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A DECISION SUPPORT SYSTEM FOR CROSS-DOCKING CENTERS WITH DIFFERENT OBJECTIVES

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ABSTRACT

The truck scheduling problem is an important problem that consists of assigning each inbound and outbound truck to a door at the dock and then determining the sequences of trucks at each door. Truck scheduling in multi-door cross-docking centers is essential for both customers and cross-docking facilities. In this study, a Decision Support System (DSS) is designed for the truck scheduling problem for multi-door cross-docking centers. The scheduling model of the DSS uses Simulated Annealing (SA) meta-heuristic. In the solution process, each schedule is established for several different objectives, such as the minimization of the maximum completion time and the total earliness and tardiness, maximization of the total number of shipping products within a working period. The designed DSS provides alternative schedules to decision makers and enables the choice of an appropriate schedule by monitoring the sequences and trade-offs between alternative solutions for the cross-docking center and the customers.
Keywords: Scheduling, decision support system, multi-door cross-docking systems, logistics.

1. INTRODUCTION

Cross-docking is a distribution strategy in which products are delivered to the distribution center via inbound trucks, reconsolidated based on customer demand and then loaded into outbound trucks for delivery to customers without storing the products. In this way, both the inventory and the time spent between the receiving and shipping dock decreases, whereas operational effectiveness increases with the synchronized flows of inbound and outbound trucks.

In supply chain management, cross-docking is a significant method for coordinating the distribution process; this method includes unloading products from inbound trucks that come from retailers, consolidating shipments to certain destinations and loading the products onto outbound trucks to deliver them to the customers. As volumes increase or when shipments are uncoordinated, the amount of storage products can increase. As a result, the cross-docking center must be effectively managed, and the truck scheduling problem is one of the most important operational management problems for distribution centers working with cross-docking systems. The first study related to the truck scheduling problem in the freight consolidation terminals to

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minimize the time span of the transfer operation belongs to McWilliams et al. [1] who presented a simulation-based algorithm that uses the Genetic Algorithm (GA). The truck scheduling aims to find where and when inbound and outbound trucks should be processed at single or multi-door cross-docking centers. For this purpose, some researches address a cross-dock with a single receiving door and a single shipping door. Yu and Egbelu [2], Vahdani and Zandieh [3], Soltani and Sadjadi [4], BolooriArabani et al. [5,6,7], Mohtashami [8], Amini and Tavakkoli-Moghaddam [9] consider the truck scheduling problem of the inbound and outbound trucks for a cross docking center with a single receiving and shipping door. Yu and Egbelu [1] introduce a mathematical model to find the best schedule for both inbound and outbound trucks to minimize the total operation time, while Vahdani and Zandieh [3] and BolooriArabani et al. [6] use different meta-heuristics to schedule trucks in cross-docking systems, based on the recommendations of Yu and Egbelu.

McWilliams et al. [1,10], Alpan, et al. [11], Boysen, et al. [12], Konur and Golias [13], Liao, et al. [14] consider cross-docks with multiple receiving and shipping doors. They address only the scheduling of the inbound trucks. However, several studies consider scheduling both inbound and outbound trucks at multiple doors. Boysen [15] considers a truck scheduling problem with different objectives, such as the minimization of processing time, flow time and tardiness at the zero-inventory cross docking centers using exact and heuristic approaches. Lee et al. [16] derive a mixed-integer programming model for the multi-door truck scheduling problem to maximize the number of products that can be shipped within a given working horizon and applied the GA to solve large-sized problems. Joo and Kim [17] consider a truck scheduling problem in a multi-door cross-docking center for three types of trucks: compound trucks, inbound trucks and outbound trucks. The GA and the self-evolution algorithm are proposed to perform truck scheduling, with the aim of minimizing the makespan. Van Belle et al. [18] present a mathematical model for scheduling both inbound and outbound trucks at multiple doors to minimize the total travel time and total tardiness. They propose a Tabu Search (TS) algorithm to solve large-sized problems. Assadi and Bagheri [19] propose SA algorithm and GA to solve the truck scheduling problem with the ready times for inbound trucks at multi-door cross-docking centers. Wisittipanich and Hengmeechai [20] apply Particle Swarm Optimization (PSO) to minimize makespan in a cross docking system with multiple inbound and outbound doors. Ozden and Saricicek propose SA algorithm to maximize the total number of shipping products within working time period [21].

The truck scheduling problem is one of the most important operational management problems at distribution centers with cross-docking systems. When the literature is examined, it is seen that for the last ten years, truck scheduling problems in cross-docking centers that have been studied considered specific features, factors and performance criteria. In the studies of Boysen [15], Lee et al. [16] and Joo and Kim [17], the arrival times of the inbound and outbound trucks to the cross-docking centers are the same. However, in real-life problems, the arrival times of the inbound, outbound and compound trucks are different. Moreover, a great number of studies assume that products aren’t interchangeable; however, in the cross docking centers, not only truck scheduling but also product assignment must be determined. The product assignment is also considered from inbound trucks to outbound trucks simultaneously with the door assignments and docking sequences of the inbound and outbound trucks in our study. Joo and Kim [17] indicate a new group of trucks as compound trucks that arrive at the receiving dock to unload the products and then visit the shipping dock to load more products. There is a need for a study that combines all features together. The cross-docking centers have a dynamic environment and features, constraints, performance indicators, etc. vary with time. Managers responsible for planning are required to generate schedules considering many factors in cross-docking centers. They need to consider many performance criteria simultaneously and view the alternative schedules including the trade-offs between them from the perspectives of both the customer and the cross-docking facilities. The cross-docking systems should provide alternative schedules according to different objective functions for the decision makers. Decision support systems are designed to assist decision makers in many areas of logistics. Long et al. [22] have developed a decision support system that considers the actual operations and constraints of the problems faced by the liner operator in managing the maritime empty container repositioning by using mathematical programming approaches to solve it.

In this study, the decision-support system is designed to generate alternative schedules. The decision maker can choose one of the appropriate schedules among the alternative schedules considering the trade-offs between different objectives according to the cross-docking center requirements.

The remainder of this paper is organized as follows. In section 2, the operational decisions in cross-docking centers are defined. In section 3, the decision-support system is proposed for operations planning in the cross-docking centers. Finally, a summary and further research issues are provided in Section 4.

2. OPERATIONAL DECISIONS FOR CROSS-DOCKING CENTERS

2.1 Truck Scheduling Problem in Cross-Docking Centers

The cross-docking center with multiple receiving and shipping doors is addressed in this study (Figure 1). The products are delivered via inbound trucks and unloaded from inbound trucks at the receiving dock. The products are shipped via outbound trucks and loaded to the outbound trucks at the shipping dock.

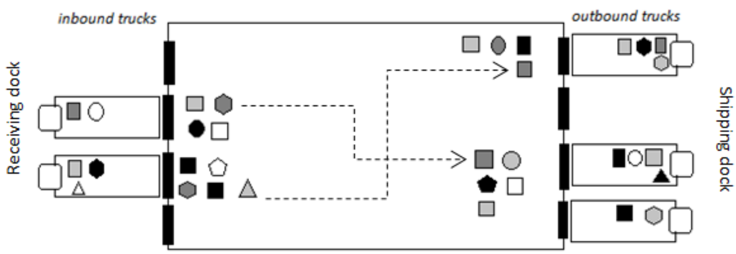

Figure 1. Cross-Docking Center with Multiple Doors and Trucks

There are inbound, outbound and compound trucks in the cross-docking center. The trucks have different arrival times and the expected arrival time is known for each truck. Inbound and outbound trucks have various products. The number of each product that is required to be loaded and unloaded is known. Inbound trucks arrive at the assigned receiving door in succession, stay until all their activities are completed and leave immediately when they finish the unloading operation. In the loading/unloading of the products, the standardized pallets are used, so the processing time is fixed, regardless of the product type. In addition, the sequence of the products is ignored. The unloaded products are transferred to the shipping dock for the loading operation. The products are moved to the shipping dock and are temporarily stored until the awaiting outbound truck arrives at the shipping dock. The outbound trucks arrive at the assigned shipping door in succession and load the products from the shipping dock.

The compound trucks are used for both unloading and loading the products. Compound trucks arrive at the assigned receiving door in succession, unload products onto the receiving dock and move to the shipping dock to load products. The unit transfer time (from a receiving door to a shipping door) is the same for all goods, and the truck changeover time is the same for all trucks. The inherent problem is to determine when and where the inbound and outbound trucks should be unloaded/loaded at the distribution centers with the multi-door cross-docking systems. There is not always same requirement for the performance of cross docking centers. The workload is sometimes very much and the aim is to maximize the number of products loaded at a given moment, while sometimes reducing truck loading time (minimizing the total earliness and tardiness) may be a priority. Cross-docking Systems may need to work for different purposes at different times. Multi-objective models provide results for multiple objectives, but this solution is not the best solution for a particular purpose. In this study, it is aimed to design a system that will provide solutions for each purpose of the decision maker.According to the notation proposed by Boysen and Fliedner [23], this truck scheduling problem with different objectives can be denoted as:

$$\langle E|r_j, \bar{d}_o, change| \sum(E_j + T_j), C_{max}, \sum_{j=1}^{o}\left(u_j \sum_{k=1}^{P} g_{jk}\right)\rangle.$$

2.2. Objectives for the Truck Scheduling Problem

The three objective functions are selected by considering the needs of the cross-docking centers to determine the objective functions in DSS.

1. To complete unloading, transfer and loading time as soon as possible: The minimizing the max completion time objective function is preferred.
2. To reduce waiting and delay times of trucks: The minimizing the total earliness and tardiness objective is used. It makes it possible to deliver products within the customer's due window.
3. To maximize the number of products loaded at a given time: The maximizing the total number of products within a working period objective is used to complete all operations without any overtime performance.

Minimizing the maximum completion time (C_{max})

The maximum completion time is the time required for all outbound trucks to leave the shipping dock with their products. The objective for minimizing C_{max} is defined as:

$$Minimize\ C_{max}$$

The minimized maximum completion time is important in the cross-docking centers where the unloading, transfer and loading operation of the products are required to be completed as quickly as possible.

Minimizing the total earliness and tardiness

This objective is especially used for the cross-docking systems that use the just-in-time approach to deliver products within the customer's due window. A due window is a time interval in which the outbound trucks' loading operation should be completed. The indicated customer's due window is shown in Figure 2.

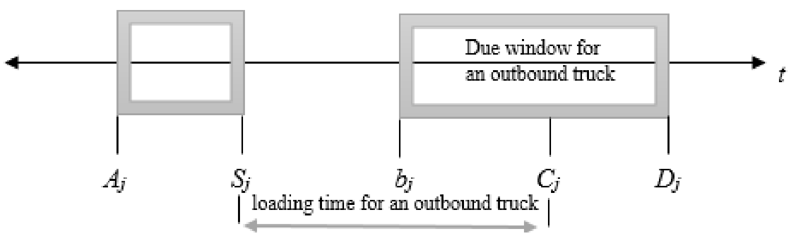

Figure 2. Due Window for an Outbound Truck

Here, b_j, A_j, D_j, S_j and C_j represent the beginning of the due window, the arrival time of the outbound truck j, the end of the due window, the starting time and completion time of the outbound truck j, respectively.

The earliness E_j and the tardiness T_j of the outbound truck j defined as:

$$E_j = \max\{b_j - C_j, 0\} \text{ and } T_j = \max\{C_j - D_j, 0\}$$

The objective for minimizing the total earliness and tardiness is achieved using:

$$Minimize \sum_{j=1}^{o} (E_j + T_j)$$

The earliness and tardiness occurs when the completion time of the loading operation for an outbound truck exceeds the due window. Yun et al. [24] is also used time windows for multimodal transportation by truck and train. The constraint of time windows is used when a container is picked up and unloaded at its origin and destination, respectively.

Maximizing the total number of shipping products within a working period

The cross-docking centers aim to deliver all scheduled shipping products during the working period. It is essential to maximize the number of shipping products via the outbound trucks to complete all operations without any overtime performance. The objective function was used by Lee et al. [16] for a similar problem, namely:

$$Maximize \sum_{j=1}^{o} \left(u_j \sum_{k=1}^{P} g_{jk}\right) \quad (1)$$

$$C_j \leq WT + M(1 - u_j) \quad (2)$$

Objective function (1) aims to maximize the total shipping products, where u_j is a decision variable and is "1" if all the shipping products of the outbound truck j are loaded within the working period and otherwise is "0". Constraint (2) indicates the outbound trucks that complete the loading operation within the working period [0, WT] where M is a positive large number and C_j is the completion time of truck j.

2.3. Parameters

$i = \{1, \dots, I\}$is the set of inbound trucks
$j = \{1, \dots, O\}$is the set of outbound trucks
$i = \{1, \dots, CI\}$and $j = \{1, \dots, CO\}$are the sets of compound trucks ($i \in I$ and $j \in O$)
$k = \{1, \dots, P\}$is the set of product types
$m = \{1, \dots, R\}$is the set of receiving doors
$n = \{1, \dots, S\}$is the set of shipping doors

AL_i	The arrival time of the inbound truck i to the cross-docking center
AD_j	The arrival time of the outbound truck j to cross-docking center
WT	Maximum working time
N	The moving time of the products from the receiving to the shipping dock
ET	The truck entering time to a door
LT	The truck leaving time from a door
TC	The changeover time of the trucks (ET+LT)
UL	The unit unloading time of the products
UT	The unit loading time of the products
TF	The transfer time for the compound truck from the receiving dock to the shipping dock
v_{ik}	The number of products of type k that are loaded in the inbound truck i
g_{jk}	The number of products of type k that are needed for the outbound truck j
b_j	The beginning of the due window
D_j	The end of the due window
M	A positive large number

2.4. Decision variables

$$u_j = \begin{cases} 1, & \textit{if all the shipping products of outbound} \\ & \text{truck j is loaded within the working period} \\ 0, & \textit{otherwise} \end{cases}$$

$$h_{ij} = \begin{cases} 1, & \textit{if any products are transferred from} \\ & \text{inbound truck i to outbound truck j} \\ 0, & \textit{otherwise} \end{cases}$$

$$p_{ijm} = \begin{cases} 1, & \textit{if truck i is assigned before truck j in the sequence} \\ & \text{at receiving door m (i} \neq \text{j); or if inbound truck i} \\ & \text{is the first truck at receiving door m (i = j)} \\ 0, & \textit{otherwise} \end{cases}$$

$$q_{ijn} = \begin{cases} 1, & \textit{if truck j is assigned before truck i in the sequence} \\ & \text{at shipping door n (j} \neq \text{i); or if outbound truck j} \\ & \text{is the first truck at shipping door n (j = i)} \\ 0, & \textit{otherwise} \end{cases}$$

$$y_{im} = \begin{cases} 1, & \textit{if inbound truck i is assigned to receiving door m} \\ 0, & \textit{otherwise} \end{cases}$$

$$z_{jn} = \begin{cases} 1, & \textit{if outbound truck j is assigned to shipping door n} \\ 0, & \textit{otherwise} \end{cases}$$

E_j The earliness of outbound truck *j*
T_j The tardiness of outbound truck *j*
x_{ijk} The number of products of type k that are transferred from inbound truck *i* to outbound truck *j*
s_i The start time of unloading for inbound truck *i*
F_i The completion time of unloading for inbound truck *i*
e_j The start time of loading for outbound truck *j*
C_j The completion time of loading for outbound truck *i*

2.5. Mathematical formulation

$$Min\ C_{max} \tag{3}$$

$$\text{Min} \sum_{j=1}^{O} (E_j + T_j) \tag{4}$$

$$Max \sum_{j=1}^{O} \left(u_j \sum_{k=1}^{P} g_{jk} \right) \tag{5}$$

s.t.

$$C_j \leq WT + M(1 - u_j) \qquad \forall (\text{j} \in \text{O}) \tag{6}$$

$$s_i \geq AL_i + ET \left(\sum_{m=1}^{R} p_{iim} \right) \qquad \forall (\text{i} \in \text{I}) \tag{7}$$

$$e_j \geq AD_j + ET \left(\sum_{n=1}^{S} q_{jjm} \right) \qquad \forall (\text{j} \in \text{O}) \tag{8}$$

$$\mathrm{e_j} + \left(UT\sum_{k=1}^{P} g_{jk}\right) \le C_j \qquad \forall(\mathrm{j} \in \mathrm{O}) \qquad (9)$$

$$C_j + TC \le e_i + M\left(1 - \sum_{n=1}^{S} q_{ijn}\right) \qquad \forall(\mathrm{i,j} \in \mathrm{O}) i \ne j \qquad (10)$$

$$F_i + N \le e_j + M\left(1 - h_{ij}\right) \qquad \forall(\mathrm{i} \in \mathrm{I}, \mathrm{j} \in \mathrm{O}) \qquad (11)$$

$$s_i + \left(UL\sum_{k=1}^{P} v_{ik}\right) \le F_i \qquad \forall(\mathrm{i} \in \mathrm{I}) \qquad (12)$$

$$F_i + TC \le s_j + M\left(1 - \sum_{m=1}^{R} p_{ijm}\right) \qquad \forall(\mathrm{i,j} \in \mathrm{I}) i \ne j \qquad (13)$$

$$\sum_{j=1}^{O} x_{ijk} = v_{ik} \qquad \forall(\mathrm{i} \in \mathrm{I}, \mathrm{k} \in \mathrm{P}) \qquad (14)$$

$$\sum_{i=1}^{I} x_{ijk} = g_{jk} \qquad \forall(\mathrm{j} \in \mathrm{O}, \mathrm{k} \in \mathrm{P}) \qquad (15)$$

$$\sum_{k=1}^{P} x_{ijk} \le M \cdot h_{ij} \qquad \forall(\mathrm{i} \in \mathrm{I}, \mathrm{j} \in \mathrm{O}) \qquad (16)$$

$$E_j \ge b_j - (C_j + LT) \qquad \forall(\mathrm{j} \in \mathrm{O}) \qquad (17)$$

$$T_j \ge (C_j + LT) - D_j \qquad \forall(\mathrm{j} \in \mathrm{O}) \qquad (18)$$

$$\sum_{n=1}^{S} z_{jn} = 1 \qquad \forall(\mathrm{j} \in \mathrm{O}) \qquad (19)$$

$$\sum_{j=1}^{O} q_{jjn} = 1 \qquad \forall(\mathrm{n} \in \mathrm{S}) \qquad (20)$$

$$\sum_{i=1}^{O} q_{ijn} = z_{jn} \qquad \forall(\mathrm{j} \in \mathrm{O}, \mathrm{n} \in \mathrm{S}) \qquad (21)$$

$$\sum_{i=1}^{O} q_{jin} \le z_{jn} \qquad \forall(\mathrm{j} \in \mathrm{O}, \mathrm{n} \in \mathrm{S}) i \ne j \qquad (22)$$

$$\sum_{m=1}^{R} y_{im} = 1 \qquad \forall(\mathrm{i} \in \mathrm{I}) \qquad (23)$$

$$\sum_{i=1}^{I} p_{iim} = 1 \qquad \forall(\mathrm{m} \in \mathrm{R}) \qquad (24)$$

$$\sum_{j=1}^{I} p_{jim} = y_{im} \qquad \forall(\mathrm{i} \in \mathrm{I}, \mathrm{m} \in \mathrm{R}) \qquad (25)$$

$$\sum_{j=1}^{I} p_{ijm} \le y_{im} \qquad \forall(\mathrm{i} \in \mathrm{I}, \mathrm{m} \in \mathrm{R}) i \ne j \qquad (26)$$

$$s_i + \left(UL\sum_{k=1}^{P} v_{ik}\right) + LT + TF \le e_i \qquad \forall(\mathrm{i} \in \mathrm{C}) \qquad (27)$$

$y_{im} \in \{0,1\}$ $\forall(\mathrm{i} \in \mathrm{I}, \mathrm{m} \in \mathrm{R})$ (28)

$h_{ij} \in \{0,1\}$ $\forall(\mathrm{i} \in \mathrm{I}, \mathrm{j} \in \mathrm{O})$ (29)

$z_{jn} \in \{0,1\}$ $\forall(\mathrm{j} \in \mathrm{O}, \mathrm{n} \in \mathrm{S})$ (30)

$u_j \in \{0,1\}$ $\forall(\mathrm{j} \in \mathrm{O})$ (31)

$p_{ijm} \in \{0,1\}$ $\forall(\mathrm{i}, \mathrm{j} \in \mathrm{I}, \mathrm{m} \in \mathrm{R}) i \neq j$ (32)

$q_{ijn} \in \{0,1\}$ $\forall(\mathrm{i}, \mathrm{j} \in \mathrm{O}, \mathrm{n} \in \mathrm{S}) i \neq j$ (33)

$e_j, C_j, E_j, T_j \geq 0$ $\forall(\mathrm{j} \in \mathrm{O})$ (34)

$s_i, F_i \geq 0$ $\forall(\mathrm{i} \in \mathrm{I})$ (35)

$x_{ijk} \geq 0$ $\forall(\mathrm{j} \in \mathrm{O}, \mathrm{k} \in \mathrm{P}, \mathrm{i} \in \mathrm{I})$ (36)

Objective function (3) aims to minimize maximum completion time, (4) to minimize the total tardiness and earliness of the loading operations of the outbound trucks, and (5) to maximize the total shipping products. Constraint set (6) is related to objective function (5) and indicates the outbound trucks that complete the loading operation within the working period. Constraint sets (7-8) ensure the start time of unloading for an inbound truck and the start time of loading for an outbound truck must be greater than the arrival times of these trucks to the cross-docking center and the truck entering time if these trucks are the first trucks at the receiving or shipping doors. Constraint sets (9-10) satisfy the precedence relation of the outbound trucks assigned to the same shipping door. Constraint set (11) connects the start time of loading for an outbound truck to the completion time of unloading for an inbound truck if any products are moved between the trucks. Constraint sets (12-13) guarantee the precedence relation for inbound trucks assigned to the same receiving door. Constraint set (14) dictates that the total number of product types k that transfer from inbound truck i to all outbound trucks is equal to the number of product types k that was already loaded into inbound truck i. Constraint set (15) ensures that the total number of product types k that transfer from all inbound trucks to outbound truck j is equal to the number of product types k needed for outbound truck j. Constraint set (16) guarantees the exact relation between the x_{ijk} variables and the h_{ij} variables. Constraint sets (17-18) are related to objective function (4) and evaluate the earliness and tardiness for outbound trucks. Constraint set (19) indicates that each outbound truck is assigned to only one door at the shipping area. Constraint set (20) guarantees that only one outbound truck is assigned at the first sequence at each shipping door and the variable q_{jj} becomes 1 if outbound truck j is the first positioned truck at door n. Constraint set (21) guarantees that, an outbound truck is immediately preceded by one inbound truck if it is assigned to a shipping door. Constraint set (22) dictates that, an outbound truck must be succeeded by at most one truck if it is assigned to a door. Constraint set (23) ensures that each inbound truck is assigned to only one door at the receiving dock. In the constraint set (24), the variable p_{ii} becomes 1 if inbound truck i is at the beginning of the sequence at the assigned door. Constraint set (25) guarantees that, an inbound truck is immediately preceded by one inbound truck if it is assigned to a door. Constraint set (26) ensures that, an inbound truck must be succeeded by at most one inbound truck if it is assigned to a door. Constraint set (27) connects the start time of unloading to the start time of loading for a compound truck. Constraints (28)-(36) impose binary and non-negativity conditions on the variables. Optimal solutions for test problems are obtained by implementing the MIP model in GAMS 23.3, CPLEX 12.1 solver and compared with the results of the meta-heuristic algorithm.

3. THE DECISION SUPPORT SYSTEM FOR TRUCK SCHEDULING

A DSS is proposed to solve the truck scheduling problem. It supports decision making for trucks scheduling and transfer of the products from inbound trucks to the outbound trucks. The DSS is coded using PyCharm Community Edition 3.4.1 to assign trucks to the doors to minimize the maximum completion time, the total tardiness and earliness, and maximize the total shipping products within a working period. This system provides alternative schedules to the decision maker. Based on the proposed system, the decision makers can monitor the trade-offs between schedules generated from different objectives and choose the appropriate schedule for the cross-docking system. The DSS can be integrated with the other applications, like the truck operations information system, the stock information system and the customer information system, etc.

The use of components and design of the DSS are connected to the centralized database server in practice. The database specifications and structure for such a DSS are out of the content of this study. The optimization model for the truck scheduling problem which is coded using object-oriented programming principles is the most important part of the DSS. In this study, Microsoft Excel is used for the database. The objects in database, their fields and features are shown in Table 1.

Table 1. Database for the DSS

Objects	***Fields and features***
Truck	Truck ID Inbound, outbound and compound trucks Number of product types in the trucks Due time windows for outbound trucks Arrival times of the trucks The start time and completion time of unloading for inbound trucks The start time and completion time of loading for outbound trucks
Doors	Door ID Receiving, shipping doors Assigned trucks and order of the assigned truck to doors
Station	Products in the cross-docking center Receiving and shipping doors The number of products in the center The station object provides communication with the trucks through the doors

The truck object is a general object created for the trucks which includes common features and functions of the trucks. This object includes status information of the trucks (ready to load, loading etc.), the truck numbers and calculation of the simulation steps. Inbound-Truck, Outbound-Truck, Compound-Truck Objects are sub-objects created from the general truck object.

Each one contains characteristics of the truck that it represents. For example, the I-Inbound Truck includes the loading times; the O-Outbound Truck contains unloading times and the C-Compound Truck contains both cases. It also includes the reactions that the trucks give in different situations. For instance, an outbound truck leaves from the cross-docking center when it completes the loading operation. The door Objects are the objects that are modelled as receiving and shipping doors. These objects save the assigned trucks and order of the assigned truck. The decisions to start loading or unloading the trucks depends on the situation of the trucks and the doors are given by the receiving and shipping doors. The station object holds the products in the cross-docking center and the receiving and shipping door objects. The station object provides communication with the trucks through the doors. There is also a solver where all the objects created for the model are held, the solution is made and the information is stored. The visual interface communicates with this object to provide data input and output. Inputs are required from the suppliers, the customers and the freight forwarders. The DSS consists of input data that is either manually entered or automatically generated, such as the arrival times of the trucks, the due time windows, etc., as shown in Figure 3.

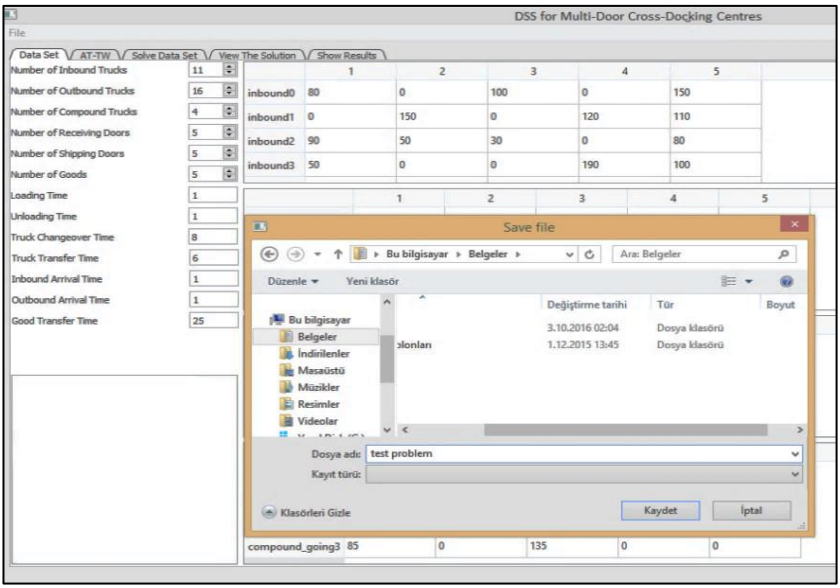

Figure 3. Record of the System Data

From Figure 3, once entered or generated, the data sets can be saved, retrieved and edited for further applications. Besides the database of the system, the model has been prepared to work in accordance with the cross-docking centers. This model visualizes a real cross-docking center dependent on system variables and parameters, such as arrival and departure times of trucks, loading times of products and truck changeover times. Using the objective function values obtained from this virtualization, the algorithm attempts to determine the best schedule according to the SA algorithm and the parameters of the algorithm. After the truck numbers, the door numbers and time parameters are specified. The following steps are used in the DSS, respectively;

- The parameters of the algorithm are selected.
- The initial solution is obtained.

- The model is started with the desired time step and start time. In each step, the following operations are performed until the trucks' operations are completed.
  - ✓ It is checked whether the situation change times of the doors and the trucks (arrival, departure, loading, unloading) are at the present time.
  - ✓ If there is a situation change for the trucks and doors, the necessary calculations for the times are made. If there are no changes, continue.
  - ✓ In case of a product transfer, product numbers are calculated.
  - ✓ The new time is calculated and repeated by adding the time step.
- A new sequence for the trucks is obtained according to the objective function values and algorithms. It continues until the desired number of iterations is reached.

In the model, the Simulated Annealing (SA) algorithm is used to solve the truck scheduling problem.

3.1. Scheduling via the SA algorithm

The truck scheduling problem is NP-hard [25], and it takes a long time to find the optimal solution for large problems. The SA meta-heuristic algorithm is applied to solve the indicated problem in a reasonable time. The SA algorithm is recommended for parallel machine scheduling problems and is widely used for the solution of these problems [26]. The truck scheduling problem has certain aspects in common with parallel machine scheduling problem. The SA algorithm is a random search algorithm and works by emulating the physical annealing process of the material. The basic idea of the SA algorithm is to generate step by step a sequence of solutions, without requiring an improvement of the solution at each step. SA keeps a solution that is worse than the previous one with a probability. The aim of this approach is to avoid being entrapped in a subset of feasible solutions. The SA algorithm is as follows [27]:

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1. Define $T, \alpha, K, \varepsilon$
2. Generate a random feasible solution G_0, calculate the value $U(G_0)$ of the criterion and set $G^* = G_0$, $U(G^*) = U(G_0)$
3. Set k=0.
4. Set k=k+1
5. Generate random a feasible solution G_1 in the neighbourhood of G_0 and calculate $U(G_1)$
6. Calculate $\Delta = U(G_1) - U(G_0)$
7. Test:
  7.1. If $\Delta \leq 0$:
    7.1.1. Set $G_0 = G_1$ and $U(G_0) = U(G_1)$
    7.1.2. If $U(G_1) < U(G^*)$, then set $G^* = G_1$ and $U(G^*) = U(G_1)$
  7.2. If $\Delta > 0$, then do;
    7.2.1. Generate random $x \in [0,1]$
    7.2.2. Calculate $p = exp\left(\frac{-\Delta}{T}\right)$
  7.2.3. If $x \leq p$, then set $G_0 = G_1$ and $U(G_0) = U(G_1)$
8. If $k \geq K$ do:
  8.1. Set T= α T
  8.2. Set k=0
  8.3. If $T \geq \varepsilon$ then go to 4.
9. Display G^* and $U(G^*)$

In the SA algorithm, U (G_k) refers to the objective function value for the corresponding sequence at iteration *k*. For a minimization problem, there is a current solution G_0 and candidate solution G_1 selected from the neighbourhood. If $U(G_1) \geq U(G_0)$, a move is made to G_1 with the acceptance probability, P (G_0, G_1). The "T" is the current temperature decreased by each iteration ($T_n = \alpha T_{n-1}\ and\ \alpha < 1$). G^* is the best solution in the sequence of solutions obtained so far. In the algorithm, the computation is stopped when the temperature becomes less than a given value ε or the number of iterations exceeds a given value W. The SA algorithm is coded to solve the truck scheduling problem. The initial solution generation mechanism is as follows:

Step 1: Sequence the inbound trucks in terms of the arrival times to the cross-docking center (from earliest to latest) ,$I = \{1,2, \dots \dots \dots . . n\}, \forall i \in I$
Step 2: Obtain the number of inbound trucks / the number of receiving doors
Step 3: Assign the receiving doors to the sequence of the inbound trucks
Step 4: Sequence the outbound trucks in terms of the arrival times to the cross-docking center (from earliest to latest), $O = \{1,2, \dots \dots \dots . . m\}, \forall j \in O$ and sequence the compound trucks in terms of the arrival times to the cross-docking center and append them to the end of the outbound truck list $O = \{1,2, \dots \dots \dots . . m\}, \forall j, c \in O$
Step 5: Obtain the number of outbound trucks / the number of shipping doors
Step 6: Assign the shipping doors to the sequence of the outbound trucks

In the neighbourhood generation mechanism, two random numbers are generated simultaneously for both the inbound (3/4/*/5/1/*/2) and outbound (1/2/*/5/*/4/3) truck sequence. During the neighbourhood generation process, two trucks/doors (*) are interchanged in the sequence according to two random numbers. The procedure is performed for both the inbound and outbound trucks simultaneously for each iteration. During the neighbourhood generation process, two trucks/doors (*) are interchanged in the sequence according to two random numbers. The procedure is performed for both the inbound and outbound trucks simultaneously for each iteration.

3.2. Validation of the SA Algorithm

Test problems are randomly generated considering the total number of inbound and outbound trucks. Test problems with less than and equal to 7 inbound and 7 outbound trucks are solved using GAMS 23.3. The optimal solutions determined by the CPLEX 12.1 solver of the test problems were compared with the solutions of the SA algorithm in Table 2. As a result of the computational experiments, parameters are obtained for the SA algorithm. The initial temperature is 100°C and the cooling ratio is %90 for the SA algorithm. The meta-heuristic algorithm is coded in Python 3.4 software. All experiments are performed on a PC with an Intel Core i7 processor, 3.0 GHz and 12 GB RAM.

Table 2. Comparison of the performance of the SA algorithm for test problems in terms of the objective function value and computational time.

						Max $\sum_{j=1}^{o}(u_j \cdot \sum_{k=1}^{P} g_{jk})$				Min $\sum_{j=1}^{o}(E_j + T_j)$				Min C_{max}			
						objective value		computational time (s)		objective value		computational time (s)		objective value		computational time (s)	
test problem	I	O	R	S	WT	**Cplex**	**SA**	**Cplex**	**SA**	**Cple**	**SA**	**Cplex**	**SA**	**Cplex**	**SA**	**Cplex**	**SA**
1	4	4	1	2	1450	960	960	0.678	21	788	788	0.582	28	1444	1444	0.618	28
2	4	4	2	1	1450	795	795	0.647	19	424	424	0.476	19	1521	1521	0.715	18
3	4	5	2	2	1100	960	960	0.654	24	132	148	2.31	30	995	995	1.679	25
4	4	5	2	3	1300	1000	1000	0.208	28	0	0	1.003	32	960	960	0.984	28
5	5	4	2	1	1300	770	770	1.707	20	502	514	1.135	20	1634	1652	2.365	19
6	5	4	2	2	1200	1130	1130	0.395	24	51	51	2.498	24	1129	1129	1.239	21
7	4	6	3	2	1050	995	995	3.471	23	0	0	0.591	25	1107	1107	24.17	23
8	4	6	2	2	1150	1030	1030	26.245	26	33	51	25.852	18	1172	1172	32.517	28
9	5	5	2	3	900	690	690	14.777	32	121	152	1.151	22	1068	1068	1.198	37
10	5	5	3	2	1000	1025	1025	5.644	24	0	0	0.526	26	1023	1023	5.043	26
11	6	4	2	2	900	760	760	3.278	20	71	71	21.186	21	956	956	29.312	22
12	6	4	3	2	900	1000	1000	0.507	19	0	0	0.5	20	838	838	2.175	20
13	5	6	3	2	1100	1165	1165	11.491	27	100	145	18.663	28	1115	1115	12.197	27
14	5	6	2	3	1200	1315	1315	0.607	35	101	101	5.966	37	1148	1148	4.082	34
15	6	5	2	3	1000	945	945	6.302	35	154	154	76.382	35	1069	1069	8.138	33
16	6	5	3	2	1000	1075	1075	2.995	26	148	175	3.815	34	1083	1083	3.169	26
17	6	6	2	2	1250	1300	1300	50.512	30	219	227	51.419	28	1160	1160	735.88	35
18	6	6	3	2	1000	1135	1135	22.231	28	146	183	770.06	25	1051	1051	93.935	30
19	6	7	2	2	1000	895	895	6308.16	32	490	522	*	31	1325	1362	4037.93	41
20	7	7	2	3	1200	1390	1330	*	36	487	543	*	29	1320	1320	2747.82	43
					Average	**1019.73**	**1016.57**		**26.73**	**167.3**	**182.15**		**26.52**	**1140.73**	**1143.63**	**407.60**	**28.21**

According to Table 2, it takes a long time to find the optimal solution for the problem with more than 6 inbound and 6 outbound trucks in the CPLEX solver. When the number of trucks increases, the computational time increases dramatically. Lee et al. (2012) point out that the optimization tool does not give results for problems over 6 inbound and 6 outbound trucks because of the long computational time. The results in Table 2 support the stated study. The computational time is extended because the first two objectives are performance criteria based on the delivery time. For these two objectives, the solution time exceeded two hours (*) when the problem size increases. The objective values of the SA algorithm and computational times show that the SA algorithm provides suitable results in a reasonable time and can be used for large-sized problems.

3.3. Interfaces of the DSS

The first screenshot is shown in Figure 4, where the user loads, saves and enters a new data set.

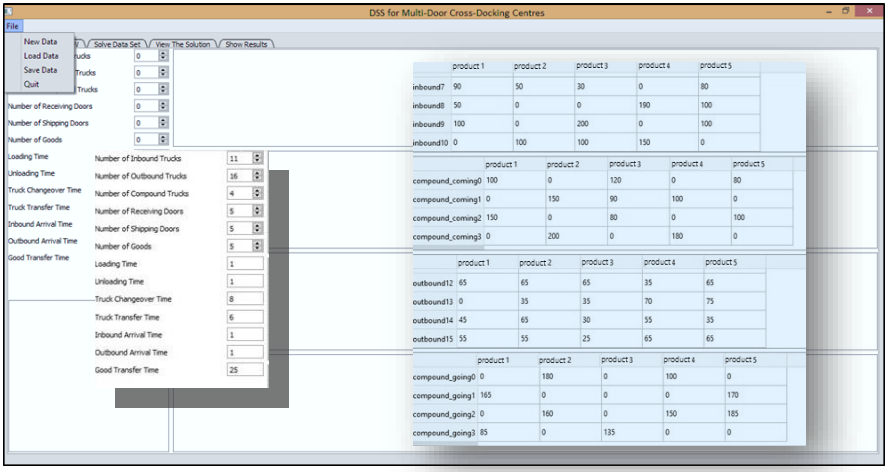

Figure 4. The Initial Screen of the System.

When the user clicks the "new data set" button, the system generates a table to enable the data entry (Figure 4). The first screen is shown in Figure 4, where the user is asked for the numbers of inbound, outbound and compound trucks, as well as the numbers of receiving doors, shipping doors and goods types. Based on the given information, the system generates tables to enter the products in the inbound, outbound and compound trucks in terms of the product types and numbers. The simplified input screen shows the necessary information (number of units of the product types that are initially loaded in the inbound trucks and the number of units of the product types that are required for the outbound trucks) that must be entered to solve the problem. Figure 4 provides a screenshot, where the user is asked for the loading and unloading times, the truck changeover time, the truck transfer time and the transfer time of the goods. After entering these parameters, the"Save Data" button is clicked to save these parameters and the "AT-TW" screen is opened as shown in Figure 5.

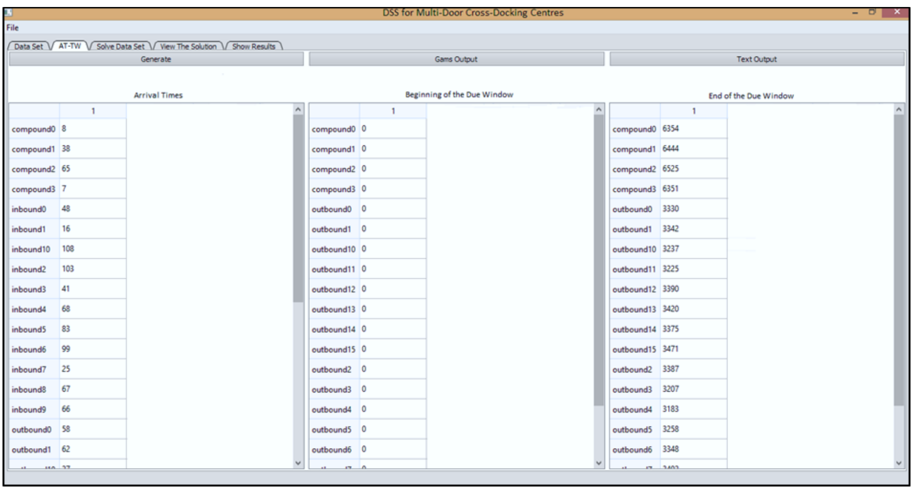

Figure 5. Screenshot Related to the Arrival Times and Due Time Windows (AT-TW).

Figure 5 enables the entry of other parameters, such as "the arrival times and the due windows" for the trucks. It shows all the data related with times, such as the arrival times of the inbound, outbound and compound trucks, and the beginning-end of the due windows for the outbound trucks. The user can click the page "Solve Data Set" in Figure 6 to solve the problem according to the SA.

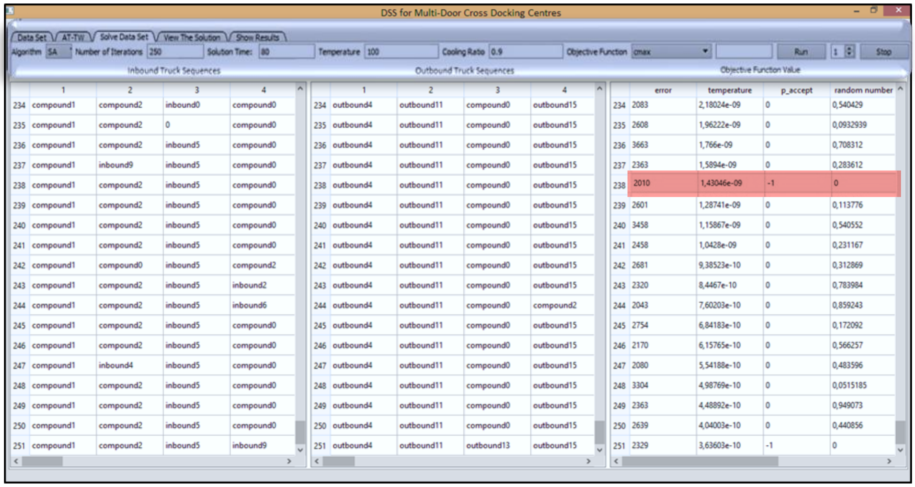

Figure 6. Screenshot of the System Used to Solve the Problem

The user can obtain the algorithm's parameters, such as the temperature and cooling ratio. In Figure 6, the highlighted row shows the best solutions, iteration-by-iteration. The user can choose the best solution so far from the last highlighted row for C_{max}. Using the related iteration number, the user can monitor the number of product types k that are transferred from inbound truck i to outbound truck j, the start time of unloading for inbound truck i, the completion time of unloading for inbound truck i, the start time of loading for outbound truck j, the completion time of loading for outbound truck j and the sequences of the trucks at the doors, as shown in Figure 7. The "Show Results" button is used to monitor the results of the problem.

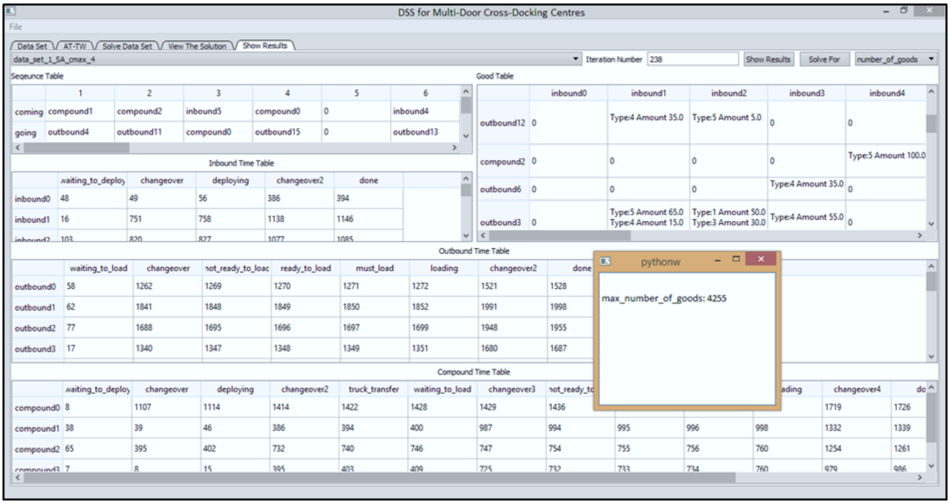

Figure 7. Screenshot of the System Used to Monitor the System Data

If the decision maker wants to see the detailed schedules for each objective function, user can click on the "Solve for" button (Figure 7). The doors, trucks, starting times, completion times, due dates, earliness and tardiness can be obtained on a schedule according to the chosen objective function.The screenshot shown in Figure 7 enables the user to find the maximum number of shipping products according to the best sequence of the C_{max} objective function and to compare them with each other. The decision maker can choose one of the appropriate schedules among the alternative schedules considering the trade-offs between different objectives.

Table 3. Trade-offs between different objectives

Objective functions	Min $\sum_{j=1}^{o}(E_j + T_j)$	Min C_{max}	Max $\sum_{j=1}^{o}(u_j \cdot \sum_{k=1}^{P} g_{jk})$
Min $\sum_{j=1}^{o}(E_j + T_j)$	**154**	1122	905
Min C_{max}	305	**1071**	420
Max $\sum_{j=1}^{o}(u_j \cdot \sum_{k=1}^{P} g_{jk})$	396	1352	**910**

In Table 3, truck scheduling problem is solved for three objective functions seperately. Firstly, it's solved for minimizing total earliness and tardiness. The objective function value is obtained as "154" and using the best sequence for this objective function, the other objective fuctions minimizing makespan and maximizing the total number of shipping products within a working period are obtained as "1122" and "905" respectively. Similarly, the truck scheduling problem is solved for minimizing makespan and maximizing the total number of shipping products within a working period. The objective function values are obtained as "1071" and "910". Thus, the user can compare all truck schedules according to three different objective functions and choose the most suitable schedule for the cross-docking center or the customer.

An other example for the truck-door assignment; there are 15 inbound trucks (I = 15), 20 outbound trucks (O = 20), 4 compound trucks (C = 4), 5 receiving doors (R = 5), 5 shipping doors (S = 5), 5 different product types and 5140 products in the truck scheduling problem. The results of the problem have been examined for the objective of minimizing C_{max}. The time tables for inbound, outbound and compound trucks can be transferred to Excel and a bar chart can be created. The start and finish times of the inbound trucks for the unlading operations were obtained as a result of the solution according to the given parameters of the problem and can be seen in Figure 8.

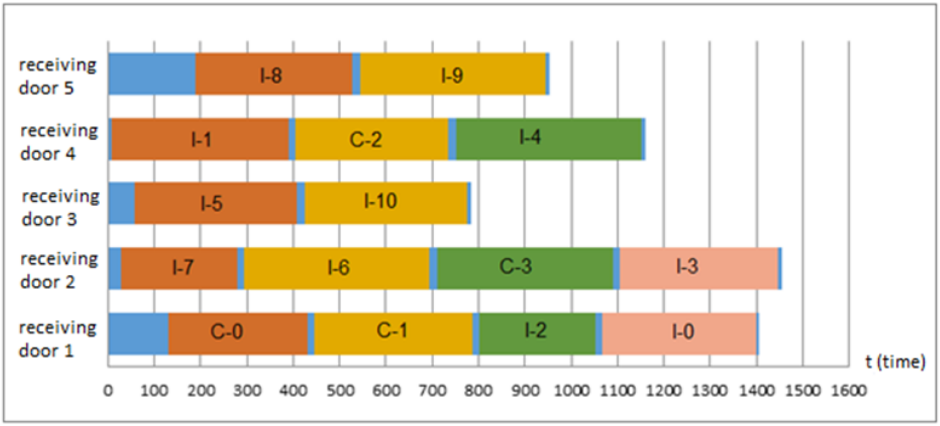

Figure 8. Bar Chart of the Sequence and Assignments for the Inbound Trucks

The user can monitor the start time of unloading for inbound truck *i*, the completion time of unloading for inbound truck *i* and the sequences of the trucks at the doors. For example, inbound truck 1 is loaded first, then compound truck 2, and then the inbound truck 4 at the forth receiving door of the cross-docking center. The truck changeover time is shown in blue. Similarly, it is possible to determine at which door and in which order the outbound trucks will be loaded, and the start and finish times for loading can be monitored (Figure 9).

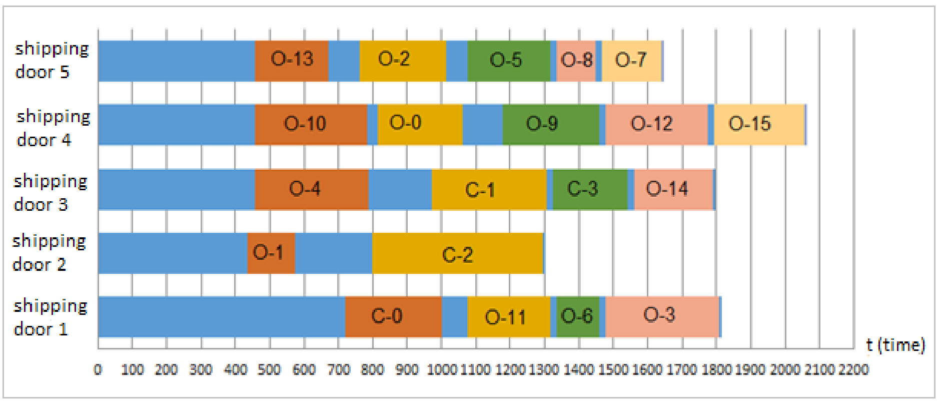

Figure 9. Bar chart of the sequence and assignments for the outbound trucks

The user can monitor the start time of loading for outbound truck *i*, the completion time of loading for outbound truck *i* and the sequences of the trucks at the doors (Figure 9). For example, the outbound truck 1 is loaded first, then the compound truck 2 at the second shipping door of the cross-docking center.The decision maker can monitor the cross docking system by switching to the 'View solution' button and simulate the system for the best sequence or any sequence he/she wants to view (Figure 10).

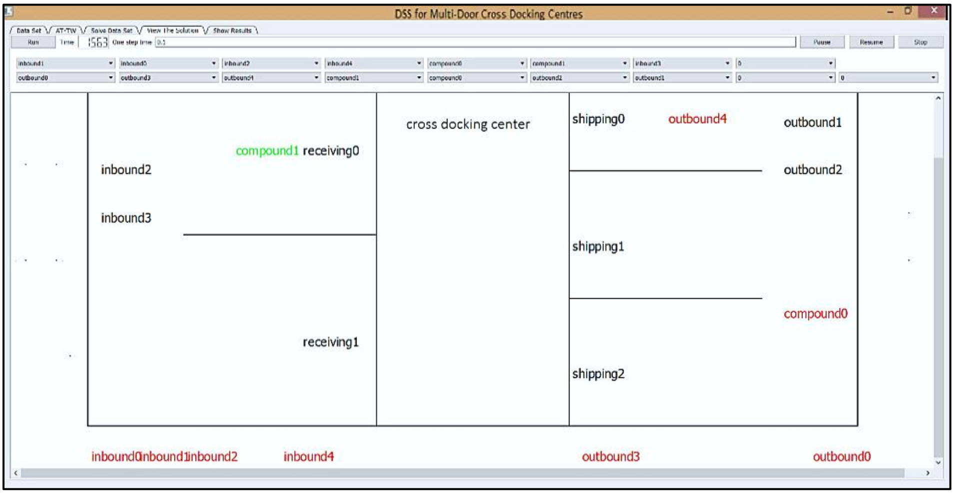

Figure 10. Simulation of the system for a sequence

The simulation is started by pressing the ‘Run’ button and the progress of the system can be seen on the screen. The status of the cross docking center can be observed at any time. The colored truck names on the screen are in motion while the simulation is running and shows the different situations of the trucks in the system. For example, the compound truck 1 (compound1) is being unloaded at receiving door 0 (receiving0). The colors of the trucks in the system: red means that the changeover of the truck or loading/unloading is completed, green is loading or unloading. After simulation is stopped, the types and amounts of the products in the truck or at the door can be seen by clicking on the doors and trucks.

4. CONCLUSION

Considering today’s dynamic and competitive environment, logistics firms need to get good solutions in a short amount of time. In this study, the DSS is designed for the truck scheduling problem in multi-door cross-docking centers. The model, based on the DSS, uses Simulated Annealing for performing the scheduling. In the solution process, each schedule is generated for several different objectives, such as the minimization of the maximum completion time, minimization of the total tardiness and earliness and the maximization of the total number of shipping products within a working period. The DSS provides alternative schedules to the decision maker. Based on the proposed system, decision makers can consider trade-offs between the unloading/loading and product dispatching plans generated from different perspectives and choose the appropriate plan for the performance criterion in the cross-docking center. The advantages provided by the DSS to the user are the ability to realistically reflect the arrival times of the trucks at the cross-docking center, the transfer of goods between inbound and outbound trucks, the scheduling of outbound trucks according to their due time windows and the scheduling of compound trucks in the system. For future work, the problem can be solved by considering the distances between the doors at the cross-docking centers. In addition, the scheduling of resources within the cross-docking center (labour force, etc.) can be included in the problem.

REFERENCES

[1] McWilliams, D. L., Stanfield, P. M., Geiger, C. D. (2005) The parcel hub scheduling problem: A simulation-based solution approach, *Computers & Industrial Engineering*, 49, 393–412.

[2] Yu, W., Egbelu, P. J. (2008) Scheduling of inbound and outbound trucks in cross docking systems with temporary storage, *European Journal of Operational Research*, 184, 377–396.

[3] Vahdani, B., Zandieh, M. (2010) Scheduling trucks in cross-docking systems: Robust meta-heuristics, *Computers & Industrial Engineering*, 58, 12–24.

[4] Soltani, R., Sadjadi, S.J. (2010) Scheduling trucks in cross-docking systems:a robust meta-heuristics approach, *Transportation Research Part E:Logistics and Transportation Review*, 46, 650–666.

[5] Boloori Arabani, A. R., Fatemi Ghomi, S. M. T., Zandieh, M. (2010) A multi-criteria cross-docking scheduling with just-in-time approach, *International Journal of Advanced Manufacturing Technology*, 49, 741–756.

[6] Boloori Arabani, A. R., Fatemi Ghomi, S. M. T., Zandieh, M. (2011) Meta-heuristics implementation for scheduling of trucks in a cross-docking system with temporary storage, *Expert Systems with Applications*, 38, 1964–1979.

[7] Boloori Arabani, A. R., Zandieh, M., Fatemi Ghomi, S. M. T. (2012) A cross-docking scheduling problem with sub-population multi-objective algorithms, *International Journal of Advanced Manufacturing Technology*, 58, 741–761.

[8] Mohtashami, A., (2015) Scheduling trucks in cross docking systems with temporary storage and repetitive pattern for shipping trucks, *Applied Soft Computing*, 36, 468-486

[9] Amini, A., Tavakkoli-Moghaddam, R. (2016) A bi-objective truck scheduling problem in a cross-docking center with probability of breakdown for trucks, *Computers and Industrial Engineerin*g, 96, 181-190

[10] McWilliams DL, Stanfield PM, Geiger CD. (2008) Minimizing the completion time of the transfer operations in a central parcel consolidation terminal with unequal-batch-size inbound trailers, *Computers & Industrial Engineering*, 54(4),709–720.

[11] Alpan, G., Larbi, R., Penz, B. (2011) A bounded dynamic programming approach to schedule operations in a cross docking platform, *Computers and Industrial Engineering*, 60, 385–396.

[12] Boysen, N., Briskorn, D., Tschöke, M. (2013) Truck scheduling in cross-docking terminals with fixed outbound departure, *OR Spectrum*, 35, 479–504.

[13] Konur, D., Golias, M. M. (2013) Cost-stable truck scheduling at a cross-dock facility with unknown truck arrivals: A meta-heuristic approach, *Transportation Research Part E*, 49, 71–91.

[14] Liao, T. W., Egbelu, P. J., Chang, P. C. (2013) Simultaneous dock assignment and sequencing of inbound trucks under a fixed outbound truck schedule in multi door cross docking operations, *International Journal of Production Economics*, 141, 212–229.

[15] Boysen, N. (2010) Truck scheduling at zero-inventory cross docking terminals, *Computers & Operations Research*, 37, 32–41.

[16] Lee, K., Kim, B. S., Joo, C. M. (2012) Genetic algorithms for door-assigning and sequencing of trucks at distribution centers for the improvement of operational performance, *Expert Systems with Applications*, 39, 12975–12983.

[17] Joo, C. M., Kim, B. S. (2013) Scheduling compound trucks in multi-door crossdocking terminals, *International Journal of Advanced Manufacturing Technology*, 64, 977–988.

[18] Van Belle, J., Valckenaers, P., Berghe, G. V., Cattrysse, D. (2013) A tabu search approach to the truck scheduling problem with multiple docks and time windows, *Computers and Industrial Engineering*, 66, 818–826.

[19] Assadi, M. T., Bagheri, M., (2016) Scheduling trucks in a multiple-door cross docking system with unequal ready times, *European Journal of Industrial Engineering*, 10, 103-125.

[20] Wisittipanich, W., Hengmeechai, P. (2017) Truck scheduling in multi-door cross docking terminal by modified particle swarm optimization, Computers and Industrial Engineering, 113, 793–802.

[21] Ozden, G., Saricicek, I. (2019) Solution approaches for truck scheduling problem in cross-docking, Pamukkale University Journal of Engineering Sciences, 25(1), 82-88.

[22] Long, Y., Lee, L.H., Chew, E.P., Luo, Y., Shao, J., Senguta, A., Chua, S.M.L. (2013) Operational planning for maritime empty container repositioning, *International Journal of Industrial Engineering: Theory, Applications and Practice*, 20(1-2), 141-152.

[23] Boysen,N., Fliedner,M.(2010) Cross dock scheduling: Classification, literature review and research agenda, *Omega*, 38, 413–422.

[24] Yun, W.Y., Wang, W.F., Ha., B.H. (2013) A Hybrid SA algorithm for inland container transportation, *International Journal of Industrial Engineering: Theory, Applications and Practice*, 20(1-2), 12-23.

[25] Chen, F., Lee, C. Y. (2009) Minimizing the makespan in two-machine cross-docking flow shop problem, *European Journal of Operational Research*, 193, 59–72.

[26] Saricicek, S., Celik, C. (2011) Two meta-heuristics for parallel machine scheduling with job splitting to minimize total tardiness, *Applied Mathematical Modelling*, 35, 4117-4126.

[27] Dolgui. A., Proth, J-M. (2010) Supply Chain Engineering: Useful Methods and Techniques, Springer.