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RESEARCH PAPER

Multi-Objective Modeling of Scheduling and Routing Trucks in a Cross-Dock for Perishable Items

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Abstract

Supply chain management plays an important role in creating competitive advantages for companies. One of the most important factors in supply chain management is the control of physical flow for materials and products. Cross dock strategy is an effective way to synchronic control of materials flow, logistic costs, distribution operations, and tuning customer service level. Today's use of this strategy, to reduce inventory holdings and reduce the time spent in the supply chain is increasing. Perishable items supply chain is more complicated than many others. In this supply chain, changing the quality of items because of the nature of perishability is very important for customers, so distributors face a lot of logistical challenges. Distribution management of these products through the cross-dock center is very efficient for delivering items to customers with appropriate quality, and, at the right time and place. In this research, we provide a multi-objective mathematical model for truck scheduling and routing in a cross-dock for perishable items by considering the perishability rate based on distribution time and condition by two types of trucks that are effective on product quality in distribution. The objective functions are minimizing the cost of delivery, including transportation costs, the penalty costs of shortage, and perishable items in distribution time and the total spent time. The VRSP system is modeled as a mixed-integer non-linear program in GAMS and an NSGA-II algorithm is provided.

Keywords:
Cross Dock;
Truck Scheduling;
Routing;
Perishable Items;
Multi Objective;
Cold Chain;
NSGA-II

Introduction

The primary purpose of the cross-dock is to make it possible to combine shipments in different sizes and use the vehicle in the full capacity and reduce operational costs. These advantages make the cross-dock an important logistics strategy that today attracts a lot of attention from the global competition with the growing volume of goods transported. The other purpose of using cross-dock is reducing the transit time. The advantage of the vehicle routing and scheduling problem in a cross-dock is that it determines the departure time of the vehicle and ensures that the items are delivered to the customers at the minimum cost and time. The design of the supply chain of perishable materials is different from the supply chain of other products due to the special characteristics of these products, including their useful life. The main difference between the supply chain of perishable materials and other products is the continuous and significant changes in the quality of these products throughout the supply chain. In this supply chain, the quality of the product is very important, which affects other activities such as warehousing, distribution, and delivery of products, and complicates these activities. Many consumers prefer to buy high-quality products at a fair price. Therefore, because of the great

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variety of most perishable products and their competitiveness, manufacturers have no choice except to design a suitable supply chain and improve it.

In this paper, we provide a multi-objective model for truck scheduling and routing in a cross-dock for perishable items to minimize the total cost and time in the distribution system. In this study, we assume that the value or quality of perishable products decreases throughout their lifetimes. When incoming trucks arrive at the warehouse, it must be decided which door they will be assigned to increase warehouse productivity and reduce transportation costs. Proper allocation of entry and exit trucks to the doors is very important due to the allocation of exit trucks to customer nodes and because of the limited number of doors, the issue of the sequence of trucks in the doors is investigated. Perishable items often have a time-dependent rate of corruption and the condition of their distribution also has a direct effect on its corruption. Therefore, by observing the conditions of correct distribution, the corruption of items during distribution can be reduced. In this research, in addition to the practical aspects, we tried to present a comprehensive and efficient model hypothesis in real-world events according to the case study. Since one of the important goals in using a cross-dock is to reduce distribution time and costs, applying a cross-dock strategy to distribute perishable items in high demand can be very effective. Also, reducing the distribution time through vehicle scheduling and routing plays an important role in maintaining the quality of perishable items.

Literature Review

In discussing the cross-dock, articles are in several areas such as locating a cross-dock in the supply chain, locating a network of cross-dock, assigning doors to tracks, vehicle scheduling, routing and allocation. In this section, we try to express the results of research about cross-dock and in the field of operation planning. Scheduling is an important decision in cross-dock operations and is related to the sequence of incoming and outgoing vehicles. This decision manages the cross-dock operations daily and optimizes or approaches the optimization of the operation schedule. Larby et al. examined the timing of exit trucks on a cross-dock with a single exit and entry door. An incoming truck is unloaded and the products are loaded with the existing outgoing truck. Other goods can also be stored temporarily with a limited capacity [1]. Boysen and Flinder presented a fuzzy optimal model for the use of fixed output scheduling modes. Exit trucks leave the warehouse in a predetermined time window. All shipments that arrive before the truck leaves will be loaded and the rest of the shipments will be delayed until the next truck leaves. Therefore, the goal is to schedule incoming trucks to minimize the number of delayed trucks. This model considers the displacement time between the allocated entrance and exit doors. The author proved this to be NP-hard [2]. Forouharfard and Zandieh studied a scheduling problem of trucks in a cross-dock with an entrance door and an exit door when it is possible to store products temporarily, and a colonial competition algorithm to find the best sequence of incoming and outgoing trucks and minimizing the number of products that are temporarily stored [3]. Baniamerian et al., provided a mixed-integer linear programming for vehicle routing in a cross-dock to maximize the total profit and a new hybrid meta-heuristic algorithm is presented [4]. Van Belle et al., have divided the problem of truck scheduling into three categories. The first category considers a simple cross-dock with a single inlet and outlet door. Scheduling in this case reduces the sequence of incoming and outgoing trucks. The second category considers cross-dock with multiple entrances and exits. But only the timing of the entrance or exit doors is considered. In the third category, the timing of incoming and outgoing trucks is considered simultaneously with multiple transit docks [5]. Yiyo effectively improved the problem of optimizing the vehicle sequence and assigning vehicles to the gates. The goal was to minimize the total operation time in the distribution process and to solve the model, innovative methods of neighborhood search and refrigeration simulation were used [6]. Konur and Golias have studied the problem of scheduling the operation of trucks with multiple entrances and exit doors in the uncertainty of the arrival time of trucks. Hence, a timeline for the arrival of trucks is used and a genetic algorithm is used to solve the problem. The purpose of this study is to minimize the average of total service costs and delays in the arrival of trucks in a situation where truck service costs are variable. This study formulates the problem of cross-dock operations to find the best schedule that minimizes the average of total service costs and the range of total service costs as a two-tier two-objective optimization problem [7]. Liau et al. considered the problem of scheduling and allocation of entrance doors in a multi-door cross-dock for two modes of the arrival time of entry trucks at zero and non-zero times to minimize operation time and developed five metaheuristic algorithms to solve the problem [8]. Mohtashami presented a model for scheduling and allocation in a cross-dock, assuming the possibility of stopping the unloading of incoming trucks and solving by genetic algorithm [9]. Madani and, Tavakoli Moghaddam et al. studied the truck scheduling model considering several passing docks and assuming limited storage capacity and delay time and have developed two meta-heuristic algorithms to solve the model [10]. Ladir and Alpan presented a model of truck scheduling in the uncertainty of the arrival time of outgoing trucks [11]. Golshahri et al. studied the modeling of the allocation and sequence of incoming and outgoing trucks and presented five meta-heuristic algorithms and two heuristic algorithms to solve the model [12].

One of the key features of the vehicle planning and routing problem in a cross-dock is the departure time for each vehicle will be determined from the cross-dock and it is ensured that products are delivered to customers with the lowest operating costs. Operating cost includes violation of arrival and departure times, inventory and transportation, and makes the product with good quality and delivered to the customer at the right time, and thus brings customer satisfaction. Hosseini et al. proposed a new integer programming model for the transportation problem and examined three types of transportation in their problem: 1- Direct transportation 2- Transportation using transit dock and 3- Milk run problem. The name is derived from the traditional milk-selling system in the West, in which a milk-seller takes milk to its customers' homes using specified routes and returns empty bottles [13]. Yin and Chuang have an environmental approach to the issue of routing. They introduced a new dual-purpose function that minimizes operating costs and makes it possible to control the day-to-day costs of trucks and labor. In the second stage, the CO2 emitted by trucks are considered. A high limit is set for the amount of CO2. Finally, fuel efficiency has been considered as an influential factor in decision making [14]. Moghadam et al. investigated the problem of vehicle routing and scheduling in a cross-dock problem with intermittent deliveries. The nonlinear problem was solved with the refrigeration and ant simulation algorithm [15]. Morais et al. proposed an innovative new local search method to solve the problem of vehicle routing with cross-dock [16]. Chen et al. examined the routing of a supply chain in a situation where the middle level of the chain consists of several cross-docks. In this routing, if the goods delivered to a cross-dock do not meet the customer's demand for that warehouse, the required amount of goods will be provided from another cross-dock. In other words, it is possible to move goods between warehouses when needed [17]. Grangier et al. presented a mathematical model for routing trucks from suppliers to cross-dock and from cross-dock to customers and developed a meta-heuristic algorithm to solve it [18].

Agustina et al. have been optimizing the integrated routing and scheduling of vehicles for food supply chain. In the distribution system, goods are perishable and transportation is done through a cross-dock. In this study, the aim is to deliver food on time, so that the early and late penalty costs, inventory costs and transportation costs are minimized. To reduce the response space, the concept of customer area is presented and the time window of the problem is considered as hard [19]. Mousavi and Tavakoli Moghaddam studied the strategic location problem and the operational problem of routing-scheduling in a cross-dock. The problem is studied in two phases. In the initial phase, decision-makers seek to find the minimum number of cross-docks from a discrete set of candidate locations. In the second stage of the problem, the goal is to determine the optimal number of trucks among the limited number of trucks and the best route for transporting products. To solve, a combined two-phase refrigeration simulation algorithm with a forbidden search algorithm is presented [20]. Also, Fatemi Qomi et al. by considering the time and capacity constraints in a cross-dock, studied the model of truck allocation and scheduling and presented an innovative algorithm [21]. Erkat et al. presented the problem of assigning trucks to doors in a cross-dock for multiple unloading and loading doors, and used a refrigeration simulation algorithm to solve the problem [22]. Mokhtarinejad et al. studied the location, routing and scheduling in a cross-dock in an integrated approach. They analyzed the problems of location, routing and scheduling and solved the problems by using the innovative method of machine-based learning. This generator algorithm puts the location of cross-dock and customers in a group with a clustering approach. Genetic algorithm has also been used to solve the warehouse scheduling problem [23].

In multi-objective problems, the objective functions are generally in conflict with each other, otherwise, several goals can be turned into one goal. From reviewing the literature on cross-dock and optimizing multi-objective problems, we found that in few numbers of articles have addressed the importance of multi-objective discussion in cross-dock scheduling and routing, including articles in this field, such as the article by Babaee Tirkolaee et al. They provided a bi-objective mixed-integer model in a cross-dock to minimize the total cost including pollution and routing costs and the other objective function is to maximize the supply reliability. Two metaheuristic algorithms (MOSA and NSGA-II) were used [24]. Yinn et al. proposed a two-objective function for the problem of routing and scheduling and developed two innovative algorithms to solve it [25]. Mohtashami et al., presented a multi-objective model for truck scheduling in a cross-dock to minimize the shipping costs, operating time, the number of trucks, and two meta-heuristic algorithms NSGA-II and MOPSO are used to solve the model [26]. Nasiri et al. presented a mathematical model for the routing of trucks in a system with multiple cross-docks; In this comprehensive model, supplier selection and order allocation are also considered, in which the total costs, including order costs, shipping, inventory, etc., are optimized [27]. Molavi et al. presented a mathematical model for scheduling trucks in a cross-dock with hard time window constraints and used the FIFO policy to sequence trucks for unloading and loading [28]. Nassief et al. solved the problem of allocating trucks to the doors and the operating costs are optimized. To solve the proposed model, a new complex integer modeling is used [29].

Perishable products can appear in a whole variety of forms. These products play an important role in the operational distribution process. In this class of goods, because of its nature and the quality decrease in the distribution system, this issue becomes very important for the people who receive it along the planning horizon. Perishable goods lose their value quickly during the delivery process, so the price of perishable goods largely depends on the situation they reach the customer. It is often a review of perishable goods literature on pricing, return policy, and inventory control for a retailer. Kopanos et al. studied the issue of stacking timing and size in a multi-product dairy product line, and the sequence, depending on installation costs and times, was considered and optimized. However, the proposed planning issue only involved in the packaging phase [30]. In another study, they proposed a mathematical model for the problem of planning the production of limited resources in the semi-continuous food process, such as the dairy industry, and considered the limitation of renewable resources [31]. Govindan et al. proposed a multi-objective optimization model by integrating decision-making sustainability into the distribution sector of a perishable food supply chain network. In this paper, a two-step time-window location-routing problem is introduced to design a sustainable supply chain network and optimize economic and environmental goals in a perishable food supply chain network [32]. Amorim et al. presented a multi-objective model that simultaneously minimized distribution costs and maximized product novelty rates and solved the model with the small-scale Epsilon constraint method and the large-scale multi-objective evolutionary algorithm [33].

According to the articles reviewed in the literature review section, we find that the cross-dock has rarely been used to distribute perishable items. However, in this strategy, reducing inventory and reducing time spent along the chain is one of the most important goals. Therefore, applying this strategy to distribute perishable items with high demand, including food items, meat products, fruits and vegetables, medicines, etc., is very effective in reducing waste due to perishability. Among all the articles, only the article by Augustina et al. [19], deals with the distribution of food items by a cross-dock, but to simplify the proposed model, a hard time window constraint has been used. Though, control of perishable waste, which is affected by three factors: corruption rate, the duration of distribution and also the conditions of distribution, is very important which is not considered in the article. One of the things that have not been considered in the studies, is the cold chain conditions for perishable items such as food items, meat products, fruits, vegetables, and medicines, which are very effective in reducing spoiled items along the chain. For example, the use of refrigerated trucks can reduce the number of perished items.

Model Development and Formulation

Most studies in the field of perishable items have dealt with issues such as pricing, return policy, ordering, and inventory control, and less has been said about how they are distributed throughout the supply chain. Also, in the literature on perishable items, the distribution of these items through a cross-dock has rarely been considered, and in the few studies that have dealt with the distribution of perishable items, and little attention has been paid to the perishable rate that depends on the distribution time and condition. In researches in the field of supply chain management, including issues related to cross-dock, only one type of truck has been considered and in some cases, only different capacities have been assumed for trucks. If in the real world and different industries, several types of trucks are used by the nature of each industry. For example, in the case of perishable items such as food, meat, fruits, vegetables, and medicines, two types of refrigerated and non-refrigerated trucks with different capacities are used. If perishable items are loaded on refrigerated trucks, they have a lower rate of spoilage. In this research, an attempt has been made to eliminate the shortcomings of the proposed models in the articles and increase the efficiency of the proposed model by integrating the decisions and applying the assumptions that bring the model closer to reality.

In this study, we studied a cross-dock for distribution of perishable items. In this regard, considering the most important factors influencing distribution management such as cost and time, and a multi-objective model for the problem of vehicle scheduling and routing is presented. In addition to the time of distribution, the conditions and quality of distribution are also effective in changing the quality of items. Therefore, in this study, by defining the rate of spoilage for products, we considered the rate of spoilage of products, depending on the type of product, time of distribution, and conditions of distribution. The terms of distribution refer to the type of vehicles. In this way, distribution by refrigerated trucks has lower rate of corrupt. On the other hand, the cost of using refrigerated trucks is more than ordinary trucks. Therefore, there is a trade-off between distribution cost and product freshness. The objective functions in this multi-objective model of truck scheduling and routing problem are to minimize the delivery costs, including transportation costs, the penalty costs of shortage, items perished in distribution time, the total time spent and waiting time to receive inbound or outbound trucks.

In the proposed scheduling and routing, the operations of allocating trucks to the doors, scheduling, combining shipments according to destinations, assigning customers to trucks and routing are performed. The planned operations in a cross-dock is as Fig. 1, shown below.

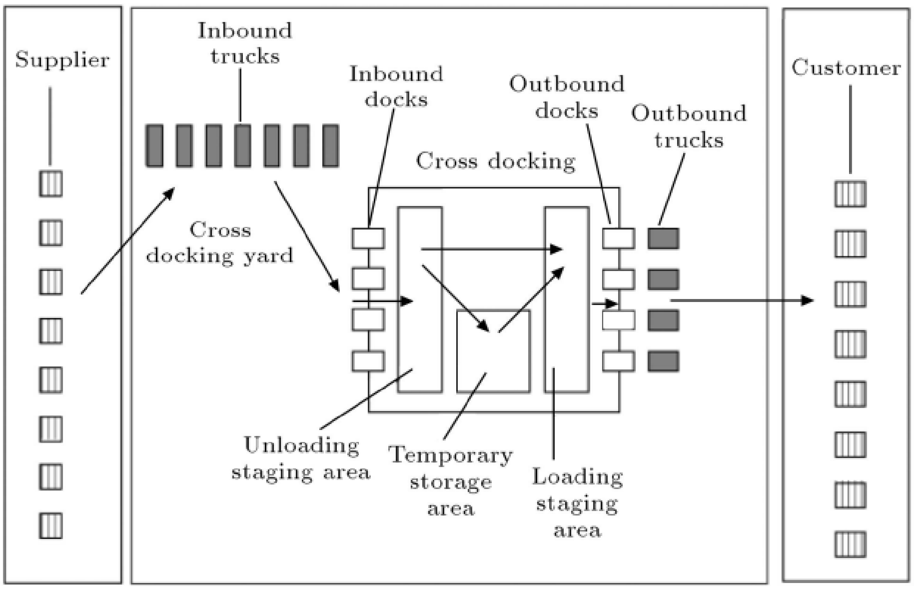

Fig. 1. The operations in a Cross-Dock (Agustina et al.)

Model Assumptions

A summary of the assumptions for modeling the problem is listed below:

- There are several entrance and exit doors in the cross-dock and these doors are located in different places of the terminal.
- The operation of the incoming trucks does not depend on the outgoing trucks, but the operation of the outgoing trucks depends on the operation of the incoming truck corresponding to the transfer of goods.
- There is no interruption of operations. This means that a truck does not leave the door until its operations don't complete.
- The time of the truck changing is the same for all incoming and outgoing trucks.
- The distance between the doors is different and the cost of transportation within the cross-dock depends on how the entry and exit trucks are allocated to the doors.
- There is temporary storage in the warehouse and the storage time is up to 24 hours and the capacity of the storage area is unlimited.
- The speed of the trucks is assumed to be the same and constant.
- Exit trucks have two types of refrigerated and non-refrigerated.
- Items have different rates of corruption.
- If items are distributed by refrigerated trucks, they will spoil at a lower rate.
- Fixed and variable costs of using trucks are different according to the type of trucks.
- Each tour starts at the cross-dock and ends at the cross-dock.
- The importance of customers is different, so the penalty for not responding to each customer is different.

Mathematical Symbols And Signs

m: receiving doors $\{1. \dots . M\}$

n: shipping doors $\{1. \dots . \mathrm{N}\}$
i: inbound truck $\{1. \dots . \mathrm{R}\}$
j: outbound truck $\{1. \dots . \mathrm{s}. \dots . \mathrm{S}\}$
j: $\mathrm{non-refrigerated\ outbound\ truck}$ $\{1. \dots . \mathrm{s}\}$
j: refrigerated outbound truck $\{\mathrm{s}+1. \dots . \mathrm{S}\}$
k: product type $\{1. \dots . \mathrm{K}\}$
$node$: set of nodes $\{\mathrm{CD}. \mathrm{n}_1. \mathrm{n}_2. \dots . \mathrm{n}_\mathrm{n}\}$
c: set of customers $\{\mathrm{n}_1. \mathrm{n}_2. \dots . \mathrm{n}_\mathrm{n}\}$
r_{ik}: number of units of product type k that is loaded in inbound truck i
DT: truck change type
t_{mn}: the time of a product′s transfer from the receiving door m to shipping door n
λ: the transportation cost in cross dock per product unit
ULT: the unloading time per product unit
LT: the loading time per product unit
dem_{nk}: demand for product type k by customer n
$T_{nn'}$: the travel time between node n and n'
$\theta_{k.j}$: the deterioration rate for product type k in truck j
Cap_j: the capacity of truck j
Fix_j: fix cost for utilization of truck j
Var_j: variable cost for utilization of truck j
p_n^s: penalty cost of shortage for customer n per product unit
p^r: penalty cost of returning items per product unit
M: a big positive number
c_i: activity start time of inbound truck i
C_i: activity finish time of inbound truck i
l_j: activity start time of outbound truck i
L_j: activity finish time of outbound truck i
x_{ijk}: number of product type k transferred from the inbound truck i to the outbound truck j
e_{nj}: time in which outbound truck j visits customer n
T: the total time
Q_{nkj}: number of products type k transported by outbound truck j when visiting customer n
${Q^s}_{nkj}$: number of products type k safely transported by outbound truck j when visiting customer n
${Q^d}_{nkj}$: number of products type k that delivered by outbound truck j to customer n
v_{ij}: 1 if any products are transferred from inbound truck i to outbound truck j
y_{im}: 1 if inbound truck i is assigned to the receiving door m
z_{jn}: 1 if outbound truck j is assigned to the shipping door n
u_{ijmn}: 1 if inbound truck i is assigned to the receiving door m and outbound truck j is assigned
to the shipping door n and $v_{ij}=1$
$p_{ii'}$: 1 if inbound trucks i and i' are assigned to the same door and truck i is a predecessor of truck i'
$q_{jj'}$: 1 if outbound trucks j and j' are assigned to the same door and truck j is a predecessor of truck j'
$Z_{nn'j}$: 1 if outbound truck j travels from node n to n'
y_j: 1 if outbound truck j is utilized

Mathematical model

$$Min\ Z_1 = \sum_i \sum_j \sum_k \sum_m \sum_n \lambda\left(x_{ijk}.u_{ijmn}.t_{mn}\right) + \sum_j Fix_j.y(j) + \sum_j \sum_{\substack{n\in node\\ n\neq n'}} \sum_{n'\in c} Var_j.T_{nn'}.z_{nn'j}$$

$$+\sum_{n\in c}\sum_k\sum_j p^d{}_n\left(dem_{nk} - Q^d{}_{nkj}\right) + p^r\left(\sum_i\sum_j\sum_k x_{ijk} - \sum_n\sum_k\sum_j Q^d{}_{nkj}\right) \quad (1)$$

$$Min\ Z_2 = T \quad (2)$$

Subject to:

$$\sum_j x_{ijk} \le r_{ik} \quad \forall\ i = 1.\dots.R \quad k = 1.\dots.K \quad (3)$$

$$\sum_k x_{ijk} \le M.v_{ij} \quad \forall i = 1.\dots.R \quad j = 1.\dots.S \quad (4)$$

$$\sum_m y_{im} = 1 \quad \forall i = 1.\dots.R \quad (5)$$

$$\sum_n z_{jn} = 1 \quad \forall j = 1.\dots.S \quad (6)$$

$$\sum_m\sum_n u_{ijmn} = v_{ij} \quad \forall i = 1.\dots.R \quad j = 1.\dots.S \quad (7)$$

$$u_{ijmn} \le y_{im} \quad \forall\ i = 1.\dots.R \quad j = 1.\dots.S \quad m = 1.\dots.M \quad n = 1.\dots.N \quad (8)$$

$$u_{ijmn} \le z_{jn} \quad \forall\ i = 1.\dots.R \quad j = 1.\dots.S \quad m = 1.\dots.M \quad n = 1.\dots.N \quad (9)$$

$$y_{im} + y_{i'm} - 1 \le p_{ii'} + p_{i'i} \quad \forall\ i.i' = 1.\dots.R \quad i \neq i' \quad m = 1.\dots.M \quad (10)$$

$$p_{ii'} + p_{i'i} \le 1 \quad \forall\ i.i' = 1.\dots.R \quad i \neq i' \quad (11)$$

$$z_{jn} + z_{j'n} - 1 \le q_{jj'} + q_{j'j} \quad \forall\ j.j' = 1.\dots.S \quad j \neq j' \quad n = 1.\dots.S \quad (12)$$

$$q_{jj'} + q_{j'j} \le 1 \quad \forall\ j.j' = 1.\dots.S \quad j \neq j' \quad (13)$$

$$c_{i'} \ge C_i + DT - M.(1 - p_{ii'}) \quad \forall\ i.i' = 1.\dots.R \quad i \neq i' \quad (14)$$

$$C_i \ge c_i + ULT\sum_k r_{ik} \quad \forall i = 1.\dots.R \quad (15)$$

$$l_{j'} \ge L_j + DT - M.\left(1 - q_{jj'}\right) \quad \forall\ j.j' = 1.\dots.S \quad j \neq j' \quad (16)$$

$$L_j \ge l_j + LT\sum_k s_{jk} \quad \forall j = 1.\dots.S \quad (17)$$

$$L_j \ge C_i + \sum_m\sum_n t_{mn}u_{ijmn} + LT\sum_k x_{ijk} - M\left(1 - v_{ij}\right) \quad \forall\ i = 1..R \quad j = 1.\dots.S \quad (18)$$

$$\sum_{\substack{n' \in node \\ n \neq n'}} \sum_{j} z_{nn'j} = 1 \qquad \forall n \in node \tag{19}$$

$$\sum_{\substack{n \in node \\ n \neq n'}} \sum_{j} z_{nn'j} = 1 \qquad \forall n' \in node \tag{20}$$

$$\sum_{\substack{n \in node \\ n \neq l}} z_{nlj} - \sum_{\substack{n' \in node \\ n' \neq l}} z_{ln'j} = 0 \qquad \forall\, j = 1. \ldots . S \qquad l \in node \tag{21}$$

$$\sum_{n \in c} z_{CDnj} \leq y_j \qquad \forall j = 1. \ldots . S \tag{22}$$

$$e_{n'j} \geq e_{nj} + T_{nn'} + ULT \sum_{k} Q^{d}{}_{nkj} - M.\left(1 - Z_{dd'j}\right) \forall\, n \in node.\ n' \in c. n \neq n'. j = 1..S \tag{23}$$

$$e_{cd.j} \geq e_{nj} + T_{n.cd} + ULT \sum_{k} Q^{d}{}_{nkj} - M.\left(1 - Z_{dd'j}\right) \forall\, n \in node.\ n' \in c. n \neq n'. j = 1..S \tag{24}$$

$$\sum_{\substack{n \in node \\ n \neq n'}} \sum_{n' \in c} z_{nn'j} \,.\, dem_{nk} \leq \sum_{i} x_{ijk} \quad \forall\, j = 1. \ldots . S \qquad k = 1. \ldots . K \tag{25}$$

$$\sum_{\substack{n \in node \\ n \neq n'}} \sum_{n' \in c} z_{nn'j} \geq y_j \qquad \forall\, j = 1. \ldots . S \tag{26}$$

$$\sum_{\substack{n \in node \\ n \neq n'}} \sum_{n' \in c} \sum_{k} Q_{nkj} \leq Cap_j. \sum_{\substack{n \in node \\ n \neq n'}} \sum_{n' \in c} z_{nn'j} \qquad \forall\, j = 1. \ldots . S \tag{27}$$

$$Q_{nkj} \leq \sum_{i} x_{ijk} + M\left(1 - z_{nn'j}\right) \quad \forall\, n \in node.\ n' \in c. n \neq n'. j = 1. \ldots . S \quad k = 1. \ldots . K \tag{28}$$

$$Q_{nkj} - Q^{d}{}_{nkj} + M\left(1 - z_{nn'j}\right) \geq Q_{n'kj} \quad \forall\, n \in node.\ n' \in c. n \neq n'. j = 1. \ldots . S \quad k = 1. \ldots . K \tag{29}$$

$$Q^{s}{}_{nkj} = Q_{nkj}\left(1 - e_{nj} \times \theta_{k.j}\right) \qquad \forall\, n \in c.\ j = 1. \ldots . S \quad k = 1. \ldots . K \tag{30}$$

$$Q^{d}{}_{nkj} = Min\left(Q^{s}{}_{nkj}. dem_{nk}\right) \qquad \forall\, n \in c.\ j = 1. \ldots . S \quad k = 1. \ldots . K \tag{31}$$

$$T \geq L_j + e_{cd.j} \quad \forall j = 1. \ldots . S \tag{32}$$

$$all\ variable \geq 0 \tag{33}$$

Description of objective functions and the constraints

The first objective of the model is to minimize the total cost, which consists of four components: transportation costs in the cross-dock, shipping costs (fix costs and variable costs of shipping), penalty costs of shortage, the penalty costs of returning items(items perished during the distribution time) and minimize the waiting time for inbound and outbound trucks. The second objective of the model is for minimizing the total time spent in the distribution system.

Constraint 3 ensures that the total number of products type k transferred from an inbound truck i to all outbound trucks are smaller than the number of products type k that are received.

Constraint 4 shows the relationship between the variables x_{ijk} and v_{ij}. Constraints 5 and 6 ensure that each inbound truck is assigned just to one receiving door and each outbound truck is assigned just to one shipping door. Constraints 7, 8, and 9 show the relationship between the variables u_{ijmn} , y_{im} , and z_{jn}. Constraints 10 and 11 show the correct relationship between the variables y_{im} and the $p_{ii'}$, while the constraints 12 and 13 show the correct relationship between the variables z_{jn} and the $q_{jj'}$. Constraint 14 shows that the entering time of each inbound truck is equal to its predecessor's leaving time plus the truck change time. Constraint 15 shows how to calculate the departure time of trucks. Constraint 16 shows that the entering time of each outbound truck is equal to its predecessor's leaving time plus the truck change time. Constraint 17 shows that the leaving time of each outbound truck is equal to its entering time plus the time required to load all products. Constraints 18 shows that the leaving time of each outbound truck is greater than, or equal to, the leaving time of inbound truck plus the transfer time of products and the time required to load all products. Constraints 19 and 20 are included to ensure that only one vehicle arrives at, and leaves from, each delivery node. Constraint 21 guarantees the consecutive movement of vehicles. Constraint 22 ensures that a trip starts and finishes in the cross-dock. Constraint 23 calculates the time that truck j visits customer n and constraint 24 calculates the time that truck j returns to the cross-dock. Constraint 25 ensures that if outbound truck j visits customer n, the total number of products type k transferred from all inbound trucks to outbound truck j is larger than the customer demand for products type k. Constraint 26 shows the correct relationship between the variables $z_{nn'j}$ and the y_j . Constraint 27 is associated with truck capacities. Constraint 28 ensures that an outbound truck's inventory for each product type is not larger than the total number of products transferred from inbound trucks to this outbound truck. Constraint 29 shows, for all trucks, the relation between the truck inventory and the number of deliveries to customers for each product type. Constraint 30 calculates the number of good items (with appropriate quality) for each product type when a truck visits customers, and the constraint 31 calculates the number of deliveries for each product type by the trucks. Constraint 32 calculates the maximum time including the makespan in the cross-dock and the distribution time.

Results

We solved this model in GAMS (CPLEX solver) and provided the NSGA-II algorithm to solve the large-scale problems. The results are shown in the following tables.

Table 1. Details of issues resolved

No	inbound doors	outbound doors	customers	outbound trucks	inbound trucks	refrigerated outbound trucks
1	2	2	5	3	3	1
2	3	3	8	5	5	2
3	3	2	12	6	6	3
4	4	3	14	8	8	4
5	5	4	15	9	9	4

Table2. Results of solving the two-objec model in Gams

GAMS Result		
Run Time	objective function2	objective function1
5	9837	3871
34	13982	5032
103	16226	9328
483	18341	12862
895	23801	19360

Table 3. Results of inbound trucks in issue 3

Sequence of trucks	Activity finish time	Activity start time	Assigned inbound door	inbound trucks No
1-3	600	0	2	1
2-6	1300	700	1	2
3-1	1300	700	2	3
5-4	600	0	3	4
5-4	1300	700	3	5
2-6	600	0	1	6

Table 4. Results of outbound trucks in issue 3

Time of return to warehouse	Truck route	Sequence of trucks	Activity finish time	Activity start time	Assigned outbound door	outbound trucks No
12654	CD-3-12-9-CD	1-2	2441	1831	1	2
10956	CD-6-1-CD	1-2	3121	2537	1	1
11946	CD-10-2-4-CD	5-6	3293	2673	2	5
14653	CD-7-5-8-11-CD	5-6	2523	1973	2	6

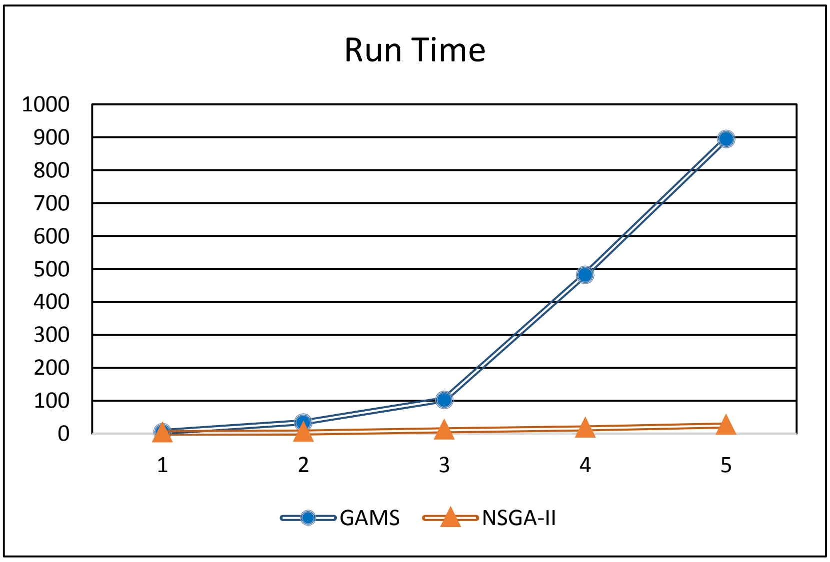

Fig. 2. Comparison of solution time

Table 5. The results of the NSGA-II algorithm

NSGA-II Result		No
objective function2	objective function1	
1023	4064	1
14401	5233	2
16712	9542	3
18524	13119	4
24062	19553	5

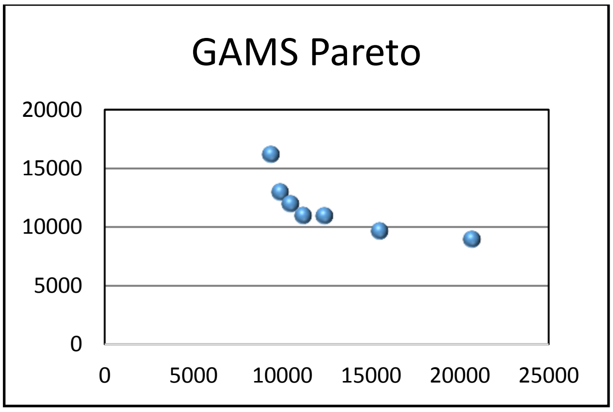

Fig. 3. The GAMS(Weighting Method) Pareto chart

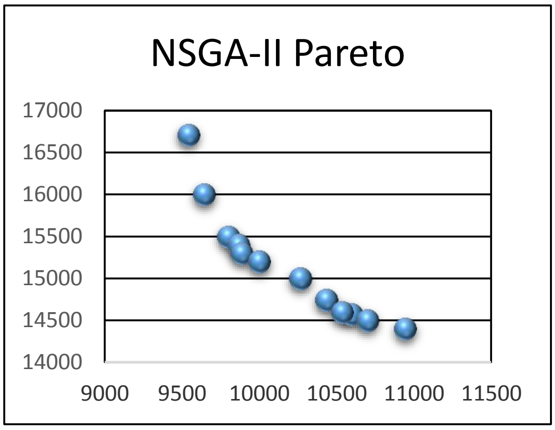

Fig. 4. The NSGA-II Pareto chart

Considering the tables presented in the field of numerical results, we found that the introduced mathematical model is designed so that the start time and end time of activity for incoming and outgoing trucks as well as the allocation of trucks to the doors and its activity sequence are also determined. Then, the goods are allocated to the trucks according to the amount of demand, customer distance and the volume of the trucks, as well as the type of product, and the optimal routes for the customers to visit are determined by the trucks. Due to the dual purpose of the model, in the presented figures, Pareto diagrams are displayed in both methods. Fig. 2, shows a diagram of the model solution duration in two ways, which shows the proper performance of the algorithm in solving the problem.

Due to the importance of measuring the efficiency of the model in optimizing real-world problems, the results of a case study using the model for the global distribution of perishable pharmaceutical and food items are discussed below.

Case Study

In this section, to study the efficiency of the proposed model in large dimensions and also to apply the model in real-world issues, a case study related to Alborz Distribution Company whose most important mission is to distribute various pharmaceutical and food items to other parts of the country. In this section, we will implement the model presented in the previous section for a real example of global drug distribution.

Table 6. The results of the Case Study

Results for one of the Pareto intersections			Number of product types	Number of customers	Number of refrigerated outbound trucks	Number of outbound trucks	Number of inbound trucks	outbound doors	inbound doors
Run Time	objective function2	objective function1							
38.59	130880	648362	65	24	5	10	7	4	4

Table 7. The results of the outbound trucks in Case Study

Time of return to warehouse (hour)	Sequence of trucks	Activity finish time	Activity start time	Assigned outbound door	Outbound truck capacity	Outbound truck number
24.49	1-7	7432	6448	2	15	1
14.47	4-2	6031	4631	1	15	2
16.25	8-3	5391	4091	3	8	3
29.45	4-2	7331	6131	1	10	4
33.66	6-5	6162	4862	4	8	5
15.88	6-5	7532	6353	4	10	6
34.62	1-7	6248	4948	2	8	7
23.20	8-3	7962	7054	3	15	8

Implementing a scheduling and routing optimization model will improve distribution costs and duration, which are key logistics issues. In the following, the diagrams of the improvements obtained after the implementation of the model are displayed in the performance indicators of the logistics field.

Conclusions and future studies

In this study, we studied a cross-dock for the supply of perishable items. In this regard, according to the most important factors influencing distribution management such as cost and time, a multi-objective model for vehicle scheduling and routing is presented and by defining the rate of spoilage for products, the rate of spoilage of products depends on the type of product, time of distribution and distribution conditions are considered. The problem presented for small and medium dimensions is solved in GAMS. The NSGA-II meta-heuristic algorithm is also proposed for large-scale problems. The time and quality of the results of the algorithm in small and medium dimensions are compared with the GAMS output. The results confirm the proper performance of the algorithm in terms of response quality and solution time.

Suggestions for future studies can be made in two parts: modeling and new hypotheses to bring the model closer to reality and make this model more practical: considering the uncertainty conditions for the demands, considering the uncertainty conditions for the routes, assuming the probability of truck failure along the distribution route, providing an inventory routing model to control better and manage items and reduce the number of perished items.

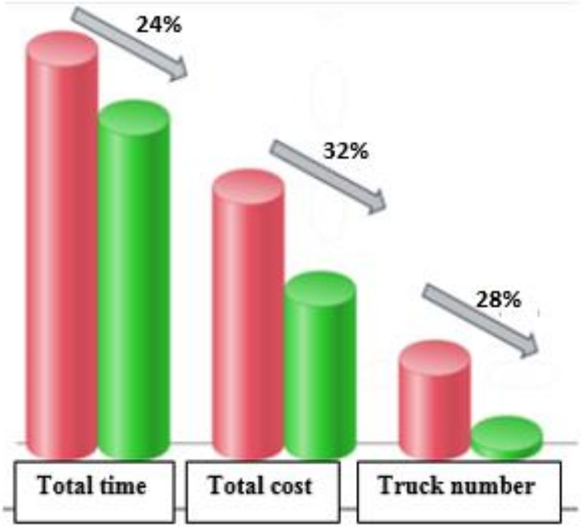

Fig. 5. The NSGA-II Pareto chart

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