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Green routing of multi-objective transport vehicles with cross docks under the time window constraint

Enrutamiento verde de vehículos de transporte de objetivos múltiples con cross docks bajo la restricción de ventana de tiempo

Farhad Bavar[1], Majid Sabzehparvar[2*], Mona Ahmadi Rad[1]

[1]Department of Industrial Engineering, Islamic Azad University, North Tehran branch, Tehran, Iran
[2]Department of Industrial Engineering, Collage of Engineering, Karaj Branch, Islamic Azad University, Karaj, Iran

[*]Corresponding author E-mail: sabze@kiau.ac.ir

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ABSTRACT

In this research, a model for green routing of vehicles in the network of cross docks under time window constraints is presented. In this model, there are two goals, include reducing the cost of transportation and reducing the emission of environmental pollutants, reducing fuel. In general, the goal of the model is to obtain the best route in the distribution network, which imposes the lowest cost on the network and, in addition, minimizes fuel consumption. The presented model was solved with GAMS software. As the dimensions of the problem increase, the execution time of the program increases drastically, and this indicates that the problem is NP-hard. Therefore, in order to solve the model in large dimensions, the meta-heuristic non-dominant sorting genetic algorithm, NSGAII, was used. The results of examining various problems with the meta-heuristic algorithm show a very high efficiency of the presented algorithms in terms of time to solve the problem. The results showed that the proposed model, in addition to reducing the total cost of transportation and the cost of constructing cross docks in the candidate points, also reduced the emission of environmental pollutants. Also, according to the mentioned time window, the products were sent to the customers on time.

Keywords: Routing, Cross dock, Time windows, Environmental pollutants.

RESUMEN

En esta investigación se presenta un modelo de enrutamiento verde de vehículos en la red de cross docks bajo restricciones de ventana de tiempo. En este modelo, hay dos objetivos, incluyen la reducción del costo del transporte y la reducción de la emisión de contaminantes ambientales, la reducción de combustible. En general, el objetivo del modelo es obtener la mejor ruta en la red de distribución, que imponga el menor costo en la red y, además, minimice el consumo de combustible. El modelo presentado se resolvió con el software GAMS. A medida que aumentan las dimensiones del problema, el tiempo de ejecución del programa aumenta drásticamente, y esto indica que el problema es NP-difícil. Por lo tanto, para resolver el modelo en grandes dimensiones, se utilizó el algoritmo genético meta-heurístico de clasificación no dominante, NSGAII. Los resultados de examinar varios problemas con el algoritmo metaheurístico muestran una eficiencia muy alta de los algoritmos presentados en términos de tiempo para resolver el problema. Los resultados mostraron que el modelo propuesto, además de reducir el costo total de transporte y el costo de construcción de cross docks en los puntos candidatos, también redujo la emisión de contaminantes ambientales. Además, de acuerdo con la ventana de tiempo mencionada, los productos fueron enviados a los clientes a tiempo.

Palabras claves: Ruteo, Cross dock, Ventanas de tiempo, Contaminantes ambientales.

1. INTRODUCTION

Cross dock is a logistics strategy that aims to reduce inventory and increase customer satisfaction (Buijs et al., 2014) The products reach the customer from the supplier through the cross dock. And the items should be collected in the cross dock before being sent to the customer, and after the weighing, packing and classification operations are done according to the destination, they should be sent to the customers by outgoing vehicles in the shortest possible time (Pan et al, 2015). Kinnear defined cross dock as "receiving products from suppliers or manufacturers for different final purposes and combining this product with other suppliers' products for final purposes" (Kinnear, 1997). The cross dock acts more as an inventory coordinator rather than a storage role (Yin et al., 2016). Usually, products are stored in the cross dock for less than 24 hours, and the cross dock must be emptied at the end of the working day (Leggieri et al., 2017). Since the cross dock has advantages such as reducing costs, reducing procurement and delivery time, improving customer service, reducing storage space, reducing inventory turnover, reducing excess inventory, consolidating shipments, improving the utilization of resources (For example, using the maximum capacity of the vehicle), better matching between the transported product and the amount of demand; Its implementation has many benefits (Goodarzi et al., 2016). In supply chain management, cross dock is a logistics method to minimize warehouse storage and coordinate distribution activities related to product loading between vehicle delegation and product transportation. In general, five activities are performed in distribution centers: receiving, organizing, temporary storage, picking and transferring. Cross dock operations must be carefully coordinated due to the lack of storage space (Miao, 2008, Yan et al., 2009).

On the other hand, the vehicle routing problem (VRP) is the heart of distribution organization. Thousands of companies that are active in the delivery, collection and transportation of objects and people face this problem every day (Santos et al., 2013). Urban logistics service providers are always looking for ways to deliver faster and cheaper than in the past (Dos Santos et al., 2019). Since organizations have different conditions, the goals and constraints of this issue are very diverse. In most cases, the capacity of the facilities is limited, and this limitation can be caused by space limitations, manpower limitations, etc. But for some cases, there is no capacity limit on the facilities (Maknoon et al., 2016). Therefore, these problems are classified into two categories, problems with limited and unlimited capacity (Nikolpoulu et al., 2017). The proposed model of this project has two levels, which includes the first level of potential locations of cross docks. On the second level are the customers of the product.

In each period of time, by minimizing the total logistics costs and considering the capacity of the vehicles, loading between cross docks is done. This research specifically pursues the following questions:

1. How are the parameters of the time windows included in the design of the routing problem?
2. How can the total cost be reduced in the vehicle routing model in the cross dock network?
3. How can the emission of environmental pollutants be reduced in vehicle routing?
4. How to consider the shortest path for vehicles in the cross dock network?

Of course, the evidence indicates that organizations have responded to the needs of customers as well as the pressures of international and governmental organizations supporting environmental issues for several years and have accepted the necessity of environmental management and implemented green supply chain management in order to compete with global markets. (Zhu et al., 2010). Many buying companies demand that their suppliers implement green supply chain management practices and even fulfill additional environmental requirements (Lee, H. L.et al., 1992). The importance of this issue globally is such that suppliers are hard pressed to find any business opportunity in a new space without green supply chain management practices and practices (Lee, D. H. et al., 2008). The environmental view of the supply chain is relevant in any country, in any industry and at any level. Therefore, according to the stated content, the aim of this research is to determine the minimum total transportation costs (distribution cost) and to minimize the emission of environmental pollutants (carbon). Also, this problem has a lot of complications due to the form of the service in a specific time frame, which in case of adding the route length limit and the time window cost, while the complexity is very high, it becomes very close to a practical issue in practice. According to the mentioned contents, the time window for truck routing is proposed.

The time window raised for this issue is of a strict type, which means that the vehicles must serve the customers within a certain period. There is also a penalty for carbon emission (more than the allowed limit). In the following, the relevant literature review is reviewed in section 2. The research problem and problem modeling are presented in Section 3. Section 4 provides a numerical example and an optimal solution for solving the model. In addition, analytical results and sensitivity analysis are discussed. Final results and some suggestions for future research are presented in Section 5.

2. LITERATURE REVIEW

The first research conducted in the field of vehicle routing for cross dock was done by (Lee, Y. H. , et al. 2006) to obtain the optimal routing schedule of vehicles; And the simultaneous scheduling and routing model of the cross dock has been considered; Since the problem is NP-HARD, they have presented an algorithm based on forbidden search to solve the problem. (Wen et al. , 2009) presented the famous paper Cross Dock Routing (VRPCD) with different vehicles and considering that the products cannot be stored in the cross dock and proposed a forbidden search algorithm to solve the model. (Hasani Goodarzi et al. , 2016) presented a vehicle routing model considering the time window, multi-product mode and considering pickup and delivery in several times. The study and research done in the literature of the pricing problem is mainly focused on linear demands with a percentage of error according to persuasive and effective analysis. In the past, research has been done on each part of the above-mentioned areas, and opportunities for expansion and future research have been presented to other researchers. The importance of pricing financial assets has led to the emergence of various theories and models in the last half century. A research titled Sustainable Design of Inventory Routing of Closed Loop Supply Chain Network under Uncertainty is presented. In this research, considering the economic, social and environmental effects, a new closed-loop model of sustainable inventory routing under uncertainty was presented. In this research, a practical study has been solved using meta-heuristic algorithms. (Zhalechian, M. et al.2016).

A research has been carried out under the title of optimization of the car supply chain network model under macroeconomic fluctuations. In this research, the model of the supply chain network was designed, which was solved by considering the problem of selecting suppliers and the problem of transportation and distribution of products using the forbidden search algorithm. (Sadri Esfahani et al., 2014). A multi-objective model for optimizing supply chain network design based on biogeography under uncertainty is presented. In this research, a new two-stage optimization method for multi-objective supply chain network design (MO-SCND) with uncertain transportation costs and uncertain customer demands is proposed. In this research, genetic algorithm is used to solve the model on a large scale and Lingo software is used on a small scale. Finally, an example of a dairy company is presented as a case study to check the applicability of the model. (Yang et al., 2015). An innovative multi-objective MBSA method for green supply chain design and planning is presented. In the algorithm proposed in this research, the capacities of supply chain institutions (factories, warehouses and distribution centers) are planned for inventory and material flow during the time horizon. The purpose of this research was to maximize the profit and minimize the environmental impact of the proposed method. (Martins et al. 2015) in another research, an optimization model for green supply chain management using a big data is presented. In this research, three scenarios are presented in order to improve green supply chain management, the first optimization scenario is divided into three options: the first option includes risk minimization (minimizing economic costs), the second option minimizes both risk and carbon, and the third option tries to minimize risk, carbon emissions, and economic costs simultaneously. (Ray et al., 2016). Some examples of recent research in the field of vehicle routing are given below:

Wong et al. (2018) in an article entitled Routing Optimization Problem in Green Supply Chain stated that by Considering the cost and crimes to reduce the use of carbon gas in the transportation of products, the fuel costs are reduced and in the supply chain, the desired places are tried to be close to each other, which will ultimately lead to a reduction in routes.(Furkan et al.,2017) in an article titled Car Routing with Cross Dock stated that solving the presented model for 20 sources and 50 destinations showed that the model is effective and reduces transportation costs and optimizes routes.(Nikolopoulou et al.,2017) presented the movement of products between paired locations of cross docks and direct shipping in an article. (Peng Ying et al.,2016) presented a paper entitled adaptive memory for green routing of vehicles with cross docks, and a mathematical bee algorithm was used for this purpose. (Baniamerian et al.,2019) in an article entitled Heterogeneous routing of profitable vehicles with cross docks stated that paying attention to quick access to products and inventories will optimize the chain problem. (Bruglieri et al.,2019) presented a path-based solution method for the green vehicle routing problem. (Reddy et al .,2017) presented a research titled a simulation system based on multiple agents to provide operation planning and scheduling with multiple cross dock. Table 1 shows the characteristics of the research conducted.

3. DESCRIPTION AND MODELING OF THE PROBLEM

In this research, the routing model in multi-product mode considering different vehicles and multiple routes with cross dock is presented under time window constraint. Also, according to the number of trucks carrying products, the shortest possible route is chosen to reduce time. The products imported by trucks are transferred to the central cross dock after sorting to be sent to the customers by the shortest route to the means of transportation. It is worth mentioning that the vehicle is unloaded after the end of the route and reaching the cross dock, and the new vehicle carries the products to the destination of the customers. First, the assumptions and then the parameters related to the problem and finally the proposed model are presented.

3-1. The basic assumptions of the problem

In this matter, there are the following main assumptions:

- The supply chain consists of a supplier and cross docks and customers.
- There are enough vehicles available for cross dock.
- The capacity of the central warehouse and the storage time of the products in the warehouses are limited.
- The location of the warehouses is fixed in advance.
- The working time and the number of vehicles of each vehicle are limited.
- The capacity of vehicles is limited.
- Vehicles have the ability to carry one or more types of special products.
- The route of each vehicle starts from a warehouse and ends at the final warehouse.
- A time window is considered for the transferred goods. The goods must be delivered at the specified time. If the demand of each customer is not met within a predetermined time window, the means of transportation will incur a delay penalty.

Table 1. Conducted research

Authors	Year	Model type		Model decisions			Objectives			Solution method		
		Single objective	Multi objective	Time window	Pricing	Demand	Routing	Cost	Environmental	precise	meta-heuristic	Fuzzy
Liao et al	2010	*				*					*	
Vahadani et al	2012		*			*	*				*	
Tarantilis	2013		*				*	*			*	
Santos et al	2013		*					*		*		
Fakhrzadeh and Esfahani	2013		*	*			*				*	
Dando and Cerda	2013		*			*		*		*		
Yu et al	2013	*									*	
Moghaddam et al	2014		*				*	*		*	*	
Lin et al	2014					*	*	*				
Pan et al	2015	*								*		
Leggieri and Haouari	2017	*							*	*	*	
Peng-Yeng and Yan-Lan	2016		*				*	*	*		*	
Wong et al	2018		*				*	*	*		*	
Baniamrian et al	2019		*		*			*			*	
Bruglieri et al	2019		*				*		*			*
Existence Research	2022		*	*	*		*	*	*	*	*	

3-2. Sets and indices

Several signs and parameters are used in the mathematical model, the definition of each of them is given below:

i , j : Index of unloading points/customers $(i.j = 1.2.\cdots.N)$ $(i = 0$ It indicates the location of the depot in the central warehouse, in other words, supplier warehouse.)

v : Vehicle index $(v = 1.2.\cdots.V)$

s : Index related to warehouse $(s = 1.2.\cdots.S)$

S: The number of warehouses

N: Number of unloading points/customers

V: A collection of available vehicles

M: Large positive constant number

3-3. Parameters

COT_{ij}:Transportation cost between the unloading point between two nodes *i* and*j*

COT_{si}: Transportation cost between cross dock and customer

d_i: The quantity demanded by the *i*-th customer

R_v: The capacity of the *v*-th vehicle

Et_i: The earliest start time of each service node *i*

L_i: The latest service start time of node *i*

$t_{i.j}$: The time interval between node *i* and node *j* unloading point

Ψ_i: The value of the penalty function defined for node *i*

δ_i: Service time at node *i*

Y_t: Maximum travel time for vehicles

ψ_i: Penalty for violation of time unit for each node

EC_{ij}: The amount of carbon emissions resulting from transporting a unit of goods from node *i* to node *j*

γ: Amount of penalty for each unit of carbon emission

EC_{max}: The maximum permissible level of carbon emissions

3-4. Decision variables

VP_{ijv}: It is equal to 1 if the vehicle v passes the edge (i, j), otherwise it is equal to 0.

VP_{siv}: It is equal to 1 if the vehicle *v* passes the edge (s, i), otherwise it is equal to 0.

u_i: Variable to remove sub-tour

Z_s: The cross dock selection variable is 1 if the warehouse is located in *s* and 0 otherwise.

t_i: Time to reach node *i*

Δa_i: Premature time penalty for node *i*

Δb_i: Delay time penalty for node *i*

3-5. Mathematical model

$$Z_1 = Min\left\{\sum_{s=1}^{s} Z_s COT_{(0)s} + \sum_{i=1}^{N}\sum_{s=1}^{S}\sum_{v=1}^{V} VP_{siv}COT_{si} + \sum_{i=1}^{N}\sum_{\substack{j=1\\ i\neq j}}^{N}\sum_{v=1}^{V} VP_{ijv}COT_{ij} + \sum_{i=1}^{N}\psi_i.(\Delta a_i + \Delta b_i)\right\} \quad (1)$$

$$Z_2 = Min\sum_{i=0}^{N}\sum_{j=1}^{N}\sum_{v=1}^{V}(EC_{ij} - EC_{max}).VP_{ijv}.\gamma \quad (2)$$

$$\sum_{i=1}^{N}\sum_{s=1}^{S} VP_{isv} \leq 1 \qquad \forall v \qquad (3)$$

$$\sum_{j=1}^{N}\sum_{s=1}^{S} VP_{sjv} \leq 1 \qquad \forall v \qquad (4)$$

$$\sum_{v=1}^{V}\sum_{\substack{i=1\\ i\neq j}}^{N} VP_{ijv} = 1 \qquad \forall j \qquad (5)$$

$$\sum_{v=1}^{V}\sum_{\substack{j=1\\ j\neq i}}^{N} VP_{ijv} = 1 \qquad \forall i \qquad (6)$$

$$\sum_{\substack{j=1\\ j\neq i}}^{N}\sum_{v=1}^{V} VP_{ijv} + \sum_{s=1}^{S}\sum_{v=1}^{V} VP_{isv} = 1 \qquad \forall i \qquad (7)$$

$$\sum_{s=1}^{S}\sum_{v=1}^{V} VP_{siv} + \sum_{\substack{j=1\\ j\neq i}}^{N}\sum_{v=1}^{V} VP_{jiv} = 1 \qquad \forall i \qquad (8)$$

$$\sum_{s=1}^{S}\sum_{i=1}^{N} VP_{siv} - \sum_{i=1}^{N}\sum_{s=1}^{S} VP_{isv} = 0 \qquad \forall v \qquad (9)$$

$$\sum_{s=1}^{S}\sum_{i=1}^{N} VP_{siv} d_i + \sum_{i=1}^{N}\sum_{\substack{j=1\\ j\neq i}}^{N} VP_{ijv} d_j \leq R_v \qquad \forall v \qquad (10)$$

$$\sum_{s=1}^{S} VP_{siv} + \sum_{\substack{j=1\\ j\neq i}}^{N} VP_{jiv} - \sum_{\substack{j=1\\ j\neq i}}^{N} VP_{ijv} - \sum_{s=1}^{S} VP_{isv} = 0 \qquad \forall i, v \qquad (11)$$

$$VP_{ijv} \leq \left(\sum_{s=1}^{S}\sum_{i'=1}^{N} VP_{siv}\right) \qquad \forall v, i, j \qquad (12)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N} t_{ij} VP_{ijv} + \sum_{i=1}^{N} \delta_i \sum_{j=1}^{N} VP_{ijv} \leq Y_t \qquad \forall v \qquad (13)$$

$$t_i + \delta_i + t_{ij} - t_j \leq M * (1 - VP_{ijv}) \qquad \forall s, j \qquad (14)$$

$$\mathrm{LB}_i \leq t_i \leq \mathrm{UB}_i \qquad \forall i \qquad (15)$$

$$\sum_{i=1}^{N}\sum_{v=1}^{V} VP_{siv} \leq M * z_s \qquad \forall s \qquad (16)$$

$$u_i - u_j + 1 \leq M * (1 - VP_{ijv}) \qquad \forall i,j \qquad (17)$$

$$\Delta a_i \geq Et_i - t_i \qquad \forall i \qquad (18)$$

$$\Delta b_{\mathrm{i}} \geq t_i - L_{\mathrm{i}} \qquad \forall i \qquad (19)$$

$$VP_{ijv} \in \{0,1\} \qquad \forall i,v \quad i \neq j \qquad (20)$$

$$VP_{siv} \in \{0,1\} \qquad \forall i,s,v \qquad (21)$$

$$VP_{isv} \in \{0,1\} \qquad \forall i,s,v \qquad (22)$$

$$u_i \geq 0 \qquad \forall i,v \qquad (23)$$

Constraint 1 is related to the first objective function. which includes reducing the cost of shipping from the central warehouse to the candidate points if selected, reducing the cost of the route between the cross dock and customers, reducing the cost of the route between customers, and the last part of the cost of not serving customers on time,time window fines, which should be minimized.

Constraint 2 is related to the second objective function, which is to reduce the emission of environmental pollutants , fuel reduction.

Constraints 3 and 4 indicate that every device enters the warehouse that has been removed from that warehouse.

Constraints 5 and 6 indicate the conditions for assigning a vehicle to each node.

Constraint 7 indicates that input to each node can only originate from one warehouse or from another node.

Constraint 8 shows that the output from each node can only end up in one warehouse or another node,In other words, these two limitations guarantee that all service points are provided.

Constraint 9 is related to the start and end of each path, which guarantees that each path starts from a warehouse and ends at a warehouse. In other words, they guarantee the continuity and continuity of the path.

Constraint 10 is related to the capacity of each vehicle, that the total demand of points in a route by each vehicle should not exceed the capacity of the vehicle.

Constraint 11 The sum of input to each node is equal to the sum of output from that node, that is, every vehicle that enters the node must leave it.

Constraint 12 guarantees that an edge *i*, *j* can be traversed by a vehicle *v* if it starts from a warehouse *s*.

Constraint 13 guarantees that the sum of service times of each vehicle cannot exceed the maximum travel time of that vehicle.

Constraint 14 is an important calculation formula used in routing models that measures the time of arrival (arrival) of transportation vehicles at the unloading/customer points.

Constraints 16 and 15 ensure that no vehicle can reach its destination before the end of the hard time window (exceed the hard time window).

Constraints 17 is an important relationship to remove the sub-tour in transportation issues.

Constraints 18 and 19 are related to the time window that calculates the penalty for early and late times of the problem.

Constraints 20 to 23 are related to the allowed values for the decision variables of the model, all of which are zero and one.

Constraints 23 are related to the non-negative variable.

4. MODEL SOLUTION METHOD

To solve the proposed model, the meta-heuristic algorithm of non-dominant sorting genetics (NSGAII) has been used. Among the multi-objective evolutionary algorithms (MOEA), NSGA-II is one of the most widely used optimization algorithms in the fields of multi-objective optimization. Non-dominated sorting genetic algorithm (NSGA) was first introduced by Deb and Srinivas in 1994. Divided the evolutionary group into several levels to provide a dominant relationship for selection and solution. They called this second version of NSGA, NSGA-II. (Tirkolaee et al., 2020)

The working method and general algorithm of NSGA-II is as follows:

1. Creating the initial population
2. Calculation of fitness criteria
3. Sorting the population based on the conditions of overcoming
4. Calculation of congestion distance

Selection: As soon as the initial population is selected, it is sorted based on the conditions of dominance, the value of the crowding distance will be calculated in it, and the selection will start from among the initial population. This selection is based on two elements:

Population Rank: Populations are selected in lower ranks and if two members are from the same rank, the member with greater crowding distance is selected.
Distance calculation: It should be noted that the selection priority is first based on rank and then based on congestion distance.

Intersection and mutation to produce new children, this work is done using the binary selection method. Combining the initial population and the population obtained from crossover and mutation and replacing the parent population with the best members of the population combined in the previous steps, in the first step, the members of lower ranks replace the previous parents and then they are sorted according to the crowding distance. In short, the initial population and the population resulting from crossover and mutation are first classified according to rank and some of them with a lower rank are removed.

In the next step, the remaining population is sorted according to the congestion distance. Here, sorting is done inside a front. All steps are repeated until the desired generation (or optimal condition). This process is shown in summary in figure 1 and 2.

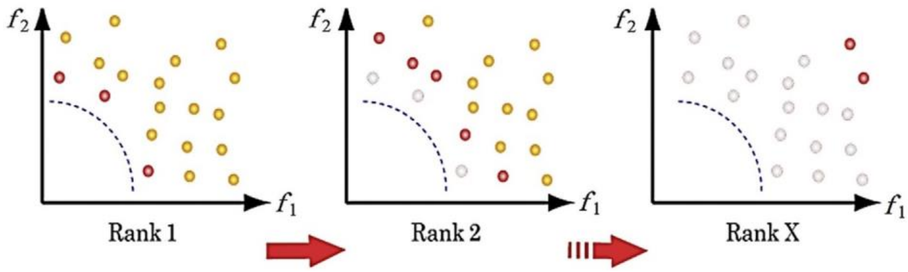

Figure 1. assigning different ranks to the solutions available in NSGA-II.(Tirkolaee et al. ,2020)

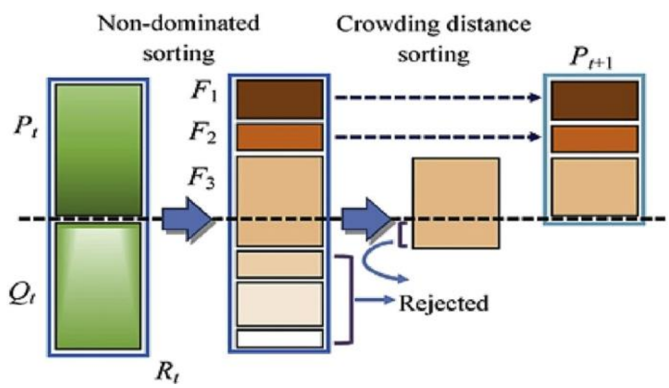

Figure 2. Block diagram of NSGA-II algorithm implementation (Tirkolaee et al., 2020)

4-1. Display the initial answer of the algorithm

The way to display the response matrix for the numerical example for meta-heuristic algorithms used in this research is explained as follows. For example, we have 13 nodes (9 customers, 3 warehouses and 1 central warehouse or supplier) and 5 vehicles.

q1	13	11	12	3	6	9	7	2	4	10	5	8
q2	2	4	4	5	4	2	5	2	4	5	5	5

Figure 3. How to define the response matrix?

In Figure 3, the first chromosome (q1) consists of a random permutation of numbers between 1 and n, and the second chromosome (q2) includes random numbers between 1 and nV (the number of available vehicles), which is 5.

Allocation to vehicle 2	13	9	2		
Allocation to vehicle 4	11	12	4		
Allocation to vehicle 5	3	7	10	5	8

Figure 4. Allocation of nodes to vehicles based on the response matrix

The cross dock index is placed at the beginning of the route.

2	13	9		
4	11	12		
3	7	10	5	8

Figure 5. Routes allocated to the warehouse

that then the chromosome of figure 3 is changed by the crossover and mutation operators in several steps to reach the best possible solution.

5. COMPUTATIONAL RESULTS

In this section, the results of the numerical solution of the model in small dimensions with the CPLEX solver by the GAMS software and in large dimensions with NSGAII meta-heuristic algorithm are presente. In order to check and confirm the validity of the presented model, first the parameters are randomly generated using uniform distribution according to table 2 and to set the initial parameters of the algorithm according to tabale 4, random samples in small and large dimensions are created in table5. Problem solving has been performed on a laptop with specifications (8GB RAM Intel Core i7) by GAMS software wirh CPLEX linear solver. In order to make the problem single-objective, the exact approach of the coefficients of the objective function is used. Then, in problems with small dimensions, the results of the NSGA II algorithm are compared with the results of the exact solution of the model by the CPLEX solver in the GAMS software, and the efficiency of the algorithm is evaluated. Then, since it is not possible to solve the model in large dimensions in an accurate way by the GAMS software, therefore NSGA II meta-heuristic algorithm will be used and solved. It should be noted that the proposed algorithm in this research is coded using MATLAB programming language. Also, a time limit of 3600 seconds is considered to solve the problems by the exact algorithm.

The numerical values of the problem are shown in Table 5 and 6. It should be noted that we consider samples number 1 to 6 as problems of small dimensions, and samples number 7 to 10 as problems of large dimensions.

Table 2. Distribution of input parameters for example problems

R_v	uniform(300,450)
Et_i	uniform(1,2)
ψ_i	uniform(10,20)
EC_{ij}	uniform(10,30)
d_i	uniform(50,100)
EC_{max}	uniform(10,15)

5-1. Setting parameters for meta-heuristic algorithms using Taguchi method

In order to implement an NSGAII meta-heuristic algorithm as well as possible, it is necessary to set its parameters in a systematic way and to set them at optimal levels. In order to measure the effect of changing the parameters on the quality of the objective function responses, in this research, a systematic method based on the design of experiments called Taguchi algorithm is used to adjust these parameters.

As can be seen in Table 3, the parameters of the problem are first guessed based on the articles on these initial values.

Table 3. Estimated parameters of multi-objective genetic algorithm

The initial parameters of the algorithm	Level 1	Level 2	Level 3
(A) Mutation percentage of Pm	0.2	0.3	0.4
(B) Percentage crossing of Pc	0.7	0.8	0.9
(C) Initial population of Npop	50	100	200

In Figure 6, the S/N values for different levels are displayed, and Figure 7, the effects of average data on the averages, also confirms the results of the S/N diagram.

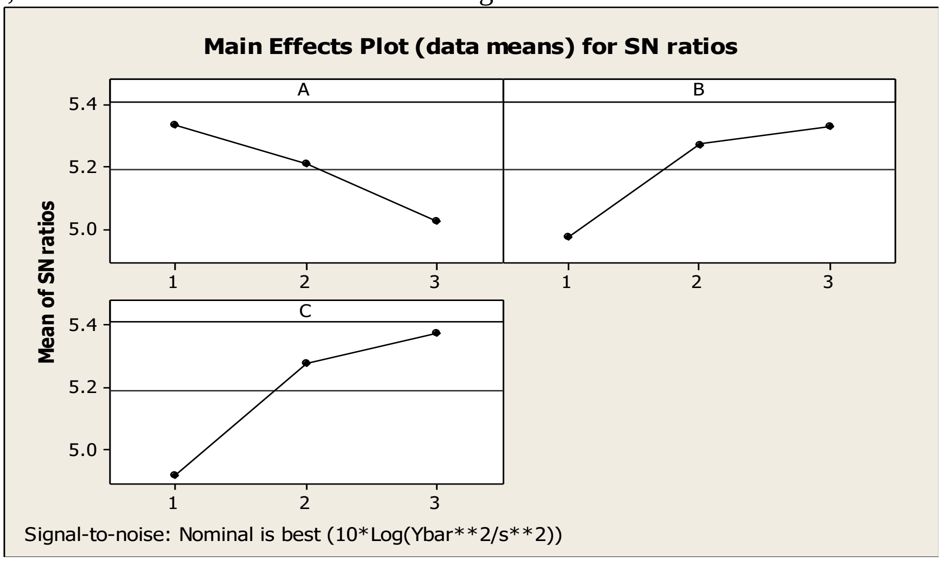

Figure 6. S/N rate diagram of objective functions at different levels of agents

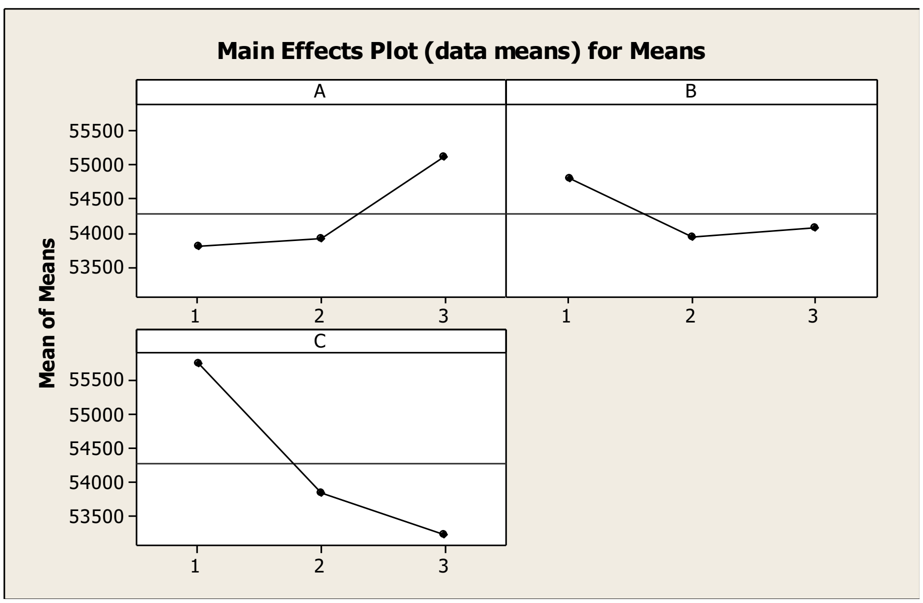

Figure 7. Diagram of the effects of average data on averages, at different levels of factors

Now, the optimal levels of the parameters of the proposed algorithm have been obtained by the Taguchi method in Table 4.

Table 4. Optimal levels of the parameters of the proposed NSGAII algorithm

NSGAII algorithm parameter values	Value
Pc intersection percentage	0.7
Pm mutation percentage	0.4
Npop population size	50
The maximum number of Iter iterations	100

In Table 5, the parameters of the problem are randomly generated using a uniform distribution which the first column is the sample number, the second column is the available vehicles, the third column is the number of demand points, and the fourth column is the number of warehouses.

Table 5. Values of numerical examples of the problem

Sample number	Available vehicles	demand points (customers)	Number of warehouses
1	5	9	3
2	5	17	3
3	5	20	3
4	6	20	4
5	5	23	5
6	6	25	5
7	8	30	6
8	7	42	6
9	8	45	6
10	8	50	7

The results of calculations for 10 problems are shown in Table 6. The column t(s) corresponds to the calculation time of the solution in seconds and the rest of the columns are related to the exact and meta-heuristic method.

Table 6. Calculation results of samples

Sample number	cplex (exact method)		NSGAII (approximate method)	
	run time t(s)	Algebraic sum of two objective functions with the same coefficient	run time t(s)	The algebraic sum of the best solution of two objective functions with the same coefficient
1	5	35028	9	35054
2	7	35901	10	35956
3	94	46901	12	47004
4	95	47012	13	47065
5	145	50021	15	51121
6	289	66765	19	66699
7	456	81235	22	80983
8	3600	*	49	245660
9	3600	*	52	367098
10	3600	*	56	798875

We have also shown the answers and solution time obtained from the exact and meta-heuristic method for comparison in Figure 8 and 9.

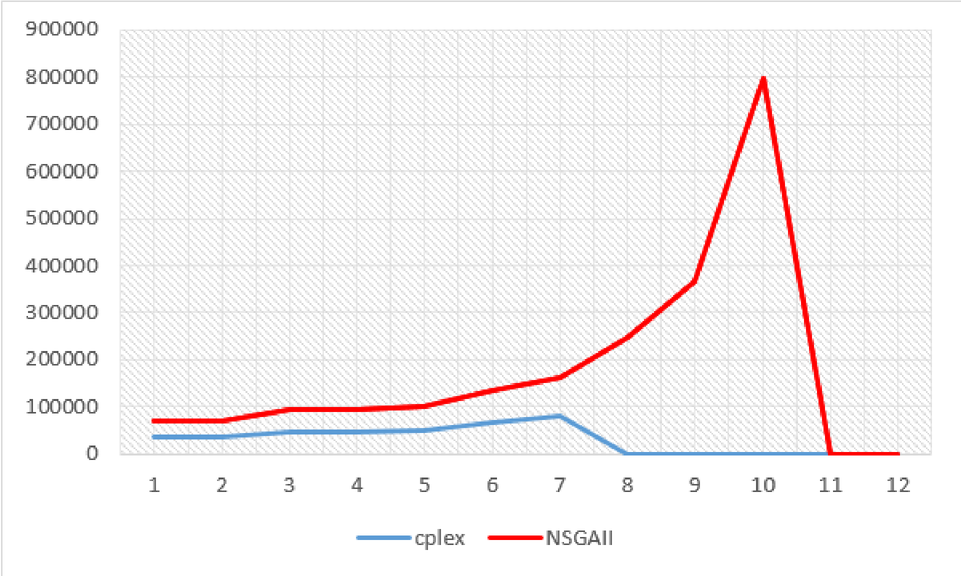

Figure 8. Comparing the solutions of exact and meta-heuristic algorithm model solution methods

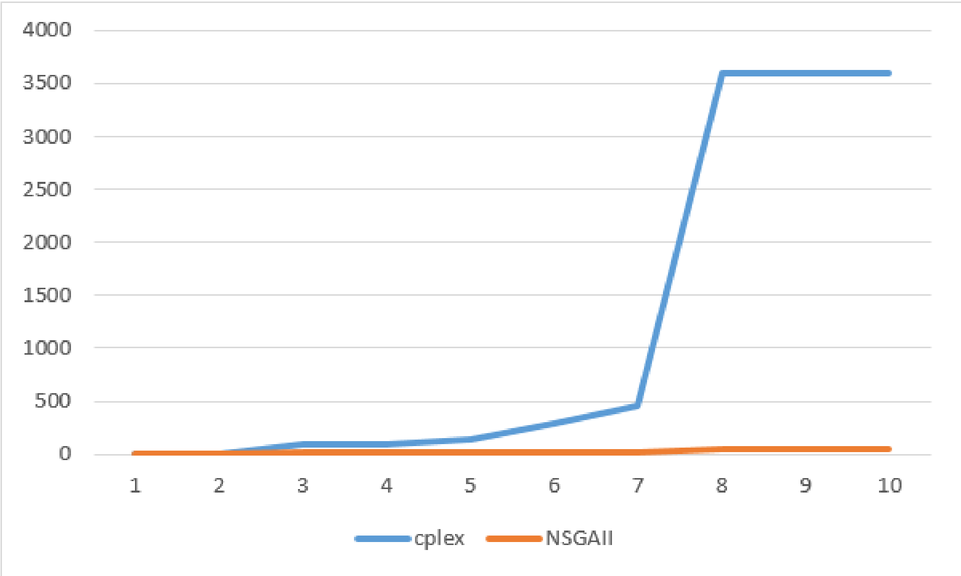

Figure 9. Comparing the solution time of exact methods and meta-heuristic algorithms

In Figure 10, as can be seen, the NSGAII algorithm has succeeded in finding 6 Pareto solutions for sample number 1.

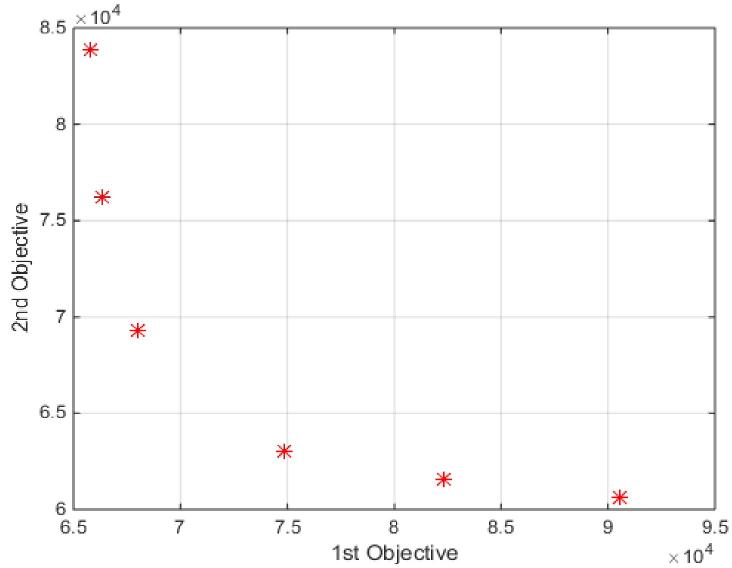

Figure 10. Pareto diagram of solving the first example with NSGAII algorithm

We classified examples number 8 to 10, for which the GAMS software was not able to provide the optimal solution in 3600 seconds, as large-dimension problems marked with (*) in Table 4, and the rest of the previous examples were classified as small-dimension problems. The best solution obtained during the solution time was considered as the final optimal solution. According to the values in Table 6 for samples 1 to 7 (small dimensions), the NSGA II algorithm works very close to the Exact method. Therefore, they can be a suitable tool to solve this problem when the exact solution is ineffective. With the increase in the dimensions of the problem, the computational time of the proposed algorithms is far less accurate compared to the method, and the efficiency of the GAMS software to solve the model decreases and reaches the point where it is no longer able to solve the problem in 3600 seconds. Therefore, due to the proper performance of the NSGA II algorithm, this algorithm is used to solve problems with large dimensions.

6. CONCLUSION

In this research, a mathematical model for green routing of vehicles in the network of cross docks under the constraints of time windows was investigated. The goals of this problem were to reduce the total cost and reduce the emission of environmental pollutants (fuel). The total cost includes the cost of constructing cross docks at the candidate points, the cost of traveling the routes between the supplier and the warehouses, the cost of the route between the customers, and finally the costs of the customers' time windows, and the emission of environmental pollutants, which was minimized. The proposed problem was solved with the CPLEX solver in GAMS software. Since it took time to solve the problems with the large size of this software, we presented the NSGAII multi-objective genetic algorithm. In order to evaluate the proposed algorithm in small dimensions, we compared its answers with the exact solutions obtained. According to the results of results 1 to 7 of small dimensions, the NSGA II algorithm works very close to the exact method, so it can be a suitable tool to solve this problem when the exact solution is inefficient. With the increase in the dimensions of the problem, the computational time of the proposed algorithms is far less compared to the exact method, and the efficiency of the software GAMS to solve the model also decreases, until the exact method is no longer able to solve the problem in 3600 seconds. Therefore, due to the good performance of NSGA II algorithm, we used this algorithm to solve problems with large dimensions.

According to the results obtained, for example sample 1, the cost of transporting goods from the supplier's central warehouse to 12 other points by direct shipping method was approximately equal to 52109 units and taking into account the cross dock, the cost of transporting goods was reduced by almost 30%, equal to 35028 units. From this, it can be concluded that if there is optimal routing between cross docks and customers, we will expect an increase in demand and of course an increase in income, as well as the amount of fuel consumed and of course the amount of produced pollutants will be less which will lead to the preservation of the environment.

Finally, suggestions in the field of development of chain structure, development of parameters, and development of evaluation criteria for those interested in this field have been presented. In this research, each customer is an applicant for a certain amount of one or more products. In the future research, in order to get closer to the real world, with the development of the model, uncertainty can be included in some of the parameters of the problem, such as the travel time on the transportation routes, the service time of the vehicles to the customers, so despite the uncertain variables, personnel costs, including employees and drivers, can be considered and the model this problem can solve in a probabilistic way. The presented model is one period that Researchers can extend the model to several periods. Simultaneously with these two objective functions, other evaluation criteria such as pollution reduction and chain reliability, delay in satisfying demand, etc. can be considered.

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