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TWO-ECHELON GREEN VEHICLE ROUTING PROBLEM CONSIDERING TRAFFIC LIMITATIONS

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ABSTRACT

The present article proposes a two-echelon vehicle routing problem wherein the routing problem of the first echelon specifies the goods delivery from the main depot to the intermediate depots and the routing problem of the second echelon has been formed based on goods delivery from the intermediate depots to a set of customers. On the other hand, making plans for on-time providing of services to the customers entails the consideration of traffic limitations for the effects they exert on the costs and vehicle's providing of on-time services to the customers. Moreover, the amount of pollution dispersed by a vehicle depends on the weight, speed and other factors and it can bring about changes in the emission of greenhouse gases, fuel consumption and travel time. Therefore, the main problem of the present article is a two-echelon distribution system wherein the traffic limitations influence the vehicles' providing of services to the customers on the due date with the objective of minimizing the greenhouse gases' emission hence reducing the fuel consumption. The proposed problem has been modeled in the form of a mathematical mixed integer planning method. Considering the fact that the problem is NP-hard, the neighborhood search metaheuristic algorithm has been used for solving the problem. In order to verify and confirm the proposed algorithm's performance in smaller dimensions, the results obtained from variable neighborhood search algorithm were compared with those obtained by CPLEX solver. In order to investigate the performance of the proposed algorithm in larger dimensions, a set of the sample problems has been solved based on the scales existent in the literature but with a little change. The obtained results indicated the suitable performance of the proposed algorithm.

Keywords: *two-echelon, vehicle, routing, problem, green, time-dependent, traffic limitations, metaheuristic algorithm*

INTRODUCTION

Load-carrying industry is considered as one of the primary sources of employment and support of the economic development in every country. However, load carriage is also envisioned as a worrisome activity due to the density and biological problems that adversely influence the quality of life, especially in urban regions. Moreover, cost- and time-effectiveness are of great importance in the product distribution. On the other hand, the activities routinely performed in the supply chain such as production, transportation and inventory result in the dispersion of pollutants. This is while transportation is viewed as the most tangible supply chain section that produces CO2 (Decker et al., 2012). According to intergovernmental panel on climate change (IPCC), 14% of the greenhouses (GHG) emitted by economic sector in 2010 pertains to transportation (USA's energy organization, 2014). Since a substantial percentage of GHG is

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comprised of CO_2, the reduction in the emission of pollutants produced by the road-based and urban cargo transportation can be a considerable bioenvironmental approach.

Furthermore, the cost of the fuel consumption is considered as an increasingly larger concern for the transportation companies (Xiao et al., 2012). Based thereon, many researchers have taken the cost of fuel consumption into account as a variable cost in transportation during the recent years in their studies; doing so, they have also been seeking for reducing CO_2 emission (Cheng et al., 2017). Such an issue was not taken into consideration in the traditional vehicle routing problems (VRPs) (Soysal et al., 2015).

On the other hand, there are two strategies of direct transfer and multi-level distribution in cargo transportation. In direct transfer strategy, the vehicle starts transporting a cargo directly from the depot whereas the cargo is delivered to the customers from the intermediate depot in the multi-level systems. The increase in the transportation volume as well as the need for considering bioenvironmental factors and traffic density has led to the performance of researches about the multi-level distribution systems during the recent years. On the other hand, due to the increase in the population and the existence of a large number of vehicles in the urban system, the bioenvironmental problems and urban traffic are amongst the problems making the transportation industry and the distribution companies faced with certain problems. That is because urban traffic results in delaying of the delivery of the suppliers' products to the customers as well as increase in the emission of the pollutants.

Based thereon, the present article has dealt with the routing of the customers whose demands are satisfied through two-echelon transportation systems; traffic limitations are taken into account in doing so. In addition, in order to improve the network's conditions in bioenvironmental terms, attentions have also been paid to greenness and minimization of fuel consumption as well as minimization of the pollutants production.

According to the fact that the vehicle routing problems are considered to be NP-hard, each of their subcategories also features the same constraint. It is evident that the proposed time-dependent periodical two-echelon routing problem is also highly complicated hence there is a need for offering an effective solving method so that the obtained result can be effectively and efficiently put into use. In line with this, a novel metaheuristic algorithm will be offered based on the metaheuristic variable neighborhood search algorithm for solving the studied problem in large scale. In order to verify and confirm the performance of the proposed algorithm in small scale, the results obtained from the variable neighborhood search algorithm will be compared with those attained through the use of CPLEX solver. Also, a set of new sample problems will be applied for examining the performance of the algorithm in large scale.

Next, the forthcoming section evaluates the studies performed regarding the present study's subject. Mathematical model of the green two-echelon vehicle routing problem with the consideration of the traffic limitations has been given in the third section. The proposed metaheuristic algorithm and the method of its implementation in the present study's intended problem have been explicated in the fourth section. The mathematical model of the problem has been solved by the use of CPLEX solver in GAMS Software as well as metaheuristic variable neighborhood search algorithm based on a sample of the example problems in the fifth section; the numerical studies have been presented through the use of the new sample problems and their solutions. Eventually, the sixth section gives the conclusion and suggestions for future studies.

LITERATURE REVIEW

The most common and most applied multi-echelon VRP is the two-echelon vehicle routing problem wherein there is only considered one intermediate level of the intermediate depots. Crainic et al. (2007) were the first persons who posited 2E-VRP as a new problem in urban logistics. In another study, Crainic et al. (2008) offered metaheuristic algorithms based on first and second echelon's separation in a 2E-VRP. Additionally, Crainic et al. (2008) presented new lower boundaries for 2E-VRP with the strategy adopted in this regard being the consideration of simpler sub-problems per every echelon of 2E-VRP. Feliu et al. (2008) offered a branch and bound algorithm for solving 2E-CVRP according to a goods-based model. Perboli et al. (2009 and 2010) offered a new group of credible inequalities for solving 2E-VRP. Crainic et al. (2010) offered a group of multi-star metaheuristic algorithms for solving 2E-VRP and divided the problem into two sub-problems that included the first and the second echelons. In another study, Perboli et al. (2011) offered a mathematical model for 2E-VRP and a number of credible inequalities and two mathematical metaheuristic algorithms. Meihua et al. (2011) offered a metaheuristic algorithm and a combination of ant colonies for solving 2E-VRP with this algorithm having been obtained by combining three heuristic or metaheuristic algorithms. Crainic et al. (2011) offered a metaheuristic algorithm based on the combination of GRASP algorithm with route reconnection algorithm for solving 2E-VRP. Hemmelmayr et al. (2012) suggested a large adaptive neighborhood search algorithm for 2E-VRP and location-routing problem. Jiang (2012) offered a heuristic algorithm comprised of greedy, ant colony and neighborhood search algorithms for solving 2E-VRP that resulted in the improvement of the solution quality and acceleration of the algorithms' convergence to the optimal answer. Baldacci et al. (2013) offered a new mathematical model for 2E-CVRP for achieving the credible lower boundaries and an accurate method. Jepsen et al. (2013) offered an accurate method for solving 2E-VRP. The method presented in this article was based on a network streaming model that provides a lower boundary for the intended problem. Santos et al. (2013) offered an integer planning problem and two branch and price algorithms for solving 2E-CVRP. One algorithm considers the routes satisfying the preliminary conditions of the problem while the other algorithm frees the constraints on the routes' pricing time. Zeng et al.. (2013) offered a combined biphasic heuristic algorithm for 2E-VRP; it had been consisted of a greedy adaptive random search method and a variable neighborhood descent algorithm. Santos et al.. (2014) introduced a branch and cut and price algorithm for 2E-VRP. This algorithm was dependent on a new formulation based on q-path. Sitek and Vikarek (2014) offered a novel approach for modeling and solving 2E-CVRP. The approach offered in this article has been compared with the classical 2E-CVRP mathematical model. Soysal et al. (2015) offered a linear mixed integer planning formulation for time-dependent two-echelon vehicle routing problem that considered the type of the vehicle, length of route taken, vehicle's speed, cargo, time, various regions and pollution dispersion. Breunig et al. (2016) proposed two optimization problems regarding urban logistics and two-echelon transportation systems. They considered the two-echelon vehicle routing problem and location-routing problem and made use of a combined metaheuristic algorithm based on a large adaptive algorithm for solving these problems; in their method, the local searches have been combined with the destruction and repair rules as well as the other operators suitable for optimization of the choice of the intermediate depots. Grangier et al. (2016) expanded the 2E-VRP through taking into account such limitations as the time windows constraints, synchronization limitations and numerous trips limitations in the second echelon. Lee et al. (2016) considered the 2E-VRP problem along with time constraints; their model was formulated in the form of nonlinear mixed integer planning and use was made of Clark and wright's savings heuristic algorithm along with neighborhood search. Yan et al.. (2016) used a sort of optimization algorithm called brainstorming based on human-computer cooperation for solving the two-echelon vehicle routing problem. Butty et al. (2016) developed a new heuristic comparative format based on open text (OpenCl) simulation environment and applied three heuristic algorithms for solving 2E-VRP. Dellaert et al. (2016) considered 2E-CVRP along with time window limitations and made use of branch and price algorithm for solving it. Wang et al. (2017) investigated the 2E-CVRP through taking the contingent demands into consideration and made use of a genetic-based algorithm for solving it. Sang et al. (2017) offered the adaptive 2E-CVRP wherein several main depots had been used and it was possible to provide direct services by the vehicles from the main depot to the customers. Wang et al. (2017) offered 2E-CVRP that considered bioenvironmental considerations. This problem was solved through the use of a mathematical heuristic algorithm based on VNS. Liu et al. (2018) offered a new type of 2E-CVRP through taking the grouping constraints into account and branch and cut algorithm was employed for solving it. Belgin et al. (2018) developed the 2E-VRP through considering the simultaneous pickup and delivery and used a combined algorithm based on variable neighborhood descent algorithm and local search method for solving it. Xu et al. (2018) considered a new problem in urban logistics according to the "last mile distribution" in e-business. In this distribution, two options are considered for the delivery of the goods to the customers. In order to solve this problem, use was made of a combined multi-population genetic algorithm.

In dense urban environments, the time of travel between two nodes (customers) is not solely dependent on the two nodes because the speed of the vehicles would undergo changes along the route and in different times. The speed of the vehicle varies in respect to the traffic volume as well as the hourly changes of the speed cycles in a daily or weekly manner. Therefore, if such dependencies as time of the day and travel time are ignored, the problem solving might result in a non-optimal answer (Ichua et al., 2003) and the increase in the traffic volume might result in the increase in the bioenvironmental pollutions stemming from the transportation sector in urban environment. Therefore, vehicle routing planning through consideration of the traffic volume and vehicles' speed variations in time can be an important step for achieving a sustainable distribution system.

The time-dependent routing problem includes n customers with a certain number of demands and m vehicles with given capacities; in such a problem, the planning horizon is divided into p time spans, T_1, T_2,…,T_p. Considering a network composed of n nodes, the n×n time-dependent matrix in the form of $C(T_k)=\left[c_{ij}(T_k)\right]$ would incorporate travel times between each pair of the nodes (I, j). The goal is finding routes with minimum costs or lowest total time of providing service to all the customers in such a way that the capacity of the vehicle is not violated and the customers' demands are met (Ichua et al., 2003).

Green vehicle routing problem, as well, has been posited with the objective of coordinating the bioenvironmental and economic costs in line with the achievement of effective and optimal routes. In general, based on a research by Lin et al. (2014), it can be stated that the green vehicle routing problem can be divided into three sets as outlined beneath:

1) Green Vehicle Routing Problem (Green-VRP9): these studies are primarily concentrated on the optimization of energy consumption. This set of problems form the basis of this research and it will be investigated in the upcoming sections.
2) Pollution routing problem (PRP): in these problems, the greenhouse gases' emission and, especially CO2 emission, is focused. PRP is at the center of the transportation planning and provides opportunities for reducing the emission of pollutants via considering the macro-level goals and bioenvironmental costs.
3) Vehicle routing problem in reverse logistics (VRPRL): reverse logistics is defined as the process of planning, implementing and controlling the raw materials return courses in the activities related to inventory, packaging and final products from the production and distribution to the retrieval or offloading points. The studies that have considered this approach in G-VRP are embedded in the category of VRP in reverse logistics.

The summary of the studies performed on 2E-VRP has been presented in table (1). In this table, the separable delivery has been abbreviated as s.d.

Table 1: summary of the studies carried out on 2E-VRP

		Problem type			Limitations												Solution method		
Year	Authors	1	2	3	Time windows	Heterogeneous fleet	Multiple depots	Uncertainty	Pickup and delivery	First echelon s.d.	Second echelon s.d.	Capacity	Periodical	Time dependency	Travel time	Fleet size	Exact	Heuristic	Metaheuristic
2007	Crainic et al.	✓								✓		✓							✓
2008	Crainic et al.	✓								✓		✓							✓
2008	Crainic et al.	✓										✓						✓	
2009	Feliu et al.	✓								✓		✓						✓	
2009	Perboli et al.	✓										✓						✓	
2010	Perboli et al.	✓										✓						✓	
2011	Crainic et al.	✓										✓						✓	
2011	Perboli et al.	✓								✓		✓					✓	✓	
2011	Meihua	✓								✓		✓						✓	✓
2011	Crainic et al.	✓								✓		✓							✓
2012	Hemmelmayr	✓								✓		✓							✓
2012	Jiang	✓								✓		✓							✓
2013	Baldacci et al.	✓								✓		✓					✓	✓	
2013	Jepsen et al.	✓								✓		✓					✓		
2013	Santos et al.	✓										✓					✓		
2013	Zheng et al.	✓										✓						✓	
2014	Santos et al.	✓										✓					✓		

2014	Sitek and Vikarek	✓										✓		✓	✓				
2015	Soysal et al.			✓						✓		✓					✓		
2015	Breunig et al.	✓								✓		✓							✓
2016	Grangier et al.		✓		✓							✓			✓				✓
2016	Li et al.		✓		✓							✓						✓	
2016	Li et al.		✓		✓							✓						✓	
2016	Yan et al.		✓									✓						✓	
2016	Butty et al.	✓										✓						✓	
2016	Dellaert et al.		✓		✓							✓					✓		
2017	Wang et al.			✓						✓		✓			✓			✓	
2017	Sang et al.			✓			✓					✓						✓	
2017	Wang et al.			✓				✓		✓		✓							✓
2018	Liu et al.	✓								✓		✓					✓		
2018	Belgin et al.			✓					✓			✓							✓
2018	Xu et al.			✓			✓					✓			✓				✓
	This study	✓								✓		✓		✓	✓				✓

Considering the importance of the concerns about bioenvironmental matters and urban traffic in the current transportation system, the problem proposed in the current research paper is of a great importance. Thus, the present study tries offering a mathematical model for green two-echelon vehicle routing problem considering the traffic limitations. According to the NP-hard nature of the proposed problem, variable neighborhood search algorithm has been employed in a large scale herein for solving the problem.

Green Two-Echelon Vehicle Routing Problem Considering the Traffic Limitations

In this section, a definition has been presented for 2E-GTDVRP, method of formulating the green assumptions and time dependency for the new problem and the new mathematical model considered for the problem.

- ***Definition of the Problem***

2E-GTDVRP can be defined on weighted directed G=(V,A) graph wherein V denotes the nodes and A specifies the arches. The system V includes sets in the form of $V = V_0 \cup V_s \cup V_c$ wherein V_0 designates the main depot, $V_s = \{1, 2, \ldots, n_s\}$ denotes n_s intermediate storehouses and $V_c = \{1, 2, \ldots, n_c\}$ indicates n_c number of customers. System A, as well, is considered in the form of $A = A^1 \cup A^2$ wherein $A^1 = \{(i, j) : i, j \in V_0 \cup V_s\}$ is the arches connecting the intermediate storehouses and the main storehouse as well as the arches connecting the intermediate storehouses to one another. $A^2 = \{(i, j) : i, j \in V_s \cup V_c, (i, j) \notin V_s \times V_s\}$, as well, includes the set of the arches that connect the intermediate storehouses to the customers as well as customers to one another. For every arch $(i, j) \in A$, the travel time t_{ij} has been considered. Each $i \in V_c$ customer can place q_i demands for enjoying the services. The service-providing duration at the locality of every $i \in V_c$ customer has been considered as st_i. System R indicates the set of vehicles used in the distribution network and it can be defined as $R = R_1 \cup R_2$. System R_1 includes the first echelon's similar vehicles in the main storehouse. Every vehicle $r \in R_1$ from the first echelon possesses a capacity equal to Q_r^1; it begins its route from the main storehouse and returns thereto after visiting several intermediate storehouses. System R_2 includes the similar vehicles in the intermediate storehouses. Every vehicle $r \in R_2$ from the second echelon has a capacity equal to Q_r^2 and begins its route from an intermediate storehouse and returns to the same intermediate storehouse after providing services to one or several customers. In the first echelon, it is possible for a vehicle to visit each intermediate storehouse for more than once whereas every customer should be visited only one time by every vehicle existent in the second echelon. In other words, the separable delivery assumption has been permitted in the first echelon but not in the second echelon.

Based on the comprehensive pollutants' dispersion model designed by Barth et al. (2009), the total amount of fuel, EC, used for traveling a distance equal to a meters in a fixed speed of fm/s with a cargo weight of F can be calculated as demonstrated in equation (1):

$$EC = \lambda(y\,(a/f\,) + \gamma\beta a f^{\,2} + \gamma s\,(\mu + F\,)a) \quad (1)$$

Where, $\lambda = \xi/(\kappa\psi)$, $y = k_e N_e V_e$, $\gamma = 1/(1000\varepsilon\varpi)$, $\beta = 0.5 C_d A_e \rho$ and $s = g \sin \phi + g C_r \cos \phi$ with $(kJ/rec/l)\, k_e$ as the engine's friction coefficient, $N_e(rev/s)$ as the engine's rpm, $V_e(l)$ as engine's displacement, $\mu(kg)$ as the reduction in the vehicle's weight, g as the gravitational constant (9.8m/s^2) and ϕ as the path angle. C_d and C_r are respectively the aerodynamic drag coefficient and rolling resistance. $A_e(m^2)$ denotes the area of the front surface, $\rho(kg/m^3)$ is the air density, ε is the vehicle's drive efficiency, ϖ is the efficiency parameter for diesel engines, ξ is the ratio of fuel to air volume, $\kappa(kJ/g)$ is the diesel fuel's normal heating rate and ψ is the gram to liter conversion factor from g/s to l/s.

Since the intended customers are in the second echelon of the urban regions, the time of travel between each pair of points depends in this echelon on the time of exiting the source node. There are proposed various approaches for covering this assumption. In this study, linear piecewise function with linear slope values above -1 has been considered; so, resultantly, it leads to the guaranteeing of FIFO property in the intended modeling. The advantage of using such a type of function in contrast to stepwise function is that it causes the smoothing of the travel time variations so the model will be closer to the real world uses. This approach guarantees that when vehicle A begins traveling between the two nodes i and j and another vehicle B begins traveling between the foresaid nodes after vehicle A, vehicle B arrives at node j later than vehicle A. This issue that was proposed by Ichua et al. (2003) for the first time has been illustrated in figure (1).

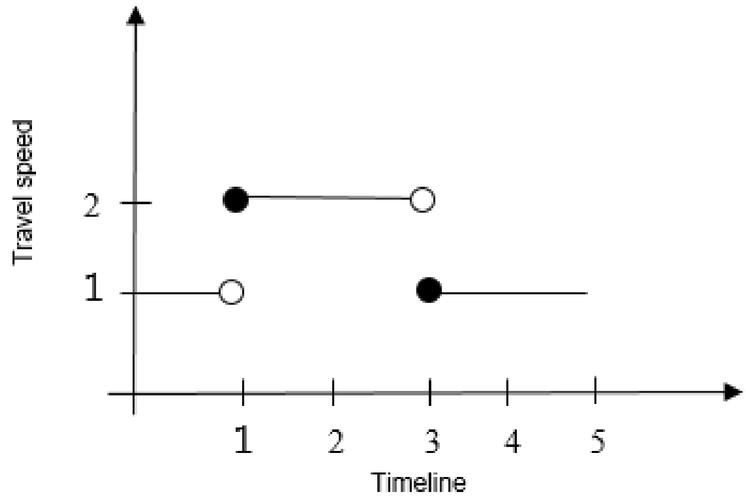

Figure 1: Travel speed function and travel time function and guaranteeing of FIFO property

The objective function of 2E-GTDVRP seeks minimization of the sum of the path-traveling costs of the vehicles in both the first and second echelons as well as minimization of fuel consumption and pollutants' dispersion.

In the problem investigated herein, the second echelon's vehicle possesses a higher capacity. In the second echelon and in every time period, the customer is provided with the required services only by one vehicle. Every customer has been given a certain service-providing time as considered in the model of the problem. All of the customers' demands should be satisfied and shortfall is not permitted. In the first echelon, it is permissible to assume separable delivery meaning that it is possible to meet the demands of every intermediate storehouse by more than first echelon's vehicles. A time constraint has been considered for the service-providing and path-traveling of the vehicles in the second echelon. The times of traveling between the intermediate storehouse points and customers as well as between the customer points has been considered in a dynamic (time variable or time dependent) manner. Direct goods' delivery from the main storehouse to the customers is not allowed. The number of vehicles is fixed in the planning horizon. The model considered for this problem is a single-goods model.

- ***Systems, Variables and Parameters***

Sets, parameters and variables related to the proposed model are as listed below:

Systems

V_0	Central storehouse: indices i and j pertain to this system
V_c	Set of customers: indices i and j pertain to this system
V_s	Set of intermediate storehouses: indices i and j pertain to this system
R_1	Set of the first echelon's vehicles: index r is related to this set
R_2	Set of the second echelon's vehicles: index r is related to this set
T	It indicates the planning periods: t is the index related to this set
M	Set of the traffic function's failure spots: index m is related to this set

Parameters

q_i	i-th customer's demand
Cap_r	Capacity of the fist echelon's vehicles
$Cap2_r$	Capacity of the second echelon's vehicles
c_{ij}	Cost of traveling through the edges i and j
B	It has a large value
W_{ir}	If the r-th vehicle is existent in i-th node, it is equal to unity otherwise it is zero in such a way that $i \in V_s$
UB_m	Failure at m-th point along axis x_i in the traffic function of travel time-time (upper boundary)
LB_m	Failure at m-th point along axis x_i in the traffic function of travel time-time (lower boundary)
UC_m	Failure at m-th point along axis y_i in the traffic function of travel time-time (upper boundary)
LC_m	Failure at m-th point along axis y_i in the traffic function of travel time-time (lower boundary)
s_i	Servicing time of i-th node
λ	Technical parameter proposed for fuel consumption and pollutants' dispersion which is equal to $\xi / (\kappa\psi)$.
f	Average speed of the vehicle which has been determined per various amounts defined in the time spans; it is used for calculating the fuel consumption of the vehicles.
w	Technical parameter posited for fuel consumption and pollutants' dispersion and it is equal to $k_e N_e V_e$.
γ	Technical parameter posited for fuel consumption and pollutants' dispersion and it is equal to $1/(1000\varepsilon\varpi)$.
β	Technical parameter posited for fuel consumption and pollutants' dispersion and it is equal to $0.5C_d A_e \rho$.
s	Technical parameter posited for fuel consumption and pollutants' dispersion and it is equal to $g \sin \phi + gC_r \cos \phi$.
μ	Vehicle's weight reduction in kg (all of the technical parameters considered in this article have been offered based on pollution routing problem posited by Demir et al. (2012).
l	Fuel price per every liter

Variables

y_{ijr}	It is equal to unity if the r-th vehicle in the first echelon moves from node i to node j otherwise it is set equal to zero.
x_{ijr}^m	It is equal to unity if the m-th vehicle in the second echelon moves from node i to node j within m-th time span otherwise it is set equal to zero.
at_i	The time at which the vehicle enters i-th node

dg_i	Amount of goods sent from the i-th intermediate storehouse in such a way that $i \in V_s$.
cg_r	The total cargo carried by r-th vehicle
Q_{ir}	The amount of cargo transferred from i-th node by an r-th vehicle in the first echelon
f_{ir}	Non-negative auxiliary variable for omitting subtour
u_{ir}^m	Non-negative auxiliary variable for omitting subtour in the second echelon

- ***Mathematical Model***

After expressing the sets, parameters and variables related to the problem, the mathematical time-dependent model of the green two-echelon vehicle routing problem is offered as shown below:

$$\min \sum_{(i,j)\in V_0 \cup V_c} \sum_{r\in R_2} \sum_{m\in M} \lambda(w(c_{ij}/f)x_{ijr}^m + \gamma\beta a f^2 x_{ijr}^m + \gamma s(\mu x_{ijr}^m + F_{ir})c_{ij})l$$
$$+ \sum_{i\in V_0\cup V_s} \sum_{j\in V_0\cup V_s} \sum_{r\in R_2} c_{ij}x_{ijr}^m + \sum_{i\in V_0\cup V_s} \sum_{j\in V_0\cup V_s} \sum_{r\in R1} c_{ij}y_{ijr}$$

(2)

$$s.t.$$

$$\sum_{i\in V_s\cup V_c} \sum_{r\in R_2} \sum_{m\in M} x_{ijk}^m = 1 \qquad \forall i \in V_s \cup V_c$$

(3)

$$\sum_{i\in V_s\cup V_c} \sum_{m\in M} x_{ijr}^m = \sum_{j\in V_s\cup V_c} \sum_{m\in M_c} x_{jir}^m \qquad \forall j \in V_s \cup V_c, r \in R_2$$

(4)

$$\sum_{i\in V_s\cup V_c} \sum_{j\in V_s\cup V_c} \sum_{m\in M} q_i \times y_{ijrm}^t \le Cap2_r \qquad \forall r \in R_2$$

(5)

$$\sum_{r\in R_2} \sum_{m\in M} u_{0r}^m = 0 \qquad \forall i \in V_s \cup V_c$$

(6)

$$u_{ir}^m + 1 \le u_{jr}^m + M \times (1 - x_{ijr}^m) \qquad \forall i \in V_s \cup V_c, j \in V_s \cup V_c, r \in R_2, m \in M \qquad (7)$$

$$\sum_{m\in M} \sum_{j\in V_s\cup V_c} x_{ijr}^m \le W_{ir} \qquad \forall i \in V_s, r \in R_2$$

(8)

$$at_{it} = 0 \qquad \forall i \in V_0 \cup V_s$$

(9)

$$at_i + s_i + \{LC(m) + \{\frac{UC_m - LC_m}{UB_m - LB_m}\} \times ((at_i + s_i) - LB_m) \times c_{ij} \le at_j + M \times (1 - \sum_{r\in R_2} x_{ijr}^m) \qquad (10)$$
$$\forall i \in V_s \cup V_c, j \in V_c, m \in M$$

$$at_i + s_i + \{LC(m) + \{\frac{UC_m - LC_m}{UB_m - LB_m}\} \times ((at_i + s_i) - LB_m) \times c_{ij} \ge at_j + M \times (1 - \sum_{r\in R_2} x_{ijr}^m) \qquad (11)$$
$$\forall i \in V_s \cup V_c, j \in V_c, m \in M$$

$$at_i \le UB_m + M \times (1 - \sum_{j \in V_s \cup V_c} \sum_{r \in R_2} x^{m}_{ijr}) \qquad \forall i \in V_s \cup V_c, m \in M \tag{12}$$

$$LB_m \le at_i + M \times (1 - \sum_{j \in V_s \cup V_c} \sum_{r \in R_2} x^{m}_{ijr}) \qquad \forall i \in V_s \cup V_c, m \in M \tag{13}$$

$$\sum_{i \in V_s \cup V_c} \sum_{j \in V_s \cup V_c} \sum_{m \in M} q_i \times x^{m}_{ijr} = F_{pr} \qquad \forall p \in V_s, r \in R_2 \tag{14}$$

$$F_{ir} - q_i \le F_{jr} + M \times (1 - \sum_{m \in M} x^{m}_{ijr}) \qquad \forall i \in V_s \cup V_c, j \in V_c, r \in R_2 \tag{15}$$

$$F_{ir} - q_i \ge F_{jr} - M \times (1 - \sum_{m \in M} x^{m}_{ijr}) \qquad \forall i \in V_s \cup V_c, j \in V_c, r \in R_2 \tag{16}$$

$$\sum_{j \in V_s} y_{ijr} \le 1 \qquad \forall i \in V_0, r \in R_1 \tag{17}$$

$$\sum_{j \in V_s \cup V_c} y_{ijr} = \sum_{j \in V_s \cup V_c} y_{jir} \qquad \forall i \in V_s \cup V_c, r \in R_1 \tag{18}$$

$$\sum_{i \in V_0} \sum_{t \in T} \sum_{r \in R_1} f_{itr} = 0 \tag{19}$$

$$f_{itr} + 1 \le f_{jtr} + B \times (1 - y_{ijr}) \qquad \forall\ i \in V_0 \cup V_s\ , j \in V_s\ , r \in R_1 \tag{20}$$

$$\sum_{r \in R_1} Q_{ir} = dg_{it} \qquad \forall\ i \in V_s \tag{21}$$

$$\sum_{i \in V_0 \cup V_s} Q_{ir} \le Cap_r \qquad \forall r \in R_1 \tag{22}$$

$$Q_{ir} \le B \left(\sum_{j \in V_0 \cup V_s} y_{ijr} \right) \qquad \forall\ i \in V_0 \cup V_s, r \in R_1 \tag{23}$$

$$cg_r = \sum_{i \in V_s \cup V_c} q_i \times \sum_{j \in V_s \cup V} \sum_{m \in M} x^{m}_{ijr} \qquad \forall\ r \in R_2 \tag{24}$$

$$dg_i = \sum_{r \in R_2} cg_r \times W_{ir} \qquad \forall i \in V_s \tag{25}$$

$$x^{m}_{ijr}, y_{jr} \in \{0,1\} \qquad \forall (i,j) \in V_0 \cup V_s \cup V_c, m \in M, r \in R_1 \cup R_2 \tag{26}$$

$$at_i, F_{ir}, f_{itr}, dg_{it}, cg_{rt}, Q_{ir} \ge 0 \qquad \forall (i,j) \in V_0 \cup V_s \cup V_c, r \in \{R_1, R_2\} \tag{27}$$

Equation (2) pertains to objective function that is comprised of three parts. The first part is related to the calculation of the fuel consumption and pollutants' emission in the distribution space in the second echelon. Travel distance has been considered in the second part. The third part takes the sum of costs for travel distances in the first echelon into account. The problem seeks minimization of the aforesaid cases. The constraint (3) specifies that each customer can be visited at most one time. Constraint (4) guarantees that the vehicle that has entered a node in the second echelon will leave it. Constraint (5) ensures that the maximum capacity limitation of the vehicles in the second echelon. Constraints (6) and (7) lead to the omission of subtour in the second echelon. Equation (8) expresses that a vehicle cannot exit a storehouse other than its related storehouse. Constraint (9) specifies that the initiation time of travel from the main storehouse and from the intermediate storehouses is equal to zero. The traffic limitation considered in this problem is covered by the time dependent limitations. Constraints (10), (11), (12) and (13) indicate these constraints that constitute the traffic function in such a way that vehicles travel in different speeds per every different time span. This issue is proposed by the use of the failure points existing in the traffic function. According to the diagram of the traffic-time function, the travel time and speed are defined per every predetermined route and time span with vehicles travelling in different speeds in each of the time spans that are determined route-specifically. For example, the traffic volume is usually less congested during mornings and it gradually increases with time till night. Of course, these assumptions differ for various regions. The advantage of the model proposed in this article is its flexibility for all of the time spans and various regions with different speeds of the vehicles. Now, considering each of the points in the coordinate system and axes, a specific traffic function can be obtained that is specified per different speeds for various times of entry to each node. Constraints (14), (15) and (16) specify the weights of the vehicles at the time of entry into the nodes. Constraint (17) expresses that every vehicle from the first echelon can visit each intermediate storehouse at most once. Constraint (18) demonstrates that a vehicle that has entered a node in the first echelon should leave it. Constraints (19) and (20) lead to the omission of subtours in the first echelon. Constraint (21) pertains to the load balance in the intermediate storehouses. Constraint (22) indicates the capacity of the vehicles existing in the first echelon. Constraint (23) guarantees that if the intermediate storehouse is visited by a vehicle from the first echelon, part of the intermediate storehouse's goods can be allocated thereto. Constraint (24) specifies the sum of the goods displaced by the r-th vehicle in the second echelon. Constraint (25) specifies the amount of goods sent from the intermediate storehouse. Constraints (26) and (27) indicate the domain of the problem's variables.

Solution Method

In order to solve the problem proposed in the current study, a metaheuristic algorithm has been suggested in large scale. The proposed algorithm has been proposed under the title of variable neighborhood search algorithm wherein special mechanisms are utilized for running the algorithm on the problem. The upcoming parts explain the stages of the algorithm's implementation.

- ***Variable Neighborhood Search Algorithm***

The variable neighborhood search algorithm designed by Mladenović and Hansen (1997) is a metaheuristic method for solving the combined optimization and general optimization problems. This algorithm searches for the current answer's neighborhood and moves towards one of the neighborhoods as the new answer if and only if improvements are found therein. In order to achieve the local optimal answers existent in the neighborhood, use is continuously made of the neighborhood search. Variable neighborhood search algorithm has been designed for estimating the answers of discrete and continuous optimization problems. VNS algorithm changes the neighborhood in two stages in a systematic manner: first is reduction for finding a local optimum and the second is deviation for exiting the corresponding valley. The stop conditions in this algorithm include cases like limitations of number of reiteration, solution time, number of reiterations between two consecutive improvements in the answer as well as finding a local optimal answer in the entire neighborhood structures with the search being continued until the algorithm's reaching of one of the termination conditions. VNS algorithm features a simpler structure in contrast to the other metaheuristic algorithms with its advantage being the low number of parameters that causes increase in the algorithm's speed. VNS algorithm has been composed of two primary shaking and local search stages.

- ✓ ***The Proposed Variable Neighborhood Search Algorithm***

VNS algorithm includes four primary steps including initial answer generation, shaking phase, local search phase and finally stop.

Initial Answer Generation

The proposed problem is comprised of two parts. These two parts are based on the two first and second echelons considered in the problem. In the first part explains the method in which the answer offered for the second echelon is displayed. Thus, at first and according to the approach intended in the problem, the second echelon's vehicles, $r \in R_2$, pertaining to each intermediate storehouse, $i \in V_S$, are determined. Then, a list is made for the customers allocated to each vehicle $r \in R_2$ from the second echelon that determines the answer intended for 2E-GTDVRP in the second echelon. Therefore, the method of displaying the intended answer for the second echelon includes $r_2 \in R_2$ series of answers each of which can be divided into three sections as shown in figure (2). Each series of the existent answers specifies the number of vehicles, $r \in R_2$, the number of the intermediate storehouse, $i \in V_s$, and the list of customers, $i \in V_c$, from left to right.

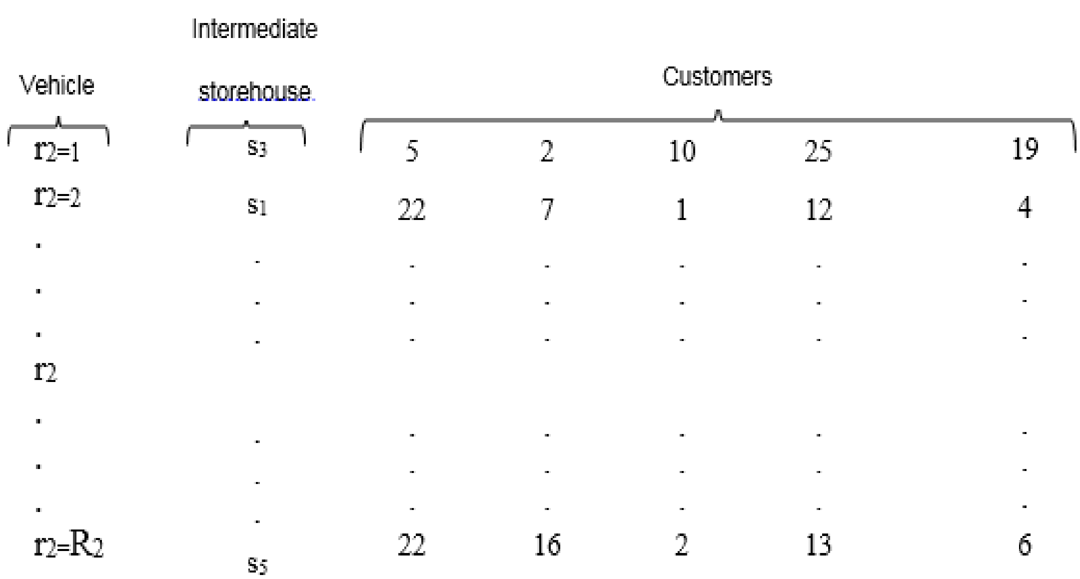

Figure (2): Method of displaying the answer in the problem's second echelon

After the process of customer allocation was carried out in the second echelon, the demand rate of each intermediate storehouse is specified in the first echelon. The second part of the displayed answer that is pertinent to the first echelon of the problem is in the form of allocation of each of the intermediate storehouses, $i \in V_S$, to the vehicle in the first echelon, $r \in R_1$, with the difference being that it is possible to separate the demands of each of the intermediate storehouses, $i \in V_s$, amongst the first echelon's vehicles, $r \in R_1$. Considering this assumption, it is possible for the vehicles to visit each of the intermediate storehouses, $i \in V_s$, more than once unlike in the second echelon. Therefore, the method in which the intended answer is displayed for each of the vehicles gives $r \in R_1$ series of answers each of which can be divided into three parts. Figure (3) depicts the method of displaying the answer for the first echelon in the second part. Each series of the answers determine the number of vehicles, $r_1 \in R_1$, main storehouse, $i \in V_0$, and the set of the intermediate storehouses, $i \in V_s$, from left to right.

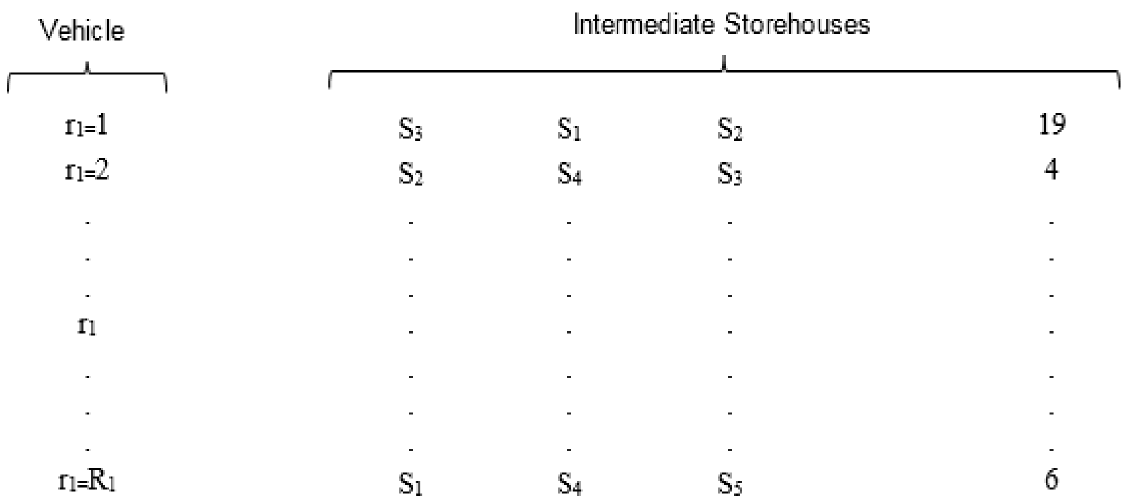

Figure (3): method of displaying the answer in the first echelon of the problem

In every metaheuristic algorithm, solution has to begin with the use of an initial answer. According to the fact that the amount of goods sent from the main storehouse to the intermediate storehouses is determined in the proposed problem based on the customers' demands, the initial allocation is seminally commenced from the second echelon. Swap, Reversion and Best Position in Tour (BPT) are the operators utilized for generating the initial answers.

A heuristic algorithm is used for generating the initial answer. Based thereon, according to certainness of the amount of customers' demands and the given places of the second echelon's vehicles in the intermediate storehouses, a list of the customers called List N is formed in a descending order of the demands for the generation of an initial answer. The cost of each vehicle's travel between the customers existent in its tour is calculated via placing each

customer in the tour of each vehicle. The vehicle with the lowest increase in the travel cost of its tour would be selected as the final vehicle to be allocated to the intended customer. This trend is continued to the last customer existent in List N. Considering the allocations performed in the second echelon, the times taken to finish the tours and the amount of the pollutants emitted by the vehicles in the second echelon are obtained and used as parts of the problem's general objective function. After the customers were completely allocated to the vehicles in the second echelon, the total cost of the demands of the customers allocated to each of the intermediate storehouses is computed and considered as the inventory of the items required by the intermediate storehouses in the first echelon. Considering the separable delivery assumption based on which it is possible to satisfy the demands of each intermediate storehouse in several visits in the first echelon, each of the intermediate storehouses is allocated to the vehicles existent in the first echelon and in the main storehouse using the separable delivery approach. According to the allocations performed in the first echelon, the time taken by the vehicle to finish the route is obtained in the first echelon and it will be considered as another part of the general objective function of the intended problem.
In the end, the sum of the times taken for completing the tours existent in the first and second echelons and the cost of fuel consumption and pollutants' emission in the distribution space of the second echelon is determined considering the traffic constraints specifying the primary objective function the minimization of which is the primary goal of this study. Based on the above stages, a feasible initial answer is obtained based on which each of the metaheuristic algorithms giving the solutions offered in the dissertation use mechanisms for improving it and achieving a final optimum or near optimum answer.

- ***Operators Used in the Proposed Algorithm for Completing the Local Search Process***

In general, a set of primary operators are used for performing a local search of the current answer in the process of problem solving as well as in the various stages of the algorithm implementation in line with improving the obtained answer and performing searches in the solution space following the completion of the metaheuristic algorithm implementation and initial answer generation.

Swap Operator

A path in the form of $\{1,...,i,i+1,..., j, j+1,...,n\}$ is considered. Swap operator chooses two points like i and j and replaces them for one another in such a way that the intended path shifts. In order to operate this operator, all of the possible values for i and j, $i \in \{1,2,...,n-1\}$ and $j \in \{i+1,...,n\}$, are investigated on a path and, amongst the investigated displacements, the one creating the highest improvement in the objective function will be selected.

Reversion Operator

A path is considered in the form of $\{1,...,i,i+1,..., j, j+1,...,n\}$. On this path, Reversion Operator chooses two points, namely i and j and reverses the series of numbers existent between them: $\{1,..., j, j-1,...,i+1,i, j+1,...,n\}$.

Best Position in Tour (BPT) Operator

The inputs of this operator are the candidate customer and a tour on which the customer is located. Then, the placement of the selected customer between each pair of consecutive customers is evaluated. The evaluation intends to calculate the time cost of the vehicle's tour. This process continues till the investigation of all the locations between the two consecutive customers in a tour. Amongst the obtained tours with given distance-travelling times, the one with the lowest time of traveling a given distance is selected.

In order to improve the tour of the obtained vehicle, the swap and reversion operators are randomly run for a given and predetermined number of times. Swap, Reversion and BOT operators are used as the local search operators in the proposed VNS algorithm.

- ***Shaking Stage***

Shaking process is a key process in the designing of variable neighborhood search. The primary goal of this process is the expansion of the search space of the current answer, reduction in the algorithm's possibility of entrapment in a local optimal answer and achievement of the better answer. The sum of the neighborhood structures used in the shaking stage forms the primary core of VNS algorithm. In the process of the shaking stage's implementation, the neighborhood structures pertaining to the current answer, x, that is designated by Ok will be selected in an order; then, based on Ok's definition, the current answer, x, is changed and the new answer, x*, is chosen. In order to implement the shaking process, use is made of the set of neighborhood structures. In order to implement each of the neighborhood structures, two vehicles are randomly selected. Next, the neighborhood structures are allocated to two given vehicles. In order to exert changes in the current feasible answer in every time of the allocation of the neighborhood structures, displacements are made to the number of the neighborhood structures on the stations existent in the list of the two vehicles. Based thereon, the neighborhood structures, *p*, are allocated in an order. Each O_i^j specifies a neighborhood structure in such a way that two vehicles are considered in every neighborhood structure following which i stations are selected randomly from the tour obtained for the first vehicle and placed in the tour obtained for the second vehicle. Then, the cost of each new tour obtained for the two vehicles will be calculated using the operator calculating the vehicle's tour cost. In case that the general objective function is found improved, the new answer is replaced for the current answer and the algorithm is continued with this answer otherwise the previous answer is not changed. Each neighborhood structure is reiterated internal_it number of times. In case that the answer is found improved in each reiteration, the algorithm is returned to the first neighborhood structure. In case that the answer is found not improved after internal_it times of iteration, the algorithm goes on to the next neighborhood structure. The sum of all the reiterations in the shaking stage is Max-it and the algorithm reaches termination point for each neighborhood structure when the number of predetermined iterations reaches Max_it.. The proposed neighborhood structures have been generally demonstrated in figure (4).

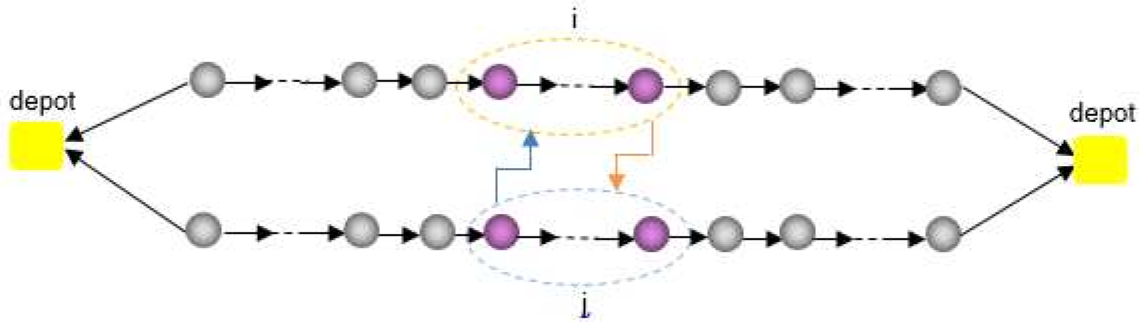

Figure (4): Performance method of neighborhood structure O_i^j

- *Addition of the Time Dependency Assumption*

Based on a research by Alinaghian et al. (2017), a designed traffic pattern is considered in each arch existent in the distribution network's graph. This traffic pattern has five time spans that are initialized with the commencement of every work day. The time required for a vehicle to take the arch's length is considered as the first time span with T4 being calculated as shown in equation (28):

$$T_4 = (\frac{n}{K}+1)\ .\ \overline{T} \tag{28}$$

Where, n is equal to the number of customers, k is equal to the number of vehicles in the second echelon and $\overline{T}$ is equal to the average time of traffic between the customers. The equations given in table (2) are used for calculating the length of all the time spans (t_i is indicative of the termination of i-th time span). In this table, $T_{\max}$ is equal to the time length of the largest arch existent in the problem. It is evident that the time of travel on each of the arches depends on the defined time span and the line slope in that time span. Figure (5) displays the piecewise linear function with five time spans explained in table (2). It is worth mentioning that the five time spans and their corresponding slopes have been heuristically determined; thus, it can be stated that the number of the considered time spans is not necessarily five. In order to exactly explicate the studied problem, this number of time spans has been considered as an objective example. These spans solely determine the vehicles' speeds in various hours of the day. For example, congestion is very high during the early hours of the morning and it gradually increases on average till noon after which a reduction is faced but the traffic reaches its peak again in the afternoon. Based thereupon, the flexibility of the proposed modelis notable in comparison to the various case studies in this area.

Table 2: determination of the time spans

I	t_i	i-th slope
1	$T_4/2$	0
2	$t_1+T_4/8$	0.9

3	$t_2 + T_4 / 4$	0
4	$t_3 + T_4 / 8$	-0.9
5	$nT_{\max}$	0

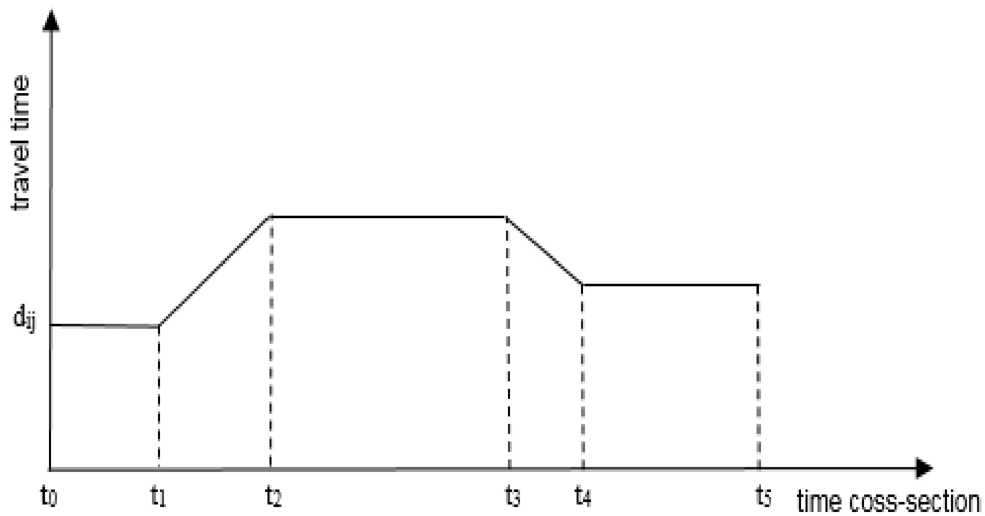

Figure (5): Piecewise linear function used in the sample problems (Alinaghian et al., 2017)

- ***Method of Fuel Consumption and Pollutants' Calculation***

In this article, the cost of fuel consumption and pollutants' emission is calculated in the distribution space based on the comprehensive pollutants' emission model designed by Barth et al. (2009). The related parameters have been given in table (3) according to Demir et al. (2012).

Table 3: parameters related to fuel consumption and pollutants' emission

Symbol	Description	Amount
ξ	Ratio of fuel to air volume	1
κ	The normal diesel fuels' heating rate (kJ/g)	44
ψ	Conversion factor (g/l)	737
k_e	Engine's friction coefficient) $(kJ/rec/l)$	0.2
N_e	Engine's speed (rev/s)	33
V_e	Engine's displacement (l)	5
ρ	Air density (kg/m^3)	1.2041
A_e	Area of the front surface (m^2)	3.912
μ	Vehicle's weight reduction (kg)	6350
s	Gravitation constant (m/s^2)	9.81
ϕ	Path angle	0
C_d	Aerodynamic drag coefficient	0.7
C_r	Rolling resistance coefficient	0.01

ε	Vehicle's drive efficiency rate	0.4
ϖ	Efficiency parameter of the diesel engines	0.9
l	Fuel price per every liter	1.7

Method of Evaluating the Proposed Algorithm

In order to validate this algorithm in solving small-scale problems, 17 sample problems have been solved using the proposed algorithm and CPLEX optimizer and the obtained answers will be compared with those obtained in the solving of the similar sample problems by the mathematical models in the software environment based on heuristic methods in small scale. The achievement of the reasonable and acceptable differences between the heuristic method and the model's exact solution would indicate the acceptance of the answers obtained from the solving of the problem using the heuristic method in large scale. According to the novelty of 2E-GTDVRP and existence of no other similar problems in the related literature in this regard, certain problems have been proposed herein. In order to investigate the performance of metaheuristic algorithm in large scale, as well, the sample problem presented by Cordeau et al. (2001) will be used. In line with this, changes will be made for adapting the intended problem with these sample problems. Moreover, the proposed mechanism will be used for adding the time dependency constraint to the sample problems.

- ***Generating Sample Problems***

In order to evaluate the performance of the proposed algorithms, 17 sample problems have been generated in small scale in a randomized manner. In order to generate the sample problems, a set of points with given coordinates and in an scattered form have been considered; then, amongst these points, one point is selected randomly as the main depot and NS number of points are chosen (dependent on the type of the sample problem) as the intermediate depots. After the determination of the vehicles' capacity in the second echelon, the capacity of the first echelon's vehicles will be considered as twice the capacity of the second echelon's vehicles. The number of the various time spans in the traffic function for the calculation of the travel time has been set to five with the determination of each of the time spans and lines' gradients following the explained mechanism. The duration of providing service to each of the customers is considered to be two time units and the maximum time spent on taking the tour distance is determined randomly according to the distances between the customers and the points existent on the transportation network. The distance between the points follows the direct line method with the distance being considered as the time cost between the two nodes. The fuel consumption and pollutants' emission have been calculated in the distribution space the parameters of which have been specified in table (3) according to Demir et al. (2012). In order to generate the sample problems in large scale, 32 initial scale samples proposed by Cordeau et al. (1997) have been considered for PVRP problem. To convert the existing sample problems to two-echelon sample problems, NS customers out of all the customers existent in each sample problem have been randomly determined to be allocated to the intermediate storehouses. The number of the vehicles existent in each sample problem remains unchanged and considered as the number of the second echelon's vehicles, as well. Efforts have also been made to allocate a similar number of second echelon's vehicles to each of the intermediate depots. Furthermore, the capacity of the first echelon's vehicles is twice that of the vehicles in the second echelon and their numbers have been set in a random manner in respect to the problem type.

- ***Parameter Setting***

The performance of each of the metaheuristic methods is considerably dependent on the amount of the parameters related to each of the methods. Therefore, proper parameter setting can exert a considerable effect on the performance of each of the approaches. Internal-It1, Internal-It2, Internal-It3 and Max_It1 parameters respectively indicate the number of internal iterations in the shaking stages of three neighborhood structures (O_i^j) that have been randomly applied; Max_It1, Max_It2 and Max_It3 respectively show the maximum number of the general iterations in the shaking stages considering the same random neighborhood structures in the proposed VNS algorithm. Table (4) specifies the parameters, their amounts and the levels determined for each of the parameters.

Table 4: Parameters and levels related to them for VNS algorithm

Parameters	Level 1	Level 2	Level 3
$Internal\_it_1$	10	50	100
Max_it_1	10000	20000	30000
$Internal\_it_2$	10	100	300
Max_it_2	10000	20000	30000
$Internal\_it_3$	10	100	300
Max_it_3	10000	20000	30000

In order to analyze the data, use has been made of MINITAB17 Software. Considering the number of the selected factors and the set levels, standard orthogonal tables in the form of L9(3*3) will be offered for the proposed metaheuristic algorithm based on Taguchi's analysis. The investigation of each of each of the orthogonal vectors offered in Taguchi table has been done for a single problem. In this problem, a total of 153 customers, 10 intermediate depots, 5 vehicles in the first echelon and 10 vehicles in the second echelon have been considered and their corresponding problem, named P12 problem, has been solved in large scale. The intended problem has been reiterated five times with various amounts of the parameters per every line in Taguchi table. It is by the reporting of the obtained mean values and introducing them into MINITAB software in the end for each of the five parameters that the level with the highest ratio of S/N is determined as the best possible level for those parameters. The amounts of each of the parameters have been presented in table (5).

Table 5: Values determined for each of the five parameters using Taguchi analysis

Index	VNS algorithm	
	Amount	Parameter
A	100	$Internal\_it_1$
B	30000	Max_it_1
C	300	$Internal\_it_2$

D	30000	*Max_it₂*
E	300	*Internal_it₃*
F	30000	*Max_it₃*

- ***Analysis and Investigation of the Proposed Algorithm's Performance in Solving Small-Scale Problems***

In this section, the mathematical model offered for 2E-GTDVRP has been validated and the performance of the proposed metaheuristic algorithm for solving the intended problem has been also analyzed. Each sample problem has been solved using CPLEX optimizer in GAMS Software, version 24.1.2, and the proposed metaheuristic variable neighborhood search algorithm (VNS). The comparison of the answers obtained from solving the sample problem by metaheuristic algorithms is carried out using the objective function's error percentage (gap) and problem-solving time (time) in seconds. The error percentage is calculated as shown in equation (30).

$$Gap\% = \frac{AS - Sol_{exact}}{Sol_{exact}} \times 100 \qquad (30)$$

Where, AS and Sol_{exact} are respectively answers obtained from algorithm and CPLEX solver. In order to solve the problems in GAMS Software, a 7200-second constraint has been used.

The results obtained from solving the generated sample problems in GAMS Software as well as the proposed metaheuristic algorithm have been shown in table (6). Based on table (6), the error percentage of all the problems is equal to zero for the metaheuristic algorithm. This is reflective of the high efficiency of the algorithm. The first column gives the numbers related to each of the sample problems. The second column gives the problem parameters within the format of nc, ns, r1st, r2nd, $Cap2_r$ and Cap_r in such a way that nc specifies the number of customers, ns designates the number of intermediate depots, r1st is equal to the number of vehicles in the first echelon, r2nd is equal to the number of vehicles in the second echelon, $Cap2_r$ shows the capacity of the vehicles in the second echelon and Cap_r determines the capacity of the vehicles in the first echelon. Each sample problem is solved in ten iterations and the lowest of their values have been reported in table (6). The presented solving time, as well, equals the average time of solving the ten problems. In addition, Obj, Time and Gap in table (6) correspondingly designate the objective function's values, time of problem solving and error percentage of the solution in contrast to GAMS Software's answers.

As it is observed in table (6), the average exact solving time of CPLEX optimizer for the sample problems in small scale is equal to 854.94 seconds. This is while the average time taken by the proposed VNS algorithm is equal to 2.17 seconds. Additionally, the mean percentage of the proposed metaheuristic algorithm's error is equal to zero which is indicative of the efficient performance of these algorithms in solving the sample problems in small scale and in a notably short time.

In figure (6), VNS algorithm's solving times have been shown for small-scale problems. In this figure, the vertical axis, on the right side, indicates the solving time of the proposed metaheuristic algorithm and the vertical axis, on the left side, shows the exact time of solving the sample problems using CPLEX optimizer. The solving times of VNS algorithm are closer to each other and the exact sample problem's solving time has been increased exponentially. The average exact solving time of the sample problems is about 393 times higher than the solving times of the two proposed metaheuristic algorithms.

Table 6: The results obtained from solving the sample problems by the proposed algorithms in small scale

Problem number	$n_c/n_s/r_{1st}/r_{2nd}/Cap2_r/Cap_r$	GAMS		VNS		
	6000/3000/2/1/2/5	*Time(s)*	*Obj*	*Gap*	*Time(s)*	*Obj*
1	5000/2500/2/1/2/4	80.93	1.2	80.93	0.17	0.00
2	7000/3500/2/1/2/7	73.68	1.5	73.68	0.16	0.00
3	6000/3000/2/1/2/6	88.23	2.19	88.23	1.19	0.00
4	8000/4000/2/1/2/9	104.14	13.8	104.14	0.16	0.00
5	8000/4000/2/1/2/8	107.5	19.26	107.5	3.21	0.00
6	8000/4000/2/4/2/9	94.46	22.58	94.46	1.7	0.00
7	6000/3000/2/4/2/9	108.3	275.3	108.3	2.27	0.00
8	6000/3000/4/3/2/6	120.3	378.9	120.3	2.3	0.00
9	6000/3000/3/2/2/6	112.2	462.1	112.2	1.6	0.00
10	6000/3000/3/4/2/8	88.22	536.8	88.22	2.69	0.00
11	7000/3500/2/3/2/7	118.3	677.7	118.3	3.4	0.00
12	8000/4000/3/2/2/9	130.3	809.3	130.3	1.18	0.00
13	4000/2000/3/4/2/8	96.27	861.4	96.27	2.4	0.00
14	8000/4000/2/4/3/10	131.3	951	131.3	0.72	0.00
15	8000/4000/2/4/2/10	125.3	1059.6	125.3	4.78	0.00
16	8000/4000/3/2/3/11	119.3	1261.4	119.3	3.9	
17	6000/3000/2/1/2/5	130.3*	7200	128.3	5.1	0.00
#	Mean	107.59	854.94	107.59	2.17	0.00
* indicates the lower boundaries obtained by GAMS Software						

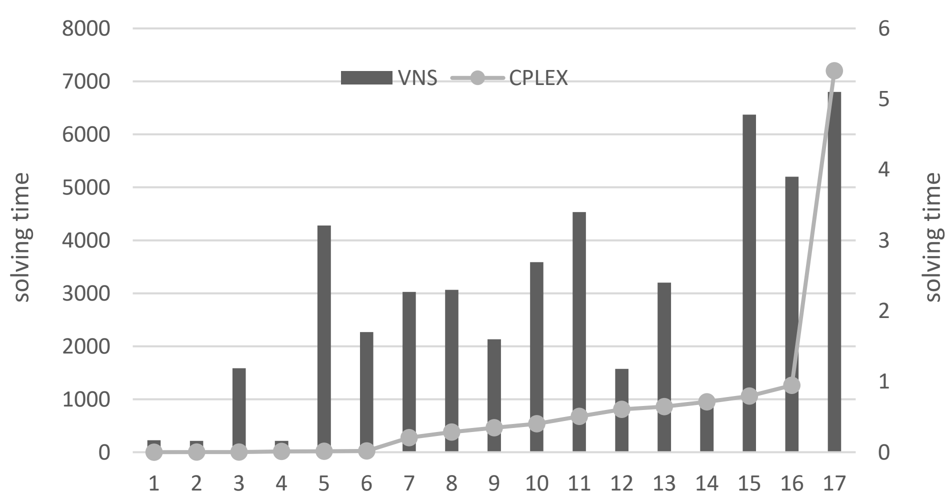

Figure (6): Solution time of the small-scale problems

- ***Analysis and Investigation of the Proposed Algorithm's Performance in Solving the Large-Scale Problems***

In order to evaluate the proposed metaheuristic algorithm for solving the large-scale problems, the sample problem offered by Cordeau et al. (2001) has been considered for solving P-VRP problem. In order to generate the sample 2E-GTDVRPs, a number of the customers were considered as the intermediate storehouses for providing services to the other customers in the sample problem p32-o01 according to the total number of the customers existent in the problem hence their demand was set equal to zero. The capacity of the vehicles in the second echelon was set equal to the capacity of the vehicles determined by Cordeau et al. (2001) and the capacity of the vehicles in the first echelon was set equal to twice as much that of the vehicles in the second echelon. The number of the vehicles in each of the echelons was set randomly and according to the dimensions of the intended sample problem. In order to add the time dependency assumption to the sample problems, use was made of the previously explained mechanism. Moreover, the objective function of the sample problems was solved via adding the green objective function presented in the current research paper. Each sample of the problem generated in this study was solved using the proposed metaheuristic algorithm and the obtained results have been given in table (7). In this table, the first column indicates the number of each sample problem. The second column presents the problem parameters within the format of nc/ns/r1st/r2nd/ $Cap2_r$ / Cap_r in such a way that nc is the number of customers, ns is the number of the intermediate depots, r1st is equal to the number of the vehicles in the first echelon, r2nd is the number of vehicles in the second echelon, $Cap2_r$ is indicative of the capacities of the vehicles in the second echelon and Cap_r indicates the capacity of the vehicles in the first echelon. Each sample problem was solved in ten iterations and the lowest of their values have been reported in table (7). The presented solving time, as well, equals the average time of solving the ten problems. In addition, Obj and Time in table (7) correspondingly designate the objective function's values and time of problem solving.

In addition, table (7) gives the times of solving the large-scale sample problems along with various amounts of the objective function that indicate the dimensions of every sample problem. The mean solving time of VNS algorithm is notably equal to 37.15 seconds that, considering the large dimensions of the problem (46 to 403 customers), it is very short and considerable. As it is observed in figure (7), various times have been obtained for each of the sample problems but the trend line of this diagram which is indicative average solving times is fixed and this is indicative of the acceptable performance of the proposed algorithm in solving the large-scale problems.

Table 7: Results obtained from solving the sample problems by the proposed algorithm in large scale

Problem number	$n_c/n_s/r_{1st}/r_{2nd}/Cap2_r/Cap_r$	VNS Obj	VNS Time (s)	Problem number	$n_c/n_s/r_{1st}/r_{2nd}/Cap2_r/Cap_r$	VNS Obj	VNS Time (s)
1	400/200/5/3/5/46	794.30	5.26	26	600/300/9/4/9/130	571.65	48.43
2	500/250/5/3/5/46	721.18	12.05	27	700/350/9/4/9/130	595.75	66.52

3	600/300/5/3/5/46	698.12	18.83	28	220/110/10/5/10/153	1067.5	52.99
4	600/300/4/3/4/46	620.86	12.99	29	16000/8000/14/7/14/403	2745.2	180.3
5	600/300/4/2/4/46	654.91	19.56	30	16000/8000/14/7/14/403	2460.3	262.3
6	400/200/5/3/5/45	674.9	7.75	31	50/25/2/1/2/18	410.01	14.99
7	400/200/4/3/4/45	656.84	13.29	32	40/20/4/2/4/34	1155.4	10.15
8	400/200/4/2/4/45	678.92	2.3	33	60/30/4/2/4/52	1779.8	38.03
9	500/250/5/3/5/45	639.78	1.6	34	50/25/4/2/4/36	721.05	18.21
10	600/300/5/3/5/45	619.7	21.82	35	50/25/6/3/6/70	2068.8	6.65
11	400/200/7/3/5/45	667.24	3.4	36	60/30/8/4/8/104	3889.4	35.83
12	500/250/7/3/5/45	631.91	1.18	37	90/45/8/4/8/176	7544.4	74.48
13	600/300/7/3/5/45	624.7	18.2	38	50/25/5/3/5/55	1073.3	6.26
14	600/300/7/3/4/45	619.83	22.44	39	75/35/6/3/6/108	2615	37.08
15	600/300/7/2/4/45	652.95	4.78	40	75/35/6/4/6/108	2529.7	35.52
16	600/300/6/4/6/69	884.5	41.22	41	75/35/7/3/6/108	2400.2	52.17
17	700/350/6/4/6/69	850.43	44.19	42	80/40/8/4/8/160	4577.6	36.15
18	800/400/6/4/6/69	834.39	39.19	43	80/40/8/5/8/160	4553.6	28.68
19	800/400/5/4/5/69	790.22	57.10	44	80/40/4/2/4/47	1944.2	18.79
20	800/400/5/3/5/69	800.28	54.15	45	80/40/6/2/4/47	1920.1	18.22
21	700/350/8/4/8/92	1197.7	53.77	46	80/40/6/3/6/96	1179.9	28.93
22	800/400/8/4/8/92	1081.2	49.12	47	80/40/7/3/6/96	1142.6	47.57
23	800/400/8/3/8/92	1224.8	56.61	48	70/35/10/5/10/143	4469.4	9.82
24	800/400/8/3/7/92	1161.6	54.57	49	70/35/10/6/10/143	4341	9.54
25	800/400/8/3/7/92	1146.5	53.73	50	80/40/10/5/10/143	4314.1	51.24
#	Mean					1639.95	37.15

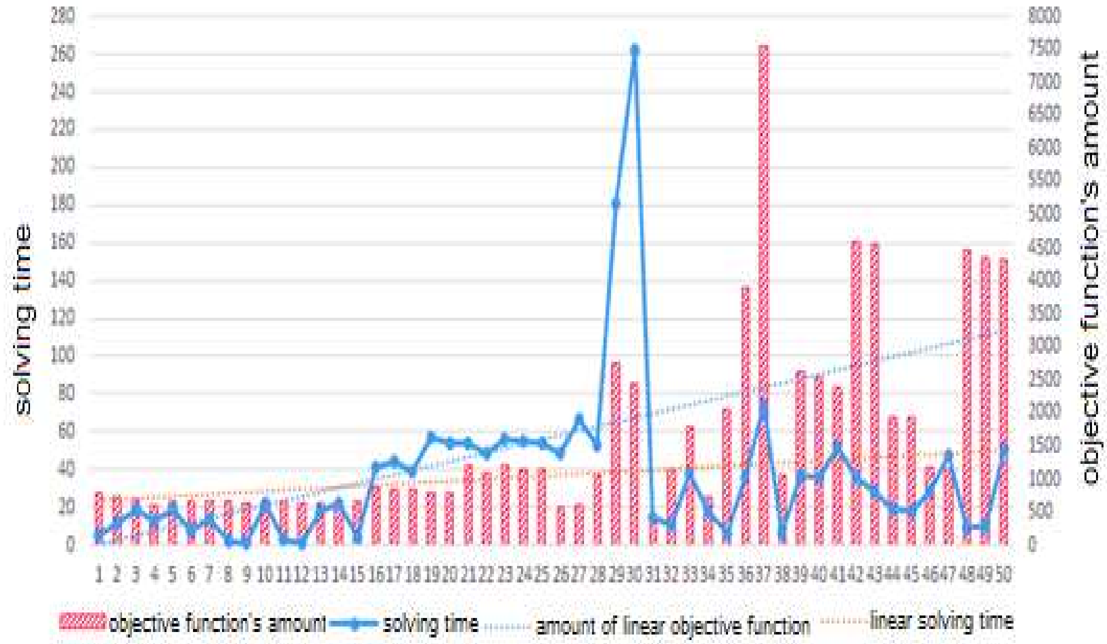

Figure (7): Solving time of the large-scale problems

According to the results obtained from solving the small-scale problems and considering the obtainment of a value equal to zero for the mean errors in the small scale, it can be discerned that the performance of the proposed algorithm is very notable for solving the problems in a very short time and that this algorithm is capable of solving the large-scale problems with a relatively exact approximation. The sample volumes have been solved for 46 to 403 customers. In order to investigate the performance of the proposed algorithm in each sample problem, various numbers of intermediate depots, various numbers of vehicles and different capacity rates have been investigated. Each of the sample problems shows that the change and increase in the aforesaid cases might cause an increase in the other costs, including the human workforce cost that can be consisted of the drivers' salaries and wages, even with the reduction in the solution and/or cost costs. The obtained results indicate the achievement of the optimum number of the vehicles.

- ***Sensitivity Analysis***

In this section, in order to investigate the effect of the application of two-echelon system will be investigated considering the traffic limitations and time dependency assumption.

✓ ***The Effect of Using the Two-Echelon Distribution System on Vehicle Routing Problem***

A problem has been considered with 9 customers that are provided with services by a primary depot and two vehicles. Furthermore, two potential nodes are considered as the intermediate depots. In order to investigate the application of the two-echelon distribution system, the vehicle routing problem is seminally solved for obtaining the problem's objective function. Table (8) gives the specifications related to the studied problem.

Table 8: specifications of customers, primary depot and intermediate depots in the intended problem

	1	2	3	4	5	6	7	8	9	S_1	S_2	Depot
X	21	20	19	22	24	25	23	25	22	21	23	12
Y	80	79	78	80	78	75	80	80	77	54	54	10

After solving the intended problem, table (8) is offered within the format of one-echelon vehicle routing problem wherein the objective function's value has been obtained equal to 426. In the next stage, considering the intermediate depots and using them for providing services to the existent customers as well as adding a vehicle to the main depot with a capacity equal to twice that of the existent vehicles, the problem is transformed into a two-echelon distribution system in which the customers are provided with their required services within a two-day time horizon. Solving the two-echelon vehicle routing problem gives a value equal to 338 for the objective function which is reflective of an improvement by 20.6% for the objective function. The performance of the two-echelon distribution system has been shown in figure (9). As it is observed in figure (8), the reason for reduction in the objective function is the omission of long paths from the main depot to the customers and, instead, providing services to the customers by the near intermediate depots. Thus, it can be concluded that the two-echelon distribution system is a reliable approach for providing services to the customers because its use in lieu of the common one-echelon systems leads to the reduction of the costs and/or total time of providing services to the customers.

- ✓ ***The Effect of Considering Traffic Limitations in Two-Echelon Vehicle Routing Problems***

One of the assumptions considered in the problem posited in this article is the time dependency presumption indicating the traffic limitations; it has been used for imposing traffic limitations in the second echelon of the problem (urban logistics). In this section, the effect of applying traffic limitations is evaluated in the two-echelon vehicle routing problem generated in the previous section.

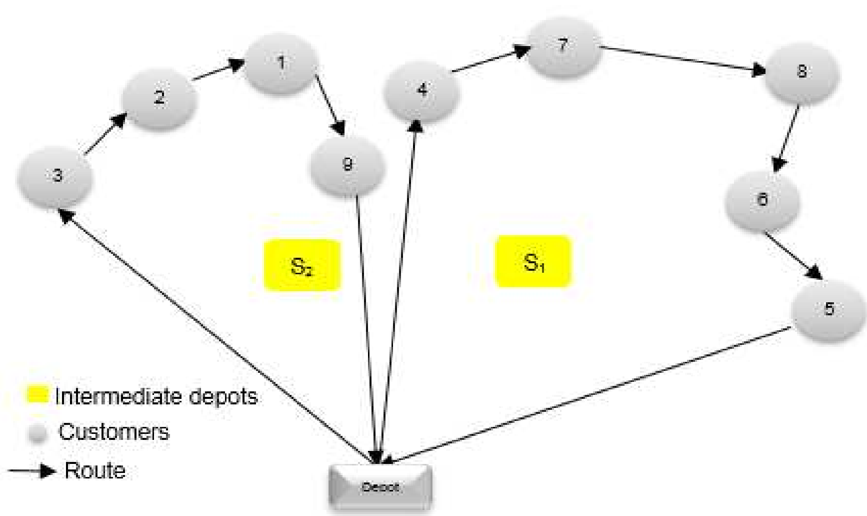

Figure (8): vehicle routing problem in two-echelon system

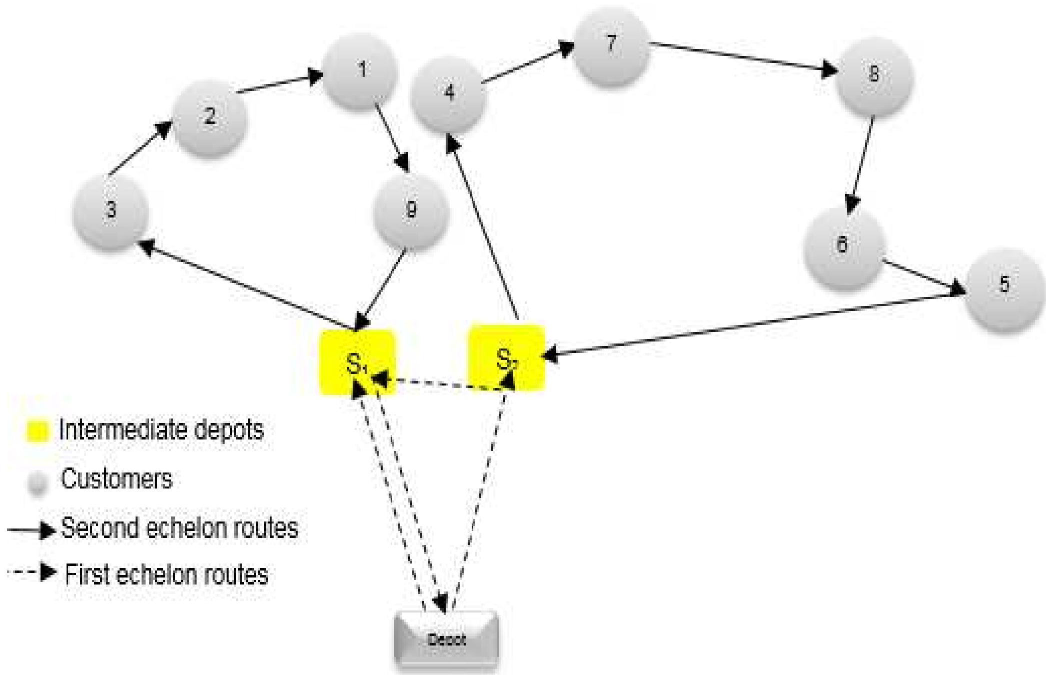

Figure (9): Implementation of two-echelon distribution in vehicle routing problem

The two-echelon problem introduced in figure (9) is once again considered. The amount of the objective function has been obtained in this problem without considering the traffic limitations equal to 338. Based thereon, use is made of the mechanism for adding the time dependency assumption put forth in section (4-2) and the various time spans are considered in the second echelon of the problem. After solving the intended problem in time dependency mode in the second echelon of the distribution system, the amount of the objective function is obtained equal to 383 which is reflective of an increase by 13.3% in the amount of the objective function in comparison to the mode wherein the traffic limitations have not been taken into account. Such a notable change in the routing plan of the vehicles existent in the second echelon is suggestive of the considerable effect of traffic limitations on the urban logistics and transportation system. Figure (10) displays the time-dependent two-echelon vehicle routing problem. As it is seen, changes in the customers and intermediate depots' allocation to the first and second echelons are completely tangible as compared to what has been shown in figure (8) and figure (9) that illustrates a two-echelon problem. Therefore, making routing plans without considering the traffic limitations causes the vehicles not to be able to provide services to the customers on the due date and at the predetermined time.

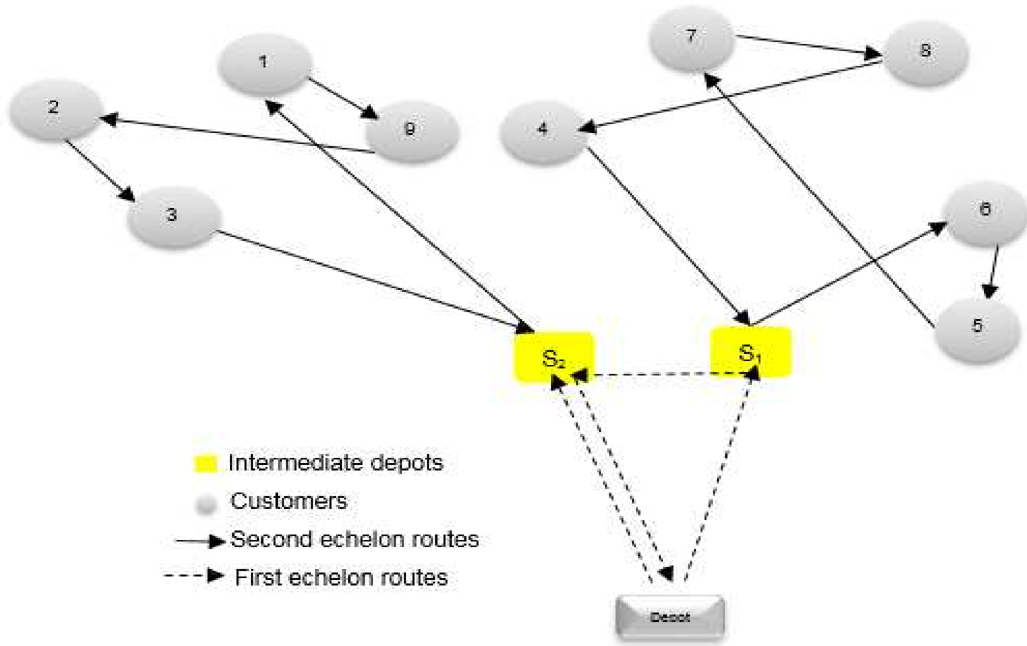

Figure (10): consideration of traffic limitations in two-echelon distribution system (time dependent two-echelon vehicle routing problem)

- ***The Effect of Considering Fuel Consumption and Pollutants' Emission in the Time-Dependent Two-Echelon Vehicle Routing Problem***

Considering the fuel consumption and pollutants' emission by the vehicles existent in the second echelon (urban logistics) and moving in line with minimizing them lead us to another kind of such problems. The assumed problem is considered with this difference that the assumptions and method offered in section (4-3) are utilized for calculating and minimizing the fuel consumption and pollutants' emission by the vehicles used in the second echelon of the problem. Based thereon, after adding the fuel consumption and pollutants' emission to the objective function of the problem and estimating them as costs based on the materials presented in sections (5-5-1) and (5-5-2), it is seen that the value of objective function is increased to 392. Therefore, it can be concluded that making routing plans without considering the traffic limitation, fuel consumption and pollutants' emission presumptions causes the vehicles not to be able to provide services to the customers on the due date and at the predetermined time; additionally, the uncertainty of the amount of fuel consumption of each of the vehicles hence the maximum length of the route that can be travelled results in a less accurate estimation of the pollutants' emission by the vehicles providing load transportation services in the cities and the subsequent negligence of such issues in the macro-scale urban plans.

CONCLUSIONS

Two-echelon vehicle routing problem (2E-VRP) wherein the routing problem of the first echelon specifies the delivery of goods from the main depot to the intermediate depots and the routing problem of the second echelon is based on goods' delivery from the intermediate

depots to the customers with the general objective being the accomplishment of an effective operation with the least cost in the distribution system in such a way that the customers' demands are satisfied on the due date and the sum of the costs or the travel times can be minimized in the transportation network. On the other hand, planning for providing on-time services to the customers necessitates consideration of the essential and applied limitations existent in the real world. Amongst the assumptions and constraints influencing the service-providing by the vehicles existent in the distribution network is the traffic limitations that play an effective role in the transportation planning with its negligence resulting in the inappropriate time and cost estimations of the service-providing process. The bioenvironmental and traffic challenges should be taken into account in the time-dependent vehicle routing (TD-VR) problem. Furthermore, the amount of the pollution emitted by the vehicles depends on the weight and speed of the vehicles as well as an array of the other factors the consideration of which leads to the problem's getting closer to the real world's issues hence the calculation of the greenhouse gases' emission and fuel consumption in the objective function along with consideration of the travel time and other costs. A two-echelon distribution system in an urban environment wherein the traffic constraints influence the vehicles' providing of services on the due date to the customers along with the consideration of ways for reducing the emission of pollutants as well as fuel consumption has led to the formation of a primary problem called time-dependent green two-echelon vehicle routing problem (2E-GTDVRP) in this dissertation. The second echelon of the distribution system considers the traffic limitations as well as the pollutants' emission and fuel consumption of the vehicles in line with their calculation and minimization. Based thereon, considering the proposed problem, the important studies performed on the time-dependent and two-echelon green vehicle routing problem have been investigated herein.
Considering the problem defined in the third section, a mixed integer linear mathematical programming model was offered. In this model, the providing of services to the customers is determined based on a linear piecewise traffic function that also meets FIFO property; use has also been made therein of the important subjects introduced in the literature related to vehicle routing parallel to the calculation of the pollutants' emission and fuel consumption so that they can be also represented within the format of the present study's proposed two-echelon distribution system.
Considering the NP-Hard nature of the problem, a new algorithm based on metaheuristic VNS algorithm was proposed for solving it. The proposed VNS algorithm applies several approaches in its local search and shaking stage that is per se comprised of numerous neighborhood structures with unique properties. In order to consider the time-dependency assumption in the second echelon, a traffic pattern was designed including five time spans and such parameters as the number of customers, number of the vehicles in the second echelon and the mean traffic time between the customers. Based on the designed traffic patter, five different time spans were obtained within the duration of a day for every arch existing in the distribution network. The computation of the cost of fuel consumption and pollutants' emission in the distribution space was carried out through using the parameters offered by Demir et al. (2012). In order to verify and validate the performance of the proposed algorithm in the small scale, the results of the mathematical model's solving by CPLEX optimizer were compared with those obtained from running VNS algorithm. The results obtained from solving the problems indicated zero mean

error percentage for the mathematical model and VNS algorithm and this is reflective of the notable performance of this algorithm. In the next approach, the proposed algorithm was used for solving large-scale problems. In order to generate large-scale problems, use was made of the sample large-scale problems offered by Cordeau et al. (1997) and a given mechanism for rendering consistent this type of sample problems with the sample problems offered herein. The mean time of VNS algorithm's solving of the problems was 37.15. It was made clear according to the error percentage rates and the times of solving the sample problems that VNS algorithm can give reliable results and it can be used for solving the 2E-GTDVRPs.

The future studies can use the other assumptions of vehicle routing problem for time-dependent green two-echelon vehicle routing problems. Amongst the time window assumptions, uncertainty, pickup and delivery, fleet size as well as mixed fleet that can render distinct the vehicles in terms of load capacity and purchase price should be taken into consideration.

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