92-12.36=19.56 > 6.18
<i>HSC5 and HSC6</i>	31.92-30.86=1.06 < 6.18

## 6. Conclusion and future research

This paper has considered truck-to-door sequencing with repeat truck holding pattern in a multi-door cross-docking system. The most important feature of this paper is to consider a repeat truck holding pattern in truck-to-door sequencing, and it is the first study that uses repeat truck holding pattern in solving truck-to-door sequencing problems. One of the ways to increase the stability of cross-dock planning against disruptions and uncertainty is repeat truck holding the pattern in inbound trucks to save time for unloading so the outbound trucks can leave the outbound doors on time, but in this study, we only considered repeat truck holding pattern without consideration of uncertainty in arrival time. This study is a basic model in this area. The objective of the presented model was to identify the proper sequence of inbound and outbound trucks in a multi-door cross-dock center and to assign the products simultaneously to minimize the total completion time. Overall, the heuristic algorithm with SC1 and SC4 compared with other SCs are in better condition and provide better solutions in most test problems. On average, the solutions are within 5.66 % away from the optimal solution. The percentage deviation from optimal solutions ranged from 2.19% to 8.32%. For future research, considering the uncertainties in arrival time, unloading time, and facility breakdown inside the cross-dock center can help simulate the real environment. In addition, an integrated model can be developed to consider the internal and external processes together. Finally, the presented heuristic can be improved in terms of finding the nearest results to the optimal solution.

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