PRESENTING A MATHEMATICAL PROGRAMMING MODEL FOR ROUTING AND SCHEDULING OF CROSS-DOCK AND TRANSPORTATION

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Abstract: Cross-docking is the practice of unloading goods from inbound delivery vehicles and loading them directly onto outbound vehicles. Cross-docking can streamline supply chains and help them move goods to markets faster and more efficiently by eliminating or minimizing warehouse storage costs, space requirements, and inventory handling. Regarding their short shelf-life, the movement of perishable commodities to cross-dock and their freight scheduling is of great importance. Accordingly, the present study developed a Mixed-Integer linear Programming (MILP) model for routing and scheduling, cross-docking, and transportation in a reverse logistics network. The model was multi-product and multi-level and focused on minimizing the logistics network costs to increase efficiency and maximizing the consumption value of delivered products. Considering cost minimization (i.e., earliness and tardiness penalty costs of customer order delivery, the inventory holding costs at the temporary storage area of the cross-dock and costs of crossover and use of outbound vehicles) as well as uncertainty in customer demand for perishable products, the model was an NP-hard problem. In this model, the problem-solving time increased exponentially according to the problem dimensions; hence, this study proposed an efficient method using the NSGA II algorithm.

Keywords: Mathematical Modeling, Routing, Scheduling, Cross-Dock, Transportation, Reverse Logistics Network, Perishable Goods

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Introduction

Cross-docking, as a warehousing strategy, is a suitable approach for reducing inventory needed to fulfill the demands of customers (Moldabekova et al. 2020; Wang, Yang, and Lu 2018). At the cross-dock, goods are directly shipped from the receiving dock-doors to shipping dock-doors – where products are stored in a dock for a short time – and are then directly delivered to the customers in at most 12 hours (Ardakani and Fei 2020; Hendalianpour 2020). In other words, although the

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cross-docking strategy removes the inventory operations of a traditional warehouse, it allows goods to be classified and unloaded via the integration process and then loaded in vehicles (Gelareh et al. 2020; Hendalianpour and Razmi 2017). If not all the vehicles of the pick-up navy can arrive at the cross-dock at the same time, the integration process is postponed after collecting all goods; as a result, the waiting time and inventory level increase exponentially (Mousavi and Vahdani 2017)**.** Almost one-third of the annual produced food in the world for human consumption (about 1.3 billion tons) is lost or wasted (Benaissa and Benabdelhafid 2010; Rabbani, Farrokhi-Asl, and Rafiei 2016). Even if just one-fourth of the food currently wasted in the world could be saved, it would be sufficient to feed 870 million hungry people in the world (Hendalianpour 2020; Rahbari et al. 2019; Starostka-Patyk 2019).

The amount of waste is significantly affected by the time spent during logistics operations and environmental conditions of transportation and warehousing. To study and optimize this issue, this study examined vehicle scheduling at cross-dock with multiple doors and vehicle routing to minimize the total cost of the system. The model used in this study determines whether or not the use of inbound vehicles as outbound vehicles is cost-effective with regard to the path to be taken by vehicles. The practical aspect of the subject has received less attention due to the simplification of the used models. In a reverse logistics network of perishable goods, delivery time plays a critical role with regard to several goals, including Just-in-Time (JIT) logistics. Failure to deliver on time or delayed delivery of perishable products for any reason at any stage of the logistics network process may lead to the spoilage of goods as well as financial and environmental losses as such several goals are considered to reduce procurement time and costs and increase customer satisfaction under conditions where products have maximum consumption value at the time of delivery and spoiled products can be collected, recycled, or destroyed. Accordingly, it was aimed to develop, solve, and analyze a mathematical programming model to remove the difficulty. Scientifically and theoretically, many researchers have examined vehicle scheduling at cross-docking. However, the present study addressed a combination of routing, scheduling, cross-docking, and transportation, less studied in recent years.

Literature Review

To provide a literature review and cover all the above-stated subjects, an investigation was performed on previous studies on scheduling and routing of cross-dock and transportation and redesign of the logistics network of perishable goods.

Jansen (2019) developed efficient routing and planning methods to use a complex logistics network. He & Li (2019) introduced a Mixed-Integer Programming (MIP) model to minimize distance in the routing process to describe the Dynamic Schedule Problem (DSP). Rahmandoust & Soltani (2019) proposed a nonlinear multiproduct Vehicle Routing Problem (VRP) with heterogeneous vehicles to find the probable minimum number of cross dockings among the available sets of discrete locations. They also minimized the total cost of establishing cross-docking centers and vehicle transportation costs as well (i.e., distribution and operation cost). Küçükoğlu & Öztürk (2019) addressed the VRP and packing problem with cross-docking and proposed an MILP model. Liu & Lin (2019) studied the problem of location routing with the limitation of the payment time window. They also applied the fuzzy processing method to define customer satisfaction performance, reduce costs, improve customer satisfaction, and enhance efficiency by selecting cross-docking centers and arranging routes properly. Baniamerian et al. (2019) designed a Profitable Heterogeneous Vehicle Routing Problem with Cross-Docking (PHVRCD) to increase the total benefit of a cross-docking connected system. Rahbari et al (2019) proposed a bi-objective MILP model for the problem of routing and programming vehicles with cross-docking for perishable products under the uncertainty in the travel time. Nikolopoulou et al. (2019) presented a new routing problem of the public vehicle with cross-docking using an adaptive memory programming method coupled with a Tabu Search algorithm. They designed a set of pick-up and delivery routes with the minimum travel distance. Nasiri et al (2018) introduced a MILP model wherein the selection and allocation of the order were incorporated into the Vehicle Routing Problem with Cross-Docking (VRPCD) to minimize total costs. Mancini (2017) introduced and formulated the hybrid VRP, which is a developed form of VRP. In their proposed model, Hiassat et al. (2017) added location decision as a strategic decision to the model developed by Lee et al. (2006) discussed the warehousing and transfer of blood units from hospital to specialized center. This study addressed a location-inventory-routing model for perishable goods. Shuang et al (2019) introduced a reverse logistics production routing model with greenhouse gas emissions control policy selection. The researcher assumed a reverse supply chain with remanufacturing options under various greenhouse gas emissions control policies. Kuşakcı et al (2019) studied the optimization reverse logistics network under fuzzy demand to prevent the rapid consumption of natural resources and convert generated waste into value for the economy. Kasravi, Mahmoudi and Feylizadeh (2019) composed two meta-heuristic methods to solve Resource-Constrained Problem. Yavari & Geraeli (2019) investigated the design of a green closed-loop supply chain network for degradable products under uncertain conditions using an MILP model. Zhang et al. (2018) studied a stochastic reverse production routing model with environmental considerations. Furthermore, they incorporated the reverse supply chain model with the remanufacturing option to reduce greenhouse gas emissions. Gardas et al. (2018) examined the reverse logistics in the automobile service sector to reduce exploration and production of oil using the multi-criteria decision-making method (Feylizadeh, Bagherpour, 2018) . Liao (2018) proposed the reverse logistics network design for recycling products and remanufacturing. Yu & Solvang (2018) proposed a model to provide a set of Pareto solutions between benefit and environmental performance. Rahimi & Ghezavati (2018) proposed a multi-period multi-objective MILP model to design and program the network benefit, increase social effects, and decrease environmental impact in a reverse logistics network(Feylizadeh, Modarres and Bagherpour 2008; Bagherpour, Feylizadeh and Cioffi 2012). Trochu et al (2018) evaluated the design problem of a reverse logistics network under environmental policies to recycle wood waste in construction, renovation, and demolition industry. Khodaparasti et al. (2018) presented a modified allocation model to avoid unwanted defects in criteria. A covering model involving the facility capacity and demand elasticity expressed this problem.

Much research has been conducted on reverse logistics of perishable goods with regard to specific goals and constraints. The assumptions of these studies are not similar to what occurs in real life. Moreover, the practical aspect of the subject has received less attention due to the simplification of the used models. In a reverse logistics network of perishable goods, delivery time plays a critical role with regard to several goals, including Just-in-Time (JIT) logistics. Failure to deliver on time or delayed delivery of perishable products for any reason at any stage of the logistics network process may lead to the spoilage of goods as well as financial and environmental losses as such several goals are considered to reduce procurement time and costs and increase customer satisfaction under conditions where products have maximum consumption value at the time of delivery and spoiled products can be collected, recycled, or destroyed. Accordingly, it was aimed to develop, solve, and analyze a mathematical programming model to remove the problem. The inclusion of these goals in the study model would help the reverse logistics network of perishable products to achieve the highest efficiency and productivity. Scientifically and theoretically, many researchers have examined vehicle scheduling at cross-docking. However, the present study addressed a combination of routing, scheduling, cross-docking, and transportation, less studied in recent years.

Research Methodology

Problem Statement

In the problem introduced in this research, in order and replenishment cycles, customers provide logistics network decision-makers with information about the amount, type, and delivery time of perishable products according to demand elasticity. Then, at cross-dock, they prepare a schedule for inbound and outbound shipments based on the orders. To increase the efficiency of the reverse logistics network of perishable products, this schedule shall minimize costs and time of routing, scheduling, cross-docking, and transportation. It should also allow for the timely delivery of perishable products to customers such that their consumption value is maximized.

According to this schedule, inbound vehicles at the cross-dock are unloaded at receiving dock-doors with regard to orders and defined schedules. Unloaded products can be sent directly to shipping doors for loading operations or be stored in the cross-dock intermediate warehouse and remain there until they are consolidated with other received orders of the cross-dock. Consolidated orders are loaded onto outbound vehicles at shipping dock-doors based on the pre-specified orders and schedules. Furthermore, after loading all the orders, outbound vehicles leave cross-dock and meet customers based on the scheduled routing sequence. Then, they return to the central collection center after delivering the orders and collecting the returned products from customers. The development of this model relies on the following assumptions:

- Manufactured products are transported to the cross-dock by inbound vehicles. Once delivered to the cross-dock, they are loaded onto outbound vehicles by consolidating products in accordance with customer demands. Finally, the outbound vehicles deliver the products according to the customers' orders and collect the returned products, and return to the central collection center.
- The loading time of outbound vehicles starts when all relevant orders are unloaded and received at receiving dock-doors and moved to the shipping doors;
- All the orders of each customer are delivered by an outbound vehicle, and the returned products are received and collected from the customers by the same outbound vehicle;
- The number of returned products is smaller than that of the ordered products; therefore, the outbound vehicle is not limited in capacity to collect the returned products from each customer receiving orders.

The consumption value of perishable products decreases as a result of organoleptic changes such as color, odor, taste, and consistency, to the extent that customers refuse to buy and consume them. These changes are mediated by the growth and activity of microorganisms such as bacteria, molds, and yeasts, toxins secreted by microorganisms and natural enzymes in products, and the secretion of enzymes by microorganisms in products, and so on. These changes are accelerated by environmental conditions, especially changes in temperature provide the grounds for the growth of perishability factors and reduce the consumption value of the product over time(Khalid and Sahu 2020).

Organoleptic changes are imperceptible because the products are shipped under the right temperature conditions from their manufacturers. Accordingly, the consumption value of products is maximum when unloading products at cross-dock. However, the activity and growth of the product perishability factors and, consequently, organoleptic changes are accelerated due to temperature changes and cross-dock conditions at the time of unloading products in the cross-dock (Hendalianpour 2018; Hendalianpour et al. 2019). Hence, in this model, the consumption value of products is modeled according to a time-dependent linear piecewise function from the delivery time of products to the cross-dock. Finally, as products lose their consumption value after this period, the value of this function is considered to be zero, which means no consumption value.

Mathematical Modeling

This section introduces the indices, parameters, decision variables, objective functions, and model constraints.

A) Sets and Indices

(1) i: Set of manufacturers, $i = \{1,2,3, \ldots, I\}$, indexed by *i*. (2) *j*: Set of nodes, indexed by *j*, where *j* = 0 denotes the cross-dock, $j = \{1,2,3, \ldots, n\}$ denoted customer and $j = n + 1$ denotes the central collection center. (3) *k*: Set of outbound vehicles at the cross-dock, indexed by *k*, where $k = \{0,1,2,3, \ldots, K+1\}$ such that $k = 0$ and $K + 1$ are considered as dummy outbound vehicles at cross-dock. (4) *l*: Set of inbound vehicles at the cross-dock, indexed by *l*, where $l = \{0,1,2,3, \ldots, L+1\}$ such that $l = 0$ and $L + 1$ are considered as dummy inbound vehicles at cross-dock. (5) *f*: Set of receiving dock-doors, $f = \{1,2,3, \ldots, F\}$, indexed by *f*. (6) *h*: Set of shipping dock-doors, $h = \{1,2,3, \ldots, H\}$, indexed by *h*. (7) *p*: Set of products, $p = \{1,2,3, \ldots, P\}$, indexed by *p*.

B) Parameters

(1) TT_{il}: Travel time from manufacturer *i* to the cross-dock for inbound vehicles *l*. (2) x_{li}: 1 if inbound vehicle *l* carries products to the cross-dock from manufacturer *i*, and 0 otherwise. (3) u_{jl}: 1 if some/all parts of order *j* are carried by inbound vehicle *l*, and 0 otherwise. (4) TU_{jl}: Time required to unload order *j* carried to cross-dock by inbound vehicle *l*. (5) Tl_{jk}: Time required to load order *j* carried to cross-dock by outbound vehicle *k*. (6) a_j: Minimum delivery time of order *j*. (7) b_j: Maximum delivery time of order *j*.(8) $TT_{jj'k}$: Travel time between Node *j* and Node j' for outbound vehicle *k* ($(j \neq j')$ $j, j' = \{0,1,2, \ldots, n = 1\}$).(9) $\mathrm{FC_k}$: Fixed cost of using outbound vehicle *k*. (10) ST_{jk}: Service time for customer *j* by outbound vehicle *k*.(11) D_{jp}: Quantity of product type *p* packages ordered by Customer *j*. (12) CV_p: The consumption value time of product type *p* from the delivery time to the cross-dock.(13) V_p: Volume of each product type *p* packages.(14) PT: Planned time for routing. (15) α_p: Earliness cost per product type *p* packages.(16) β_p: Tardiness cost per product type *p* packages.(17) γ_p: Inventory holding cost of each product type *p* packages at cross-dock.(18) C_k: Crossover cost of outbound vehicle *k*.(19) Q_k: Volume capacity of outbound vehicle *k*. (20) M: Big number.

C) Variables

(1) at_{li}: Movement time towards cross-dock from manufacturer *i* of vehicle *l*.(2) rt_l: Release time of inbound vehicle *l*. (3) r_j: Release time of order *j*.(4) y_{lf}: 1 if inbound vehicle *l* is processed at the receiving dock-door *f* , and 0 otherwise.(5) $x_{lj'}$: 1 if inbound vehicles j' is processed at the same the receiving dock-door, and inbound vehicle *l* immediately precedes inbound vehicle j', and 0 otherwise ($(l \neq j')\ l, j' = \{0,1,2,\dots,L+1\}$). (6) $z_{jj'k}$: 1 if outbound vehicle *k* travels from node *j* to Node j',and 0 otherwise ($(j \neq j')\ j, j' = \{0,1,2,\dots,n+1\}$). (7) v_{jk}: 1 if outbound vehicle *k* carries order *j*, and 0 otherwise. (8) τ_k: 1 if outbound vehicle *k* is used, and 0 otherwise. (9) s_{jk}: Time at which outbound vehicle *k* leaves node *j*.(10) s_j: Time at which order *j* is delivered. (11) dt_j: Departure time of order *j*.(12) Y_{kh}: 1 if outbound vehicle *k* is processed at the shipping dock-door *h*, and 0 otherwise. (13) $X_{kj'}$: 1 if outbound vehicles *k* and $j'$are processed at the same shipping dock-door, and outbound vehicle *k* immediately precedes Outbound Vehicle j', and 0 otherwise ($(k \neq j')\ k, j' = \{0,1,2,\dots,K+1\}$).(14) e_j: Order j earliness. (15) t_j: Order j tardiness. (16) CV_{jp}: Consumption value of product type *p* ordered by customer *j* when it is delivered to the customer $(0 \leq CV_{jp} \leq 1)$. The closer CV_{jp} is to 1, the customer is more consented. (17) CVs_{jp}: Auxiliary variable for the consumption value piecewise linear function of products, $(-\infty \leq CVs_{jp} \leq 1)$. (18) δ_{jp}: 1 if $(CVs_{jp} \leq 0)$, and 0 otherwise

E) Objective functions:

The objective function (1) is to minimize costs and increase the efficiency of a logistics network. The following costs are considered here. The first and second sections of the function calculate the earliness and tardiness penalty costs of orders to customers, to achieve just in time logistics goals, respectively. The third section calculates the cost of temporary storage at cross-dock. The fourth section calculates the cost of the crossover outbound vehicle. Finally, the fifth section estimates the cost of using each outbound vehicle. The objective function (2) to maximize the consumption value of delivered products.

$$\begin{aligned} Minimize\ F_1 = & \sum_{j=1}^{n}\sum_{p=1}^{P}\sum_{l=1}^{L}\sum_{f=1}^{F}\sum_{k=1}^{K}\sum_{h=1}^{H} y_{lf} Y_{kh} v_{jk} \alpha_p D_{jp} e_j \\ & + \sum_{j=1}^{n}\sum_{p=1}^{P}\sum_{l=1}^{L}\sum_{f=1}^{F}\sum_{k=1}^{K}\sum_{h=1}^{H} y_{lf} Y_{kh} v_{jk} \beta_p D_{jp} t_j \\ & + \sum_{j=1}^{n}\sum_{p=1}^{P}\sum_{l=1}^{L}\sum_{f=1}^{F}\sum_{k=1}^{K}\sum_{h=1}^{H} y_{lf} Y_{kh} v_{jk} \gamma_p D_{jp} (dt_j - r_j) \\ & + \sum_{j=0}^{n}\sum_{\substack{j'=1 \\ j\neq j'}}^{n+1}\sum_{k=1}^{K} C_k z_{jj'k} TT_{jj'k} + \sum_{k=1}^{K} FC_k \tau_k \end{aligned} \quad (1)$$

$$Maximize\ F_2 = \sum_{p=1}^{P}\sum_{j=1}^{n}\sum_{k=1}^{K}\sum_{h=1}^{H} v_{jk} Y_{kh} CV_{jp} \quad 2)\ ($$

F) Constraints

$$x_{li} rt_l = x_{li} at_{li} + x_{li} TT_{il} + x_{li} \sum_{j=1}^{n} TU_{jl} u_{jl} \quad l = \{1,2 \dots, L\};\ i = \{1,2, \dots, I\} \quad (3)$$

$$rt_{j'} \geq rt_l - M(1 - x_{lj'}) \quad l = \{1,2 \dots, L\};\ j' = \{1,2 \dots, L\} \quad (l \neq j') \quad (4)$$

$$r_j \geq rt_l - M(1 - u_{jl}) \quad j = \{1,2 \dots, n\};\ l = \{1,2 \dots, L\} \quad (5)$$

$$\sum_{f=1}^{F} y_{lf} = 1 \quad l = \{1,2 \dots, L\} \quad (6)$$

$$x_{lj'} - 1 \leq y_{lf} - y_{j'f} \leq 1 - x_{lj'} \quad l, j' = \{1,2 \dots, L\}\ (l \neq j');\quad f = \{1,2 \dots, F\} \quad (7)$$

$$\sum_{\substack{l=0 \\ l\neq j'}}^{L} x_{lj'} = 1 \quad j' = \{1,2 \dots, L\} \quad (8)$$

$$\sum_{\substack{j'=1 \\ l\neq j'}}^{L+1} x_{lj'} = 1 \quad l = \{1,2 \dots, L\} \quad (9)$$

$$\sum_{j'=1}^{L} x_{0j'} = F \quad (10)$$

$$\sum_{l=1}^{L} x_{l,L+1} = F \quad (11)$$

$$x_{0l} + x_{0j'} + y_{lf} + y_{j'f} \leq 3 \quad l, j' = \{1,2 \dots, L+1\}, (l \neq j');\quad f = \{1,2 \dots, F\} \quad (12)$$

$$s_{0k} \geq r_j + TL_{jk} - M(1 - v_{jk}) \quad j = \{1,2 \dots, n\};\ k = \{1,2 \dots, K\} \quad (13)$$

$$s_{0j'} \geq s_{0k} - M(1 - X_{kj'}) \quad k, j' = \{1,2 \dots, K\}; \; (k \neq j') \tag{14}$$

$$dt_j \geq s_{0k} - M(1 - v_{jk}) \quad j = \{1,2 \dots, n\}; \; k = \{1,2 \dots, K\} \tag{15}$$

$$\sum_{h=1}^{H} Y_{kh} = 1 \quad k = \{1,2 \dots, K\} \tag{16}$$

$$X_{kj'} - 1 \leq Y_{kh} - Y_{j'h} \leq 1 - X_{kj'} \quad k, j' = \{1,2 \dots, k\}; (k \neq j') \; h = \{1,2 \dots, H\} \tag{17}$$

$$\sum_{\substack{k=0 \\ k \neq j'}}^{K} X_{kj'} = 1 \quad j' = \{1,2 \dots, K\} \tag{18}$$

$$\sum_{\substack{j'=1 \\ k \neq j'}}^{K+1} X_{kj'} = 1 \quad k = \{1,2 \dots, L\} \tag{19}$$

$$\sum_{j'=1}^{K} X_{0j'} = H \tag{20}$$

$$\sum_{k=1}^{K} X_{k,K+1} = H \tag{21}$$

$$X_{0k} + X_{0j'} + Y_{kh} + Y_{j'h} \leq 3 \quad k, j' = \{1,2 \dots, K+1\} \; (k \neq j'); \; h = \{1,2 \dots, H\} \tag{22}$$

$$\sum_{k=1}^{K} \sum_{\substack{j=0 \\ j \neq j'}}^{n} z_{jj'k} = 1 \quad j' = \{1,2 \dots, n\} \tag{23}$$

$$\sum_{j'=1}^{n} z_{0j'k} = 1 \quad k = \{1,2 \dots, K\} \tag{24}$$

$$\sum_{j=1}^{n} z_{j,n+1,k} = 1 \quad k = \{1,2 \dots, K\} \tag{25}$$

$$\sum_{j=0}^{n} z_{jhk} - \sum_{j'=1}^{n+1} z_{hj'k} = 0 \quad h = \{1,2 \dots, n\}; \; k = \{1,2 \dots, K\} \tag{26}$$

$$\frac{1}{M} \sum_{\substack{j=0 \\ j \neq j'}}^{n} z_{jj'k} \leq v_{j'k} \leq \sum_{\substack{j=0 \\ j \neq j'}}^{n} z_{jj'k} \quad j' = \{1,2 \dots, n\}; \quad k = \{1,2 \dots, K\} \tag{27}$$

$$\sum_{j=1}^{n}\sum_{p=1}^{P} v_{jk}.D_{jp}.V_p \leq Q_k \qquad k=\{1,2\ldots,K\} \tag{28}$$

$$+TT_{jj'k}+ST_{j'k}-M(1-z_{jj'k}) \qquad j=\{0,1,2\ldots,n\}, j' = \{1,2,\ldots,n+1\}, (j\neq j'); \qquad k=\{1,2,\ldots,K\} \tag{29}$$

$$s_j \geq s_{jk}-M(1-v_{jk}) \qquad j=\{1,2\ldots,n\};\ k=\{1,2\ldots,K\} \tag{30}$$

$$s_j \leq s_{jk}+M(1-v_{jk}) \qquad j=\{1,2\ldots,n\};\ k=\{1,2\ldots,K\} \tag{31}$$

$$s_j \leq PT \qquad j=\{1,2\ldots,n\} \tag{32}$$

$$t_j \geq s_j-b_j \qquad j=\{1,2\ldots,n\} \tag{33}$$

$$e_j \geq a_j-s_j \qquad j=\{1,2\ldots,n\} \tag{34}$$

$$CVs_{jp}CV_p \leq CV_p-(s_j-r_j) \qquad j=\{1,2\ldots,n\};\ p=\{1,2\ldots,P\}\ \forall\ D_{jp}\neq 0 \tag{35}$$

$$CVs_{jp}+M\delta_{jp} \geq 0 \qquad j=\{1,2\ldots,n\};\ p=\{1,2\ldots,P\}\ \forall\ D_{jp}\neq 0 \tag{36}$$

$$CV_{jp} \geq CVs_{jp} \qquad j=\{1,2\ldots,n\};\ p=\{1,2\ldots,P\}\ \forall\ D_{jp}\neq 0 \tag{37}$$

$$CV_{jp} \leq CVs_{jp}+M\delta_{jp} \qquad j=\{1,2\ldots,n\};\ p=\{1,2\ldots,P\}\ \forall\ D_{jp}\neq 0 \tag{38}$$

$$CV_{jp} \leq 1-\delta_{jp} \qquad j=\{1,2\ldots,n\};\ p=\{1,2\ldots,P\}\ \forall\ D_{jp}\neq 0 \tag{39}$$

$$v_{jk} \leq \tau_k \qquad j=\{1,2\ldots,n\};\ k=\{1,2\ldots,K\} \tag{40}$$

$y_{lf} \in \{0,1\} \qquad l=\{0,1,2\ldots,L+1\};\ \ f=\{1,2\ldots,F\}$
$x_{lj'} \in \{0,1\} \qquad l=\{0,1,2\ldots,L\};\ \ j'=\{1,2\ldots,L+1\}\ \ (l\neq j')$
$Y_{kh} \in \{0,1\} \qquad k=\{0,1,2\ldots,K+1\};\ \ h=\{1,2\ldots,H\}$
$X_{kj'} \in \{0,1\} \qquad k=\{0,1,2\ldots,K\};\ \ j'=\{1,2\ldots,K+1\}\ \ (k\neq j')$
$z_{jj'k} \in \{0,1\} \qquad j=\{0,1,2\ldots,n\};\ \ j'=\{1,2\ldots,n+1\}; (j\neq j');\ \ k=\{1,2\ldots,K\}$
$v_{jk} \in \{0,1\} \qquad j=\{1,2\ldots,n\};\ \ k=\{1,2\ldots,K\}$
$at_l, r_j, rt_l, DT_k, s_{0k}, dt_j, s_{jk}, s_j, e_j, t_j \in R_+$
$CV_{jp} \in R_+;\ CVs_{jp} \in R;\ \ \delta_{jp} \in \{0,1\} \qquad j=\{1,2\ldots,n\};\ \ p=\{1,2\ldots,P\}$

Constraint (3) schedules the movement of inbound vehicle l from the manufacturer to cross-dock as well as unloading completion and release time. Constraint (4) ensures that, if an inbound vehicle precedes another inbound vehicle, the release time of the latter should ensure that there is enough time for the former to complete its unloading. Constraint (5) calculates the release time of customer's order, which is the maximum release time of the vehicles that bring some/all parts of the customer's order. Constraint (6) states that each inbound vehicle is serviced at only one receiving door. Constraint (7) ensures that, if an inbound vehicle precedes another inbound vehicle, they should be at the same receiving door. Constraints (8) and (9) indicate that each non-dummy inbound vehicle is exactly ahead of an inbound vehicle (it may be a dummy vehicle). Constraints (10)- (12) restrict the dummy inbound vehicles '0' and 'L+1' to be the first and the last inbound vehicles at each receiving dock-doors, respectively.

Constraint (13) applies the dependency of an outbound vehicle on its related incoming customer's orders and connects the departure time of an outbound vehicle to the release time of its related customer's orders. Constraint (14) ensures that, if an outbound vehicle precedes another outbound vehicle, then the departure time of the latter should ensure that there is enough time for the former to complete its loading. Constraint (15) calculates the departure time of each customer's order, which is the departure time of the vehicle that delivers the same order. Constraint (16) stipulates that each outbound vehicle can be processed at only one shipping door. Constraint (17) ensures that, if an outbound vehicle precedes another outbound vehicle, they should be at the same shipping door. Constraints (18) and (19) each non-dummy outbound vehicle is exactly precisely ahead of another outbound vehicle (it may be a dummy outbound vehicle). Constraints (20)-(22) restrict the dummy outbound vehicles '0' and 'K+1' to be the first and the last outbound vehicles at each shipping dock-doors, respectively.

Constraint (23) determines that each customer's orders are delivered by only one outbound vehicle (this constraint prevents split delivery). Constraints (24) and (25) enforce each outbound vehicle leave cross-dock and return to the central collection center. Constraint (26) ensures the continuity of the outbound vehicle route from the cross-dock. Constraint (27) determines that the customer's order must be delivered by one of the outbound vehicles. Constraint (28) limits the load of the outbound vehicle to its capacity. Constraint (29) schedules the order delivery process. Constraints (30) and (31) compute the delivery time of the order to the customer. Constraint (32) indicates that the delivery process of all orders should be carried out within the planning time horizon. Constraint (33) specifies the tardiness in the delivery of the order. Constraint (34) specifies the earliness in the delivery of the order. Constraint (35) models the Consumption value of product that delivered to the customer, as a linear decreasing function since, unloading of product at the cross-dock which the product has a maximum consumption value. Constraint (36) specifies whether a product type ordered by a customer is delivered after its consumption value period. Constraints (37)-(39) model the consumption value function and ensure that the consumption value of the products delivered after their consumption value period should be equal to zero. Constraint (40) specifies whether a vehicle is used.

Solution Approach (Non-Dominated Sorting Genetic Algorithm-II)

The NSGA-II algorithm is one of the most widely used and robust existing algorithms to solve multi-objective optimization (MOO) problems, the effectiveness of which in solving various problems is now proved. Srinivas and Deb (1994) introduced the NSGA optimization method to solve MOO problems. Regarding this optimization method, note the following highlights:

- One solution, definitely unrivaled by no other solution, scores higher. Solutions are ranked and sorted based on the number of better solutions;
- The fitness value is assigned to the solutions in accordance with their ranks, and they are not dominated by other solutions;
- The fitness sharing method is used for close solutions to optimally adjust the distribution of solutions and ensure the uniform distribution of solutions in a search space.

Regarding above mention, A multi-objective mathematical model is solved for routing, scheduling, cross-docking, and transportation in a reverse logistics network of perishable goods, the results of which are described in the next section.

Discussion & Numerical Study

This study investigated a mathematical programming model for Ramek co in Iran. In this study, we used the real data of Ramek co for five years from 2014 to 2018. In the following, using the data obtained from this company, we solve and implement the designed mathematical programming model. We also analyze this model in the company considering the two modes of development of the company with the modes of increasing the number of manufacturers, incoming and outgoing vehicles, cross-dock doors (for loading and receiving), and customers.

As seen in Section 3, a mathematical model was developed to solve the model optimally. The concerned mathematical model was solved by determining the inputs for a group of manufacturers, the total inbound and outbound vehicles, dock-doors (for shipping and receiving), and a set of customers. Accordingly, three small, medium, and big problems were designed and implemented to solve the mathematical model of the research problem. The number of manufacturers was considered to be 3, 6, and 10 for the three aforementioned problems (namely small, medium, and big), respectively. Accordingly, for Index j, which is set to zero in this study at the beginning of the problem, $j = n$ represents the number of customers. Additionally, the number of outbound vehicles for small problems is initially considered to be 1, so that $k = 0$ and $K + 1$ are considered as dummy outbound vehicles at cross-docking operations. The maximum value for the

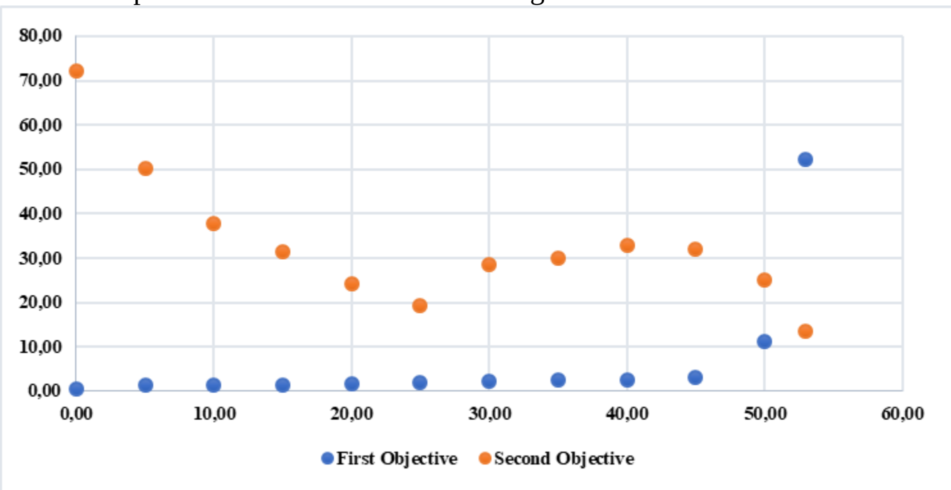
number of vehicles in a large-scale solution is deemed to be 10. This process is also true for outbound vehicles.
The numbers of shipping and receiving dock-doors are 3, 6, and 10 for small, medium, and big problems, respectively. Finally, the number of products in the process of solving small, medium, and big problems are 5, 10, and 15, respectively. Due to its complexity in terms of the number of variables, constraints, and data, the concerned model was programmed in MATLAB software. NSGA optimization was used in the MATLAB environment to solve this model. The parameters of the solution method were set based on the Taguchi method. Moreover, the input values of the problem were generated as random numbers and fed to the model as inputs. After solving this problem, the output is as follows:

Table 1. Solution results for the objective functions of the small, medium, and big problems

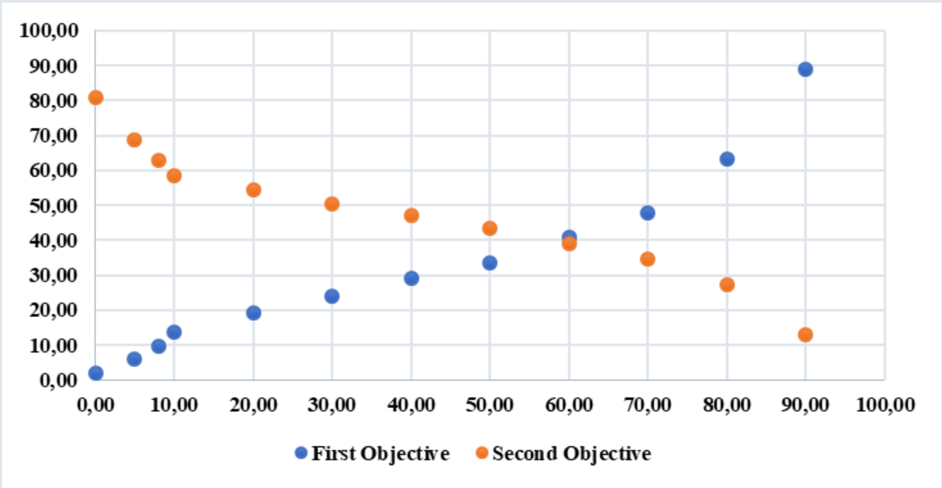
Problems	First Objective			Second Objective		
	F1 – S	**F1 - M**	**F1 - L**	**F2 - S**	**F2 - M**	**F2 – L**
T1	0.59	2.03	14.34	72.18	81.02	93.76
T2	1.25	6.20	33.27	50.30	68.94	84.53
T3	1.41	9.70	40.37	37.80	62.80	81.30
T4	1.53	13.59	47.85	31.55	58.56	77.10
T5	1.70	19.39	52.57	24.14	54.54	71.62
T6	1.96	24.14	56.99	19.39	50.51	67.74
T7	2.14	29.12	63.04	28.66	47.12	62.35
T8	2.42	33.56	67.49	29.87	43.31	55.12
T9	2.65	40.97	71.55	32.88	39.07	44.38
T10	3.24	47.96	75.21	32.00	34.83	38.78
T11	11.21	63.20	78.55	25.00	27.21	33.10
T12	52.11	88.89	89.24	13.59	13.15	16.97

According to the above-mentioned explanations, the data generated for the solution were considered as input problems. Table 1 shows the results of solving the objective functions for the three research problems. As shown in this table, the first objective function, indicating the minimized cost of the increased logistics and efficiency network, is presented in 12 time periods. In Table 1, T1 shows the results of the objective functions for the problems in the first period. In this course, the problem is solved in three sizes, namely small, medium, and big, and the results are expressed for the first objective function. The remarkable difference is caused by the different costs imposed on the research problem, resulting in increased penalties for delays. This is because the early delivery of demands leads to an increase in the cost of stopping and wasting time, holding costs, and problem failure. For the problem tardiness, in addition to the problem tardiness cost, it also imposes customer dissatisfaction costs. According to Table 1, as the number of periods for the system operations increases (Period 6 et seq.), the costs of the medium and big problems in the reverse logistics network system become closer. This implies that more product flows in the network make the delivery time more balanced as such, the costs become closer. As observed, in the periods 11 and 12, the system costs get closer to each other for problems at any size. This presents a rise in the increasing trend of demand and flow of goods among producers, a cross-dock, and customers; thus, the system cost is optimal. The right column in Table 1 shows the values for the second objective function of the three research problems. As stated in the research model, the second objective function indicates the maximum consumption value of the delivered products. Accordingly, this table shows the consumption value of products to customers.

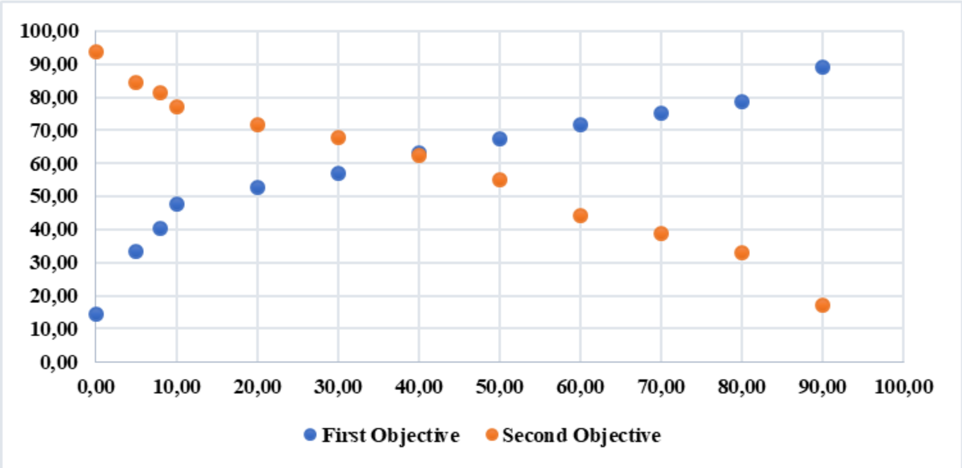
To analyze the algorithms, we have defined different tests with small and large complexities. 12 tests are generated with regards to benchmarks in the literature. For each test problem as given in Table 1, based on the Pareto solutions of the metaheuristics, we have considered the upper and lower bound of the solutions as well as the optimal solution which is the average of the Pareto fronts.



(A): Small Pareto front



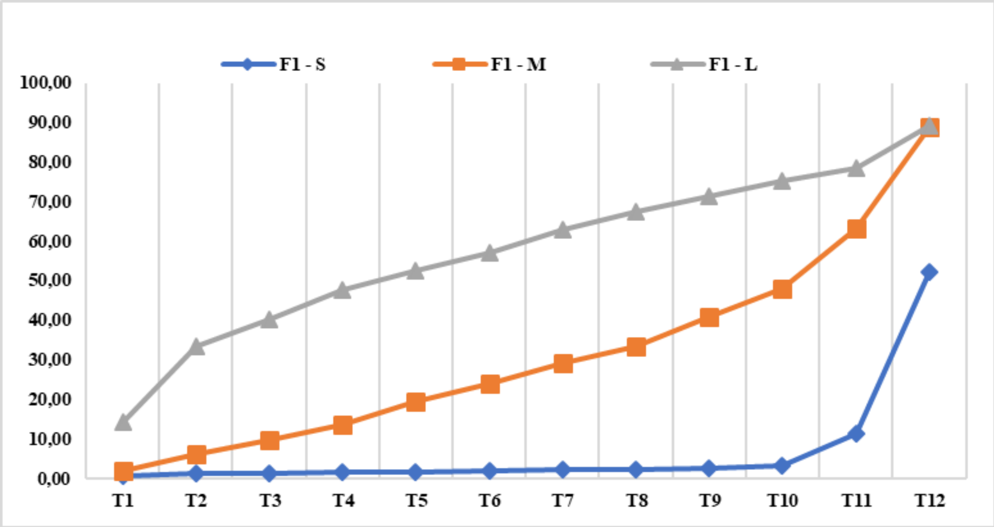
(B): Medium Pareto front



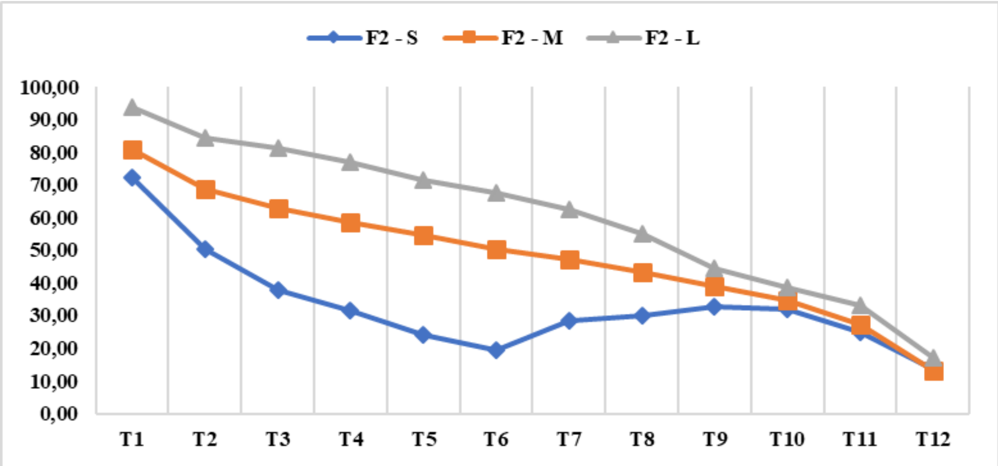
(C): Large Pareto front

Figure 1: Non-dominated solutions in the first test problem

To further analyze the performance of the algorithms statistically, the interval plots for each assessment metric are provided. In this regard, we firstly normalize the data and then depict the data to show the robustness of the algorithms. In these plots as shown in Figures 1 (A) to (C), the lower value brings the better accuracy and robustness of the algorithms.



(A): Convergence of first objective function



(B): Convergence of the second objective function

Figure 2: Convergence of the objective functions

Solving and implementing this model in the case study increased the efficiency of the reverse logistics network of perishable products and reduced costs and times related to routing and planning of cross-dock and transportation. The use of this model also planned the timely delivery of perishable products in such a way that the consumption value of the company's products is at its best. This issue significantly increased customer satisfaction.

Conclusion

Deciding on transportation and vehicle routing is one of the main decisions in the category of short-term decisions in logistics management and supply chain. Transportation is one of the most critical components affecting the total cost of the final product, as well as one of the integral components of any society and one of the key sectors of any country's economy. The vehicle routing problem is one of the most challenging problems in supply chain management. It is a type of combinatorial optimization problem and integer programming, one of the practical concepts of operational research. Much research has been conducted on the types of vehicle routing problems and how to solve them. The present study looked at routing, scheduling, cross-docking, and transportation in a reverse logistics network of perishable goods, to minimize costs and time and maximize the consumption value of perishable delivered products during logistics operations by manufacturers. Ignoring these goals would lead to an increase in the time and cost of logistics operations and a reduction in the consumption value of delivered products, and consequently, a decrease in customer satisfaction and loss of these products. Then, an efficient method was demonstrated using the NSGA II algorithm. The algorithm provides a series of convergent solutions to solve three small, medium, and big problems for two objective functions of the mathematical model: minimizing costs and maximizing the consumption value of perishable delivered products. The present study assumed that there was no uncertainty in the input parameters of the problem. Accordingly, future researchers can investigate the effect of uncertainty in input parameters on design and problem-solving. The proposed model and the results of this study can be used in all the reverse logistics networks of perishable goods. Moreover, the mathematical model can be generalized to the supply chains of most manufacturing companies.

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PRZEDSTAWIENIE MATEMATYCZNEGO MODELU PROGRAMOWANIA DO WYZNACZANIA TRAS I HARMONOGRAMOWANIA MIĘDZY DOKAMI I TRANSPORTEM

Streszczenie: Cross-docking to praktyka polegająca na rozładowywaniu towarów z przychodzących samochodów dostawczych i ładowaniu ich bezpośrednio na pojazdy wyjeżdżające. Cross-docking może usprawnić łańcuchy dostaw i pomóc im szybciej i wydajniej przemieszczać towary na rynki, eliminując lub minimalizując koszty magazynowania, wymagania przestrzenne i obsługę zapasów. Ze względu na ich krótki okres przydatności do spożycia ogromne znaczenie ma przemieszczanie łatwo psujących się towarów do cross-dockingu i planowanie ich przewozu. W związku z tym w niniejszym badaniu opracowano model programowania liniowego (MILP) z mieszaną liczbą całkowitą do wyznaczania tras i harmonogramów, przeładunku towarów i transportu w sieci logistyki zwrotów. Model był wieloproduktowy i wielopoziomowy oraz koncentrował się na minimalizacji kosztów sieci logistycznej w celu zwiększenia wydajności i maksymalizacji wartości konsumpcyjnej dostarczanych produktów. Uwzględniając minimalizację kosztów (tj. Koszty karne za wczesne i spóźnione dostawy zamówień do klienta, koszty magazynowania w tymczasowej strefie składowania cross-docku oraz koszty crossovera i wykorzystania pojazdów wychodzących), a także niepewność dotyczącą zapotrzebowania klientów na łatwo psujące się produkty model był problemem NP-trudnym. W tym modelu czas rozwiązywania problemów wzrastał wykładniczo zgodnie z wymiarami problemu; stąd w badaniu zaproponowano skuteczną metodę wykorzystującą algorytm NSGA II.

Słowa kluczowe: modelowanie matematyczne, wyznaczanie tras, planowanie, cross-dock, transport, sieć logistyki zwrotnej, towary łatwo psujące się

提出用于跨码头和运输路线和调度的数学编程模型

摘要:对接是从入库运输车辆中卸下货物并将其直接装载到出库车辆中的一种做法。交叉配送可以消除或最小化仓库的存储成本，空间需求和库存处理，从而简化供应链，并帮助他们更快，更有效地将商品运送到市场。关于它们的保质期短，易腐商品向跨码头的运输及其货物调度至关重要。因此，本研究开发了一种混合整数线性规划(MILP)模型，用于在逆向物流网络中进行路线和调度，交叉对接和运输。该模型是多产品，多层次的，其重点是最小化物流网络成本以提高效率并最大化已交付产品的消费价值。考虑成本最小化(即客户订单交付的提前和拖延罚款成本，跨码头临时存储区的库存持有成本以及跨界和使用出境车辆的成本)以及客户对易腐烂产品的需求不确定，该模型是一个NP难题。在该模型中，解决问题的时间根据问题的规模呈指数增长。因此，本研究提出了一种使用NSGA II算法的有效方法。

关键字:数学建模，路由，调度，跨码头，运输，逆向物流网络，易腐货物