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Multi-objective robust optimization approach for green routing problem considering load-dependent time window and service time

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ABSTRACT

In today's world, transportation is one of the most important sectors of the economy that influence the process of economic development and is the core of business and the key to economic and social development. For this reason, researchers have focused on the issue of vehicle planning to reduce transportation costs and reduce pollution and traffic. In this study, a mathematical model for multi-objective transport optimization in the form of a mixed integer linear programming model is proposed. This thesis presents a multi-objective planning model for the green routing problem considering the time window for customer service and service time dependent on the amount of loading Also, a robust optimization approach has been used to address the uncertainties in the nature of the problem, which is another of the objectives of the present study Also, the first objective function is financial function and maximizes the problem of profit from the transport network, the second objective function is time function and minimizes the working time duration, the third objective function is also environmental function and the total amount of pollution created Minimizes Due to the uncertainty in the nature of the problem, in this research the problem under uncertainty is investigated and a robust optimization approach is used to deal with the uncertainty. The LP_metric approach is also used to solve the multi-objective model Plastonic Co. is considered as the case study of the present study. The research problem is solved in different dimensions and the results are reported. The results show that the developed algorithm offers optimal / near-optimal solutions at the right time than Lingo software.

Keyword: Green routing, robust optimization, time window, multi-purpose

1. INTRODUCTION

Transport plays an important role in the economic, manufacturing and service systems and accounts for a significant portion of each country's GDP. For this reason, researchers have sought to improve routes and eliminate unnecessary travel or alternate short paths. The problem of routing vehicles is to optimize the product distribution system so that the distribution costs and other goals of the organization are optimized. The increasing development of urbanization, especially support industries, has made human and commodity transportation an issue whose complexity is constantly increasing. On the other hand, urban growth has driven demand and increased distribution companies in the transportation industry. Each of the distributors on the one hand is looking for maximum profit and on the other hand with problems such as traffic congestion, air pollution, wasting time on people's daily commute routes, increased fuel consumption and depreciation of vehicles to distribute goods. And gain liquidity. The transport problem was first investigated by Hitchcock [1]. Koopmans also wrote an article entitled "Transport Network Optimization" and Kantarowicz on "Mathematical Methods and Product Planning and Planning" in which he examined the topic of transportation. And have applied mathematical methods Danzing first used the simplex method to get answers to transportation problems for the first time in years. In recent years the problem of transportation has attracted the attention of many scholars, which has led to the development of various algorithms and solutions in this field.

Tattengio [1] presented a random greedy algorithm with a search for adaptive memory programming for the problem of vehicle routing with heterogeneous fleets of vehicles, and the same algorithm was applied to HFFVRPB. He has implemented this approach as an intuitive decision-making system and has enabled individuals to incorporate different decision-making alternatives in the field under consideration.Mirabi, Fatemi Qomi, and July [2] considered the MDVRP problem, in addition to routing and scheduling, they also posed the problem of grouping. They developed a possible hybrid heuristic to solve their proposed model, which is one of the best heuristics available.Bentley et al. [3] proposed this problem by considering different time windows and vehicles and presented a detailed approach to solve the problem using the branching algorithm.Zakaradis et al. [4] developed an efficient local search algorithm for the VRPB, which examines neighborhoods in a robust solution consisting of exchanges between sequences of clients with variable path lengths. Operational costs related to vehicles and manpower to deliver goods are important costs in the production process.Sankar et al.[5] have used two modified heuristic saving algorithms along with a genetic algorithm for a dual-purpose VRPB problem including minimizing the total cost of routing and the cost of traveling a tour.Criticus et al. [6] presented a new model for the VRPTW problem considering different vehicles and attempted to solve it through the innovative insertion method.Zhang et al. [7] used a synthetic method (ant colony system and forbidden search) to solve TDVRP. As can be seen, studies in this area are scarce and of course increasing.Tavakoli Moghadam [8] introduced a multi-purpose vehicle routing problem with uncertainties in customer demand and priority, which seek to minimize the number of vehicles, mileage, and waiting time imposed on vehicles. As well as maximizing customer satisfaction.MohammadAsghari et.al [9] In this paper, we address a green delivery-pickup problem for Home Hemodialysis Machines (HHMs) categorized as scarce commodities. The system supplies the HHMs either from the central depot of the company or from the individual owners. Based on the sharing economy concept, the individuals who own the HHM devices can involve in this home health care system and share them with others through the fleet of the company to make money. After delivery of portable HHM devices to the clients (patients), they will be collected, disinfected and reallocated to fulfill the demands of the other customers.MansourehNaderipour et.al[10] In this paper, a new comprehensive model has been presented for the measurement, evaluation and minimization of CO2, NOx and CO as three important emissions (emitted from vehicles) in the open time dependent vehicle routing problem (OTDVRP). In the OTDVRP, traffic properties of congested regions like city centers are considered. Travel time between two points depends on the time of departure, and the vehicles do not come back to the depot.RaminRaeesi et.al[11] the paper focuses on a key complication arising from emissions minimisation in a time and load dependent setting, corresponding to the identification of the full set of the eligible road-paths between consecutive truck visits a priori, and to tackle the issue proposes new combinatorial results leading to the development of an exact Path Elimination Procedure (PEP). A PEP-based Mixed Integer Programming model is further developed for the SPRP and embedded within an efficient mathematical programming technique to generate the full set of the non-dominated points on the Pareto frontier of the SPRP.ZhitaoXu.et.al[12] the GVRP is developed as a multi-objective mixed integer nonlinear programming (MINLP) model that incorporates a fuel consumption calculation algorithm. The proposed model considers the vehicle load and capacity as well as time-varying speed in order to account for traffic congestion. An improved non-dominated sorting genetic algorithm (NSGA-II) with adaptive strategies and greedy strategies is developed to solve the GVRP.Therefore, the main purpose of this thesis is to present a multi-objective planning model for the green routing problem considering the time window for servicing, the service time dependent on the amount of loading and to deal with the uncertainty in the problem using the optimization approach.The rest of this paper is organized as follows. Section 2 states the problem and formulations, Section 3 indicates uncertainty modeling. The solution methodology (LP-metrics) is presented in Section 4, the results are reported in Section 5 and finally, in Section 6 the conclusions and future suggestion are provided.

2. Problem Definition

In this section, the research problem is defined and a mathematical model for the VRP management network is presented. Suppose we have n nodes and m vehicles and each node has a certain degree of demand and the vehicles are also heterogeneous. And each vehicle has a different capacity and speed, and the demand for each node is met by the central warehouse.

Similarly, in some areas of demand, in addition to delivering goods, vehicles at the same node also load some of the goods that must be returned to the warehouse. For each vehicle, the travel time between the two nodes and the service time is considered to be the demand point. Two virtual nodes with n and 1 are used to represent the central point, which is the starting and ending point of the envelopes. The demand and service time at these locations are zero and only travel time from warehouse to nodes and from node to central warehouse is calculated. The time window is also considered in this issue and the service time of the demand points must be set at a specific time. It should be noted that the service time in this study depends on the amount of loading per node. Also, with fluctuations in the business environment, there is uncertainty in the Tumble Chain problem, and it is difficult to estimate parameters such as demand and transport costs. To make the problem more similar to the real world and increase the performance of the proposed model, we investigate the problem under uncertainty in this research and use a robust optimization approach to avoid uncertainty. And to solve the proposed multi-objective mathematical model, we use the approaches in the science of multi-objective programming The proposed VRP network is illustrated in Fig.1. How nodes are assigned to vehicles is illustrated below. The red arrow is the first vehicle, the green is the second type of vehicle, and the black is the third vehicle.

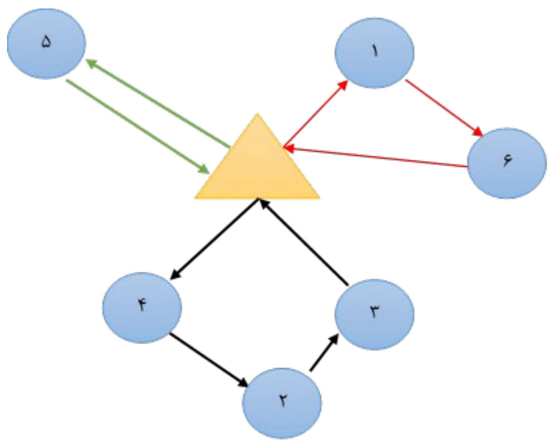

Fig. 1- The proposed VRP network design

In this study, the following assumptions are considered:
1. The capacity of vehicles is limited and is defined as weight capacity.
2. All points of demand must be met by vehicles.
3. Each customer receives service only from one vehicle and multiple servicing is not allowed.
4. Service time depends on the amount of downloads done.
5. The time to start servicing each node must be within the time limit of that node.Due to aforementioned definitions, the research problem can be formulated as follows:

2-1. Notation

Sets

i , j	Index of node (i,j=1,…,n)
P	Index of vehicles (k=1,…,m)
k	Index of Products (p=1,…,P)

Parameters

CaP_K	The amount of vehicle capacity k
S_{ik}	Standard time required for k vehicle to service node i
D_{ip}	The amount of node demand for product p
$[E_i, L_i]$	Node Time Window i
a	Coefficient of Effect of Loading at Service Time
Rev_p	Return on earnings per unit product p
T_{ijk}	Travel time required for vehicle k to travel between two nodes i and j
C_{ijk}	Cost of shipping the product between points i and j via vehicle k
P_{ip}	The amount of product loading p in node i

λ_{ijk}	The amount of pollution created by vehicle k at a distance i to j
M	Large positive number

Decision variables

X_{ijkp}	1 If vehicle k carries product p from node i to node j 1 0 otherwise
Z_{ijkp}	The amount of product p delivered by vehicle k traveling between nodes i and j
RS_{ik}	Actual service time to node i by rescue unit k
ST_{ik}	Time to start service to node i by vehicle k
Y_{ijkp}	The amount of product p loaded by the k vehicle for traveling between nodes i and j

2-2. Mathematical Model

According to the above definitions and symbols, the MOMINLP is a mathematical model of nonlinear mixed integer programming (MOMINLP) for the research problem as follows.

$$Max\ Z_1 = \sum_i \sum_j \sum_p Rev_p Y_{ijkp} - \sum_i \sum_j \sum_k \sum_p C_{ijk} X_{ijkp} \qquad (1)$$

$$Min\ Z_2 = ST_{(n+1)k} - ST_{0k} \qquad (2)$$

$$Min\ Z_3 = \sum_i \sum_j \sum_k \sum_p \lambda_{ijk} X_{ijkp} \qquad (3)$$

Subject to:

$$\sum_{j=1} \sum_p X_{0jkp} = 1 \qquad k = 1,\ldots,m \qquad (4)$$

$$\sum_{i=0} \sum_p X_{i(n+1)kp} = 1 \qquad k = 1,\ldots,m \qquad (5)$$

$$\sum_{i=0} \sum_k X_{ijkp} = 1 \qquad i = 1,\ldots,n;\ p = 1,\ldots,P \qquad (6)$$

$$\sum_{j=1} \sum_k X_{ijkp} = 1 \qquad i = 1,\ldots,n;\ p = 1,\ldots,P \qquad (7)$$

$$\sum_{i=0} \sum_p X_{ijkp} - \sum_{h=1} \sum_p X_{jhkp} = 0 \qquad j = 1,\ldots,n;\ k = 1,\ldots,m \qquad (8)$$

$$\sum_{j=0} \sum_k \sum_p Y_{0jkp} = 0 \qquad (9)$$

$$\sum_{i=0} \sum_k \sum_p Z_{i(n+1)kp} = 0 \qquad (10)$$

$$\sum_{h=1} \sum_k Y_{jhkp} - \sum_{i=0} \sum_k Y_{ijkp} = P_{jp} \qquad j = 1,\ldots,n;\ p = 1,\ldots,P \qquad (11)$$

$$\sum_{i=0} \sum_k Z_{ijkp} - \sum_{h=1} \sum_k Z_{jhkp} = D_{jp} \qquad j = 1,\ldots,n;\ p = 1,\ldots,P \qquad (12)$$

$$Y_{ijkp} \le M . X_{ijkp} \qquad k = 1,\ldots,m;\ p = 1,\ldots,P \qquad (13)$$

$$Z_{ijkp} \le M . X_{ijkp} \qquad k = 1,\ldots,m;\ p = 1,\ldots,P \qquad (14)$$

$$\sum_p (Z_{ijkp} + Y_{ijkp}) . X_{ijkp} \le Cap_k \qquad i, j = 0,\ldots,n+1, i \neq j;\ k = 1,\ldots,p \qquad (15)$$

$$RS_{ik} = (s_{ik} + \alpha . \sum_{p} \sum_{j=1} Y_{ijkp}) . \sum_{p} \sum_{j=1} X_{ijkp} \qquad i = 0,\dots,n+1; k = 1,\dots,m \qquad (16)$$

$$ST_{jk} \geq (ST_{ik} + RS_{ik} + T_{ijk}) . \sum_{p} X_{ijkp} \qquad i,j = 0,\dots,n+1; k = 1,\dots,p \qquad (17)$$

$$E_i \leq ST_{ik} \leq L_i \qquad i = 0,\dots,n+1; k = 1,\dots,m \qquad (18)$$

$$X_{ijkp} = \{0,1\}$$

$$Y_{ijkp}, Z_{ijkp}, ST_{ik} \geq 0 \qquad \forall i,j,k,p \qquad (19)$$

Equation (1): The first objective function represents the maximum that denotes the Torque's profit from the difference in revenue from expenses. Equation (2): Objective The second objective is to minimize the duration of the work period. Equation (3): Objective Function The third objective is to minimize the emissions created by the transportation network.
Constraint sets (4) ensures that all vehicles start their journey from the origin (central warehouse). Constraint sets (5) states that all vehicles return to the destination after the service operation is completed. Constraints (6) and (7) indicate that all demand points must be serviced and each node assigned to a vehicle. In equation (8) the equilibrium flow of the problem is stated. Constraints (9-14) calculate the rate of delivery and loading of items. Equation (15) shows the limited capacity of vehicles.In limitation (16) the service time is calculated depending on the amount of loading. Constraint (17) calculates the start time of service to each node by each vehicle. Equation (18) gives the time window constraint. Constraint (19) specifies the range of decision variables.

3. Robust programming

Consequently, the robust equivalence model of the research problem is as follows:

$$Max\ Z_1 = \sum_{i} \sum_{j} \sum_{p} Rev_p Y_{i(n+1)kp} - \sum_{i} \sum_{j} \sum_{k} \sum_{p} C_{ij} X_{ijkp} \qquad (20)$$

$$Min\ Z_2 = ST_{(n+1)k} - ST_{0k} \qquad (21)$$

$$Min\ Z_1 = \sum_{i} \sum_{j} \sum_{k} \sum_{p} A_{ijk} X_{ijkp} \qquad (22)$$

Subject to:

$$\sum_{j=1} \sum_{p} X_{0jkp} = 1 \qquad k = 1,\dots,m \qquad (23)$$

$$\sum_{i=0} \sum_{p} X_{i(n+1)kp} = 1 \qquad k = 1,\dots,m \qquad (24)$$

$$\sum_{i=0} \sum_{k} X_{ijkp} = 1 \qquad i = 1,\dots,n; p = 1,\dots,P \qquad (25)$$

$$\sum_{j=1} \sum_{k} X_{ijkp} = 1 \qquad i = 1,\dots,n; p = 1,\dots,P \qquad (26)$$

$$\sum_{i=0} \sum_{p} X_{ijkp} - \sum_{h=1} \sum_{p} X_{jhkp} = 0 \qquad j = 1,\dots,n; k = 1,\dots,m \qquad (27)$$

$$\sum_{j=0}\sum_{k}\sum_{p} Y_{0jkp} = 0 \qquad (28)$$

$$\sum_{i=0}\sum_{k}\sum_{p} Z_{i(n+1)kp} = 0 \qquad (29)$$

$$\sum_{h=1}\sum_{k} Y_{jhkp} - \sum_{i=0}\sum_{k} Y_{ijkp} \geq P_{jp} - \rho_P G_{jp}^{P} \qquad j = 1,\dots,n;\ p = 1,\dots,P \qquad (30)$$

$$\sum_{h=1}\sum_{k} Y_{jhkp} - \sum_{i=0}\sum_{k} Y_{ijkp} \leq P_{jp} + \rho_P G_{jp}^{P} \qquad j = 1,\dots,n;\ p = 1,\dots,P \qquad (31)$$

$$\sum_{i=0}\sum_{k} Z_{ijkp} - \sum_{h=1}\sum_{k} Z_{jhkp} \geq D_{jp} - \rho_D G_{jp}^{D} \qquad j = 1,\dots,n;\ p = 1,\dots,P \qquad (32)$$

$$\sum_{i=0}\sum_{k} Z_{ijkp} - \sum_{h=1}\sum_{k} Z_{jhkp} \leq D_{jp} + \rho_D G_{jp}^{D} \qquad j = 1,\dots,n;\ p = 1,\dots,P$$

$$Y_{ijkp} \leq M.X_{ijkp} \qquad k = 1,\dots,m;\ p = 1,\dots,P \qquad (33)$$

$$Z_{ijkp} \leq M.X_{ijkp} \qquad k = 1,\dots,m;\ p = 1,\dots,P \qquad (34)$$

$$\sum_{p} (Z_{ijkp} + Y_{ijkp}).X_{ijkp} \leq Cap_k \qquad i,j = 0,\dots,n+1,\ i \neq j;\ k = 1,\dots,p \qquad (35)$$

$$RS_{ik} = (s_{ik} + \alpha.\sum_{p}\sum_{j=1} Y_{ijkp}).\sum_{p}\sum_{j=1} X_{ijkp} \qquad i = 0,\dots,n+1;\ k = 1,\dots,m \qquad (36)$$

$$ST_{jk} \geq (ST_{ik} + RS_{ik} + (t_{ijk} + \rho_T G_{ijk}^{T}).\sum_{p} X_{ijkp} \qquad i,j = 0,\dots,n+1;\ k = 1,\dots,p \qquad (37)$$

$$E_i \leq ST_{ik} \leq L_i \qquad i = 0,\dots,n+1;\ k = 1,\dots,m \qquad (38)$$

$$X_{ijkp} \in \{0,1\} \qquad \forall i,j,k,p \qquad (39)$$

$$Y_{ijkp}, Z_{ijkp}, ST_{ik} \geq 0 \qquad (40)$$

4. LP-METRICS

Since the proposed model is a multi-objective MILP model whose objective functions are completely inconsistent, we used the LP-metrics method which is one of the famous Multi-Criteria Decision Making (MCDM) methods for solving multi-objective problems with conflicting objectives simultaneously. According to this method, a multi-objective problem is solved by considering each objective function separately and then a single objective is reformulated which aims to minimize the summation of normalized differences between each objective and the optimal values of them. In our proposed model, you can assume that two objective functions are named as Z_1, Z_2. Based on LP-metrics method, MILP should be solved for each one of these two objectives separately Assume that the optimal values for these two problems are Z_1^*, Z_2^*. Now the LP-metrics objective functions can be formulated as follows:

$$Min(Z_3) = [w.\frac{Z_1 - Z_1^*}{Z_1^*} + (1-w).\frac{Z_2 - Z_2^*}{Z_2^*}] \quad (41)$$

Where $0 \le w \le 1$ are the relative weight of components of the objective function (31) which given by the decision maker(s). Using LP-metrics objective function and considering MILP model constraints, we have a single objective, MILP model, which can be efficiently solved by linear programming solvers.

5. COMPUTATIONAL RESULTS

In this section, numerical experiments are conducted to investigate the performance of the proposed model.

5-1. Report of Results

In this section, results of solving problem in 6 test problem reported and analyzed. It should be noted that the necessary data is taken from the similar research in this field (like [4], [15]) Table 1 shows the results of experiments.

Table 1- Results of experiments

T. P	$\|i\|\times\|k\|\times\|p\|$	**L.O.U**	**T.F.V *LP-Metric***	**CPU time (s)**
1	$\|5\|\times\|2\|\times\|1\|$	$\rho = 0.1$	0.071	3
2	$\|7\|\times\|3\|\times\|1\|$	$\rho = 0.1$	0.130	75.3
3	$\|11\|\times\|4\|\times\|1\|$	$\rho = 0.3$	0.153	582.3
4	$\|12\|\times\|5\|\times\|2\|$	$\rho = 0.3$	0.233	1328.2
5	$\|15\|\times\|6\|\times\|2\|$	$\rho = 0.5$	0.3	2442
6	$\|15\|\times\|6\|\times\|3\|$	$\rho = 0.5$	0.338	3078.4

Where in Table 1, T. P denote the number of test problem, second column shows the size of problem, **L.O.U** is **Level of uncertainty**, **T.F.V**. denote second **Target function value *LP-Metric*** objective function value and last column showed computational times of solving model. The CPU times of the test problems illustrated in Fig. 2. As can be seen in Fig. 2 the CPU time of solving the model increased with increasing in size of the problem.

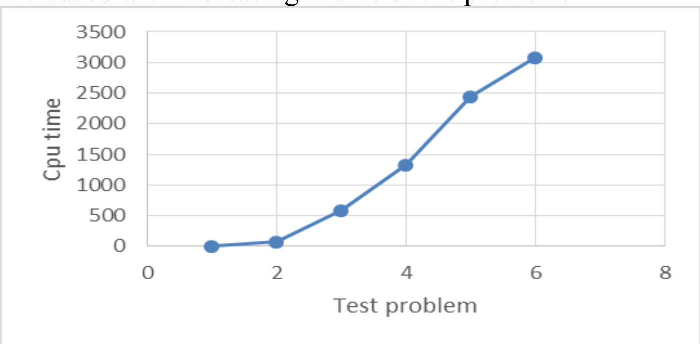

Fig. 2- CPU time of the problem

5-2. Sensitivity analysis

In this section the sensitivity of the first objective function on demand of recycled materials and total amount of waste are examined.

Sensitivity analysis for demands

We examined the values of the objective function in five different modes for the demands (Based case, +10% . +20% .+30%). The sensitivity analysis results are illustrated in Fig. 3.

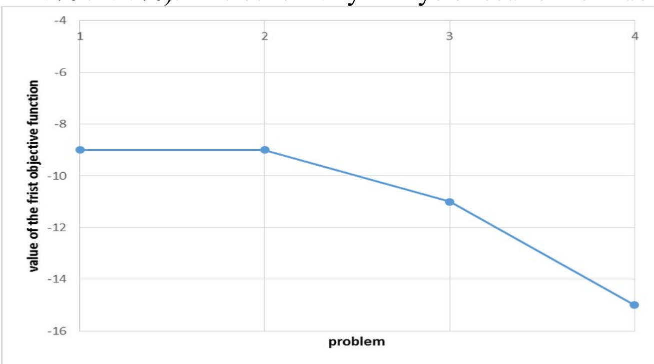

Fig. 3- Sensitivity analysis for demands

According to Fig. 3 with decreasing the quantity of demand the value of first objective function decreased.

Sensitivity analysis of the second objective function on the service time parameter

We examined the values of the objective function in four different modes for the total amount of service time (Based case, -20%, -10%, +10% and +20%). The sensitivity analysis results are illustrated in Fig. 4.

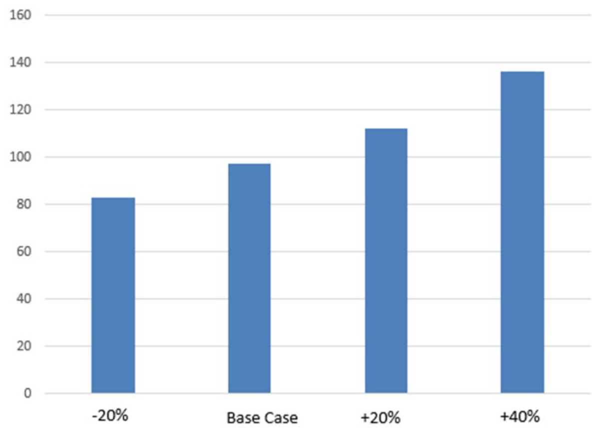

Fig. 4- Sensitivity analysis of the second objective function on the service time parameter

According to Fig. 4 with increasing the quantity of total amount of service time the value of first objective function increased.

6. Conclusions

In this study, a bi-objective MILP model for designing a robust MSW management network is presented.In this research the problem of green routing of vehicles in heterogeneous state, considering time window and loading and delivery That heterogeneous vehicles include vehicles that have different capacities and speeds and that the time window means that the service of the nodes should start at a certain time. The proposed model considers the first objective function is the financial function and maximizes the problem of profit from the transport network. The second objective function is the time function and minimizes the duration of the work period. The third target function is the environmental function and minimizes the total amount of pollution created.In this study, a Robust Programming approach applied in order to tackle the uncertainty in the parameter of the model. Then, the multi-objective model solved using LP-metric method and results are reported. Future studies can develop metaheuristic algorithms to solve the proposed model in large-sized instances.

7. References

[1] Tütüncü, G. Y.. An interactive GRAMPS algorithm for the heterogeneous fixed fleet vehicle routing problem with and without backhauls. European Journal of Operational Research 201(2), (2010) .593–600.

[2] Mirabi, M., Fatemi Ghomi, S.M.T. & Jolai F Efficient stochastic hybrid heuristics for the multidepot vehicle routing problem, Robotics and Computer-Integrated Manufacturing (2010); 26(564-569).

[3] Bettinelli, A., Ceselli, A. Righini, G.. A branch-and-cut-and-price algorithm for the multidepot heterogeneous vehicle routing problem with time windows, Transportation Research - Part C.(2011),19:723

[4] Zachariadis, E.E., Kiranoudis, C.T.. An effective local search approach for the vehicle routing problem with backhauls. Expert Systems with Applications 39(3). (2012), 3174

[5] Anbuudayasankar, S.P., Ganesh, K., Lenny Koh, S.C., Ducq, Y.. Modified savings heuristics and genetic algorithm for bi-objective vehicle routing problem with forced backhauls. Expert Systems with Applications 39(3) .(2012), 2296–2305.

[6] Kritikos, M.N. Ioannou, G. The heterogeneous fleet vehicle routing problem with overloads and time windows, Int. J. of Production Economics, (2013).144:68-75.

[7] Zhang, T., Chaovalitwongse ,W. A., Zhang, Y. Integrated Ant Colony and Tabu Search approach for time dependent vehicle routing problems with simultaneous pickup and delivery, Journal of Combinatorial Optimization: . (2014).1-22.

[8] Ghannadpour, S.F., Noori, S., Tavakkoli- Moghaddam, R. A multi-objective vehicle routing and scheduling problem with uncertainty in customers' request and priority, Journal of Combinatorial Optimization, (2014).28:414-446.

[9] Asghari, Mohammad, and S. Mohammad J. Mirzapour Al-e. "A green delivery-pickup problem for home hemodialysis machines; sharing economy in distributing scarce resources." *Transportation Research Part E: Logistics and Transportation Review* (2019).

[10] Naderipour, Mansoureh, and Mahdi Alinaghian. "Measurement, evaluation and minimization of CO2, NOx, and CO emissions in the open time dependent vehicle routing problem." *Measurement* 90 (2016): 443-452.

[11] Raeesi, Ramin, and Konstantinos G. Zografos. "The multi-objective Steiner pollution-routing problem on congested urban road networks." *Transportation Research Part B: Methodological* 122 (2019): 457-485.

[12] Xu, Zhitao, et al. "A model for capacitated green vehicle routing problem with the time-varying vehicle speed and soft time windows." Computers & Industrial Engineering 137 (2019): 106011.