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# A new Bi-objective model for a Two-echelon Capacitated Vehicle Routing Problem for Perishable Products with the Environmental Factor

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*A B S T R A C T*

In multi-echelon distribution strategy freight is delivered to customers via intermediate depots. Rather than using direct shipments, this strategy is an increasingly popular one in urban logistics. This is primarily to alleviate the environmental (e.g., energy usage and congestion) and social (e.g., traffic-related air pollution, accidents and noise) consequences of logistics operations. This paper represents a two-echelon capacitated vehicle routing problem (2-ECVRP) in which customers' satisfaction and environmental issues are considered for perishable goods delivery for the first time. The paper proposes a novel bi-objective model that minimizes: 1) total customers waiting time, and 2) total travel cost. A restriction on maximum allowable carbon dioxide ($CO_2$) emissions from transport in each route is considered as environmental issue in the problem. The proposed model is solved by simple additive weighting (SAW) method. Finally, the proposed model is applied to a real world problem in a supermarket chain. The results achieved by GAMS optimization software confirm the validity and high performance of the model in respect to the importance of the each objective function. Furthermore, the sensitivity analysis performed on the model reveals that less restrictive policies on carbon emissions lead to more total emissions but less total travel cost and customers waiting time.

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## 1. INTRODUCTION

The two-echelon capacitated vehicle routing problem (2E-CVRP) is a distribution system where intermediate capacitated depots, known as satellites, are placed between a supplier and final customers [1]. Direct shipments from suppliers to customers as in Vehicle Routing Problems (VRPs) [2, 3], are not allowed in this setting. Freight must first be sent from a depot to a satellite and thence to the destination. Soysal et al. [4] indicated that the 2E-CVRP has two types of vehicle routes: (i) first echelon routes that start and end at the depot visiting the satellites, and (ii) second echelon routes that start and end at the same satellite visiting the customers (see Figure 1). Satellites usually have limited capacities and are allowed to be serviced by more than one first echelon route. In the second echelon, however, each customer is visited exactly once by a route. A homogeneous vehicle fleet is used at each echelon. Second echelon vehicles are smaller in capacity than the first echelon ones. A handling cost proportional to loading or unloading quantity is incurred for the satellites due to the unloading of first echelon vehicles and loading of second echelon vehicles.

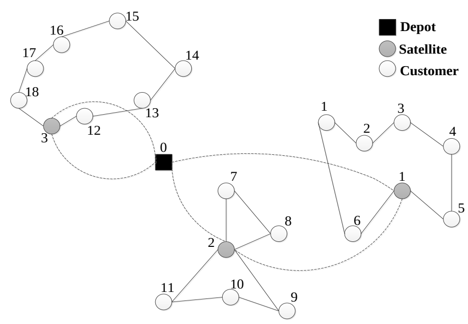


**Figure 1.** A solution for 2E-CVRP

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Satellites do not perform any other activity; for example significant physical installations and warehousing are not required. The objective of the basic 2E-CVRP is to determine two sets of first and second echelon routes that minimize total routing and handling cost. The basic 2E-CVRP assumes that distribution costs and travel times between nodes are known in advance and are constant [1, 5]. The 2E-CVRP is an NP-Hard problem due to the fact that it is a special case of the VRP. One of the common points of all the above studies is the assumption of constant cost or travel times between the nodes. Our proposed model has this assumption, too. The two echelon formulation in this paper is adopted from [5]. The interested reader is referred to the review by [6] on the two echelon vehicle routing problem (2-EVRP).

It is known that environmental issues in distribution systems are very important. The road transport sector accounts for a large percentage of Greenhouse Gas (GHG) and in particular $CO_2$ emissions. The pollution from the emissions has direct or indirect hazardous effects on humans and on the whole eco-system. The Pollution Routing Problem (PRP) aims at choosing a vehicle dispatching scheme with less pollution, in particular reduction of carbon emissions [7]. The interested reader is referred to the reviews by [7-9] on the green routing problem. Sadegheih et al. [10] considered carbon emission costs in total cost of the supply chain. Their optimisation model has the ability to minimise the total costs and provides the best solutions, which are both cost-effective and environmental-friendly. Khanghah and Jafari [11] put an environmental restriction on transport activities. This restriction caused total carbon emissions from the transport network not to be more than the maximum allowed in each period. Inspired from the last paper, environmental restriction for each level routes is considered in this contribution.

In distribution systems, another important issue is customers' satisfaction, especially for food products. In general, food products are characterized as perishable items. The quality of perishable food products decays rapidly during the delivery process. Their freshness is significantly affected by the time duration and environment temperature during the delivery. Hence, it is important that perishable foods must be delivered within allowable delivery time windows, or a penalty shall be incurred for late arrivals [12]. Duk song and Dae ko [13] developed a nonlinear mathematical model with the objective of maximizing the total level of the customer satisfaction which is dependent on the freshness of delivered food products and assumed that each vehicle has a maximum allowable delivery time. This paper considers a maximum allowable delivery time for perishable goods that they should be delivered within that. The end customer's satisfaction has a reverse relation with his waiting time. This means that the less waiting time they have, the more satisfaction they achieve specially for perishable products. Francisco et al. [14] considered a routing problem with multiple use of a single vehicle and service time in demand points (with the aim of minimizing the sum of clients waiting time to receive service). So, in order to achieving more customers' satisfaction we minimize total waiting time in our research.

Our brief review about customer satisfaction shows that there is not any research which has taken customer satisfaction factor into account for two-echelon capacitated vehicle routing problem. This paper represents a novel bi-objective two-echelon capacitated vehicle routing problem with environmental consideration for perishable goods delivery. The objectives are: 1) minimization of travel costs in both echelons and 2) minimization of customers waiting time in second echelon. The aim is maximizing customer satisfaction which is inversely proportional to customers waiting time. The developed mixed integer programming (MIP) model simultaneously selects the routes with less environmental impacts of $CO_2$ emissions by considering an upper bound for each level routes emissions. Finally, the proposed model is implemented in a supermarket chain. Results by GAMS software show that we can obtain a good solution with respect to the importance of each objective function. Furthermore, the sensitivity analysis performed on the model reveals that less restrictive policies on carbon emissions lead to more total emissions, but less total travel cost and customers waiting time.

The rest of this paper is organized as follows. Section 2 describes the problem. In Section 3, the problem is formulated as a mathematical model with two objectives. The solving method, case study and the results of sensitivity analysis are described in Section 4. Conclusions and some directions for future research are presented in Section 5.

## 2. PROBLEM DEFINITION

The present paper proposes a novel bi-objective two-echelon capacitated VRP. The goal is to simultaneously minimize the total travel cost and the customers waiting time for perishable food delivery. The customer waiting time is considered which is inversely proportional to customer satisfaction, especially for perishable goods. If the customer has less waiting time, it means that the food has passed less time in truck; so, it is fresher and more customer satisfaction would be achieved. Beside these two objectives, model selects the routes with emissions less than the maximum allowable emissions for a route. This maximum amount is determined by distributer with respect to the environmental issues importance for him.

The two echelon base model and environmental restriction on maximum allowable emissions are adopted from [1] and [11], respectively. The restriction on maximum allowable delivery time for perishable goods is inspired from [13]. Finally, we modify the model by adding the minimization of total customer waiting time.

To formulate the mathematical model, the assumptions are as follows:

1. Vehicles in the same level have the same capacity and speed.
2. Fixed costs of the vehicles are not considered, since they are available in fixed numbers.
3. Each satellite receives its freight from one or more 1st level vehicles, but each customer receives its freight from one of the 2nd level vehicles.
4. For simplicity, the customers waiting time is recorded from the satellites in the second level.

The satellites are capacitated and each satellite is supposed to have its own capacity, usually expressed in terms of maximum number of 2nd-level routes starting from the satellite.

## 3. MATHEMATICAL MODEL

### 3. 1. Sets

| | |
|---|---|
| $V_O$ | Depot |
| $V_S$ | Set of satellites ( $k = 1,2,...,V_S$ ) |
| $V_C$ | Set of customers ( $j = 1,2,..V_C$ ) |

### 3. 2. Parameters

| | |
|---|---|
| $n_s$ | Number of satellites |
| $n_c$ | Number of customers |
| $m_1$ | Number of the 1st-level vehicles |
| $m_2$ | Number of the 2nd-level vehicles |
| $m_{s_k}$ | Maximum number of 2nd-level routes starting from satellite k |
| $K^1$ | Capacity of the vehicles for the 1st level |
| $K^2$ | Capacity of the vehicles for the 2nd level |
| $d_i$ | Demand required by customer i |
| $C_{ij}$ | Cost of the arc (i, j) |
| $S_k$ | Cost for loading/unloading operations of a unit of freight in satellite k |
| $GH_1$ | Carbon emissions in each distance unit for first level vehicle (kg/km) |
| $GH_2$ | Carbon emissions in each distance unit for second level vehicle (kg/km) |
| $\max GH_1$ | Maximum allowable Carbon emissions in 1st level routes (kg) |
| $\max GH_2$ | Maximum allowable Carbon emissions for each satellite routes in second level (kg) |
| $\upsilon_1$ | Speed of 1st level vehicles (km/h) |
| $\upsilon_2$ | Speed of 2nd level vehicles (km/h) |
| $T_{\max}$ | Maximum allowable travel time for each perishable food |
| $st_j$ | The service time in node j |

### 3. 3. Decision Variables

| | |
|---|---|
| $Q^1_{ij}$ | Flow passing through the 1st-level arc (i, j) |
| $Q^2_{ij}$ | Flow passing through the 2st-level arc (i, j) and coming from satellite k |
| $x_{ij}$ | Number of 1st-level vehicles using the 1st-level arc (i, j) |
| $y^k_{ij}$ | Boolean variable equal to 1 if the 2nd-level arc (i, j) is used by the 2nd-level routing starting from satellite k |
| $z_{kj}$ | Boolean variable set to 1 if the customer j is served by the satellite k |
| $y_{ij}$ | Boolean variable equal to 1 if the 1st-level arc (i, j) is used |

### 3. 4. Mathematical Formulation

$$\min Z_1 = \sum_{i,j \in V_O \cup V_S, i\neq j} C_{ij} x_{ij} + \sum_{k \in V_S} \sum_{i,j \in V_S \cup V_C, i\neq j} C_{ij} y^k_{ij} + \sum_{k \in V_S} S_k D_k \tag{1}$$

$$\min Z_2 = \sum_{l \in V_C} \Big( \sum_{k \in V_S} ts_k z_{kl} + \sum_{k \in V_S} \sum_{i} \sum_{j=1, i\neq j}^{l-1} \Big(\frac{C_{ij}}{\upsilon_2} + \mathrm{ts}_j\Big) y^k_{ij} + \sum_{k \in V_S} \sum_{i} \sum_{j=l+1, i\neq j}^{n_c} \Big(\frac{C_{ij}}{\upsilon_2} + \mathrm{ts}_j\Big) y^k_{ij} + \sum_{k \in V_S} \sum_{j} \frac{C_{jl}}{\upsilon_2} y^k_{jl} \Big) \quad i,j \in V_S \cup V_C, l \in V_C \tag{2}$$

$$D_k = \sum_{j \in V_C} d_j z_{kj} \qquad \forall k \in V_S \tag{3}$$

$$\sum_{i \in V_S} x_{oi} \le m_1 \tag{4}$$

$$\sum_{j \in V_O \cup V_S, k\neq j} x_{jk} = \sum_{j \in V_O \cup V_S, i\neq k} x_{ki} \qquad \forall k \in V_S \cup V_O \tag{5}$$

$$\sum_{k \in V_S} \sum_{j \in V_C} y^k_{kj} \le m_2 \tag{6}$$

$$\sum_{j \in V_C} y^k_{kj} \le m_{s_k} \qquad \forall k \in V_S \tag{7}$$

$$\sum_{i \in V_O \cup V_S, i\neq j} y_{ij} = \sum_{i \in V_O \cup V_S, i\neq j} y_{ji} \qquad \forall j \in V_O \cup V_S \tag{8}$$

$$\sum_{j \in V_C} y^k_{kj} = \sum_{j \in V_C} y^k_{jk} \qquad \forall k \in V_S \tag{9}$$

$$\sum_{i \in V_O \cup V_S, i\neq j} Q^1_{ij} - \sum_{i \in V_O \cup V_S, i\neq j} Q^1_{ji} = \begin{cases} D_j & \text{j is not the depot} \\ \sum_{i \in V_C} -d_i & \text{otherwise} \end{cases} \qquad \forall j \in V_O \cup V_S \tag{10}$$

$$Q_{ij}^{1} \le K^{1} x_{ij} \qquad \forall i, j \in V_O \cup V_S, i \ne j \qquad (11)$$

$$\sum_{i \in V_S \cup V_C, i \ne j} Q_{ijk}^{2} - \sum_{i \in V_S \cup V_C, i \ne j} Q_{jik}^{2} = \begin{cases} z_{kj} d_j & \text{j is not a satellite} \\ -D_j & \text{otherwise} \end{cases} \qquad \forall j \in V_S \cup V_C \qquad (12)$$

$$Q_{ijk}^{2} \le K^{2} y_{ij}^{k} \qquad \forall i, j \in V_S \cup V_C, i \ne j, k \in V_S \qquad (13)$$

$$\sum_{i \in V_S} Q_{iV_O}^{1} = 0 \qquad (14)$$

$$\sum_{j \in V_C} Q_{jkk}^{2} = 0 \qquad \forall k \in V_S \qquad (15)$$

$$\sum_{i \in V_S \cup V_C} y_{ij}^{k} = z_{kj} \qquad \forall j \in V_C, \forall k \in V_S \qquad (16)$$

$$\sum_{i \in V_S \cup V_C} y_{ji}^{k} = z_{kj} \qquad \forall j \in V_C, \forall k \in V_S \qquad (17)$$

$$\sum_{i \in V_S} z_{ij} = 1 \qquad \forall j \in V_C \qquad (18)$$

$$y_{kj}^{k} \le \sum_{l \in V_O \cup V_S} x_{kl} \qquad \forall k \in V_S, \forall j \in V_C \qquad (19)$$

$$x_{ij} \le M \times y_{ij} \qquad \forall i, j \in V_O \cup V_S, i \ne j \qquad (20)$$

$$x_{ij} \ge y_{ij} \qquad \forall i, j \in V_O \cup V_S, i \ne j \qquad (21)$$

$$\sum_{i, j \in V_O \cup V_S, i \ne j} GH_1 C_{ij} y_{ij} \le MaxGH_1 \qquad (22)$$

$$\sum_{i, j \in V_S \cup V_C, i \ne j} GH_2 C_{ij} y_{ij}^{k} \le MaxGH_2 \qquad \forall k \in V_S \qquad (23)$$

$$\sum_{k \in V_S} ts_k z_{kl} + \sum_{k \in V_S} \sum_{i} \sum_{j=1, i \ne j}^{l-1} \left(\frac{C_{ij}}{\upsilon_2} + ts_j\right) y_{ij}^{k} + \sum_{k \in V_S} \sum_{i} \sum_{j=l+1, i \ne j}^{n_c} \left(\frac{C_{ij}}{\upsilon_2} + ts_j\right) y_{ij}^{k} + \sum_{k \in V_S} \sum_{j} \frac{C_{jl}}{\upsilon_2} y_{jl}^{k} \le T_{\max} \qquad i,j \in V_S \cup V_C, \forall l \in V_C \qquad (24)$$

$$y_{ij}^{k} \in \{0,1\} \qquad i,j \in V_S \cup V_C, k \in V_S \qquad (25)$$

$$y_{ij} \in \{0,1\} \qquad i,j \in V_S \cup V_O \qquad (26)$$

$$z_{kj} \in \{0,1\} \qquad k \in V_S, j \in V_C \qquad (27)$$

$$x_{ij} \in Z^{+} \qquad i,j \in V_S \cup V_O \qquad (28)$$

$$Q_{ij}^{1} \ge 0 \qquad i,j \in V_S \cup V_O \qquad (29)$$

$$Q_{ijk}^{2} \ge 0 \qquad i,j \in V_S \cup V_C, k \in V_S \qquad (30)$$

The objective function (1) minimizes the sum of the traveling and handling operations costs. The second objective function (2) minimizes the total customers waiting time. Constraints (3) represent the freight passing through each satellite k. The number of routes in each level must not exceed the number of vehicles for that level, as imposed by constraints (4) and (6). Constraints (5) ensure that when $k$ is a depot (i.e. $k = v_o$), all the routes in the first level commence and end at that depot, and when it is a satellite, the numbers of vehicles entering and leaving that satellite are equal. The limit on the satellite capacity is satisfied by constraints (7). Based on constraint sets (8), the number of input paths in one first level node will be equal with the number of that node's output paths. They limit the maximum number of 2nd-level routes starting from every satellite (notice that the constraints also limit the freight capacity of the satellites at the same time). Constraints (9) force each 2nd-level route to begin and end to one satellite and the balance of vehicles entering and leaving each customer. Constraints (10) and (12) indicate that the flow balance on each node is equal to the demand of this node, except for the depot, where the exit flow is equal to the total demand of the customers, and for the satellites at the 2nd-level, where the flow is equal to the demand (unknown) assigned to the satellites. In fact, each node receives an amount of flow equal to its demand to prevent the presence of subtours.

The capacity constraints are formulated in (11) and (13), for the 1st-level and the 2nd-level, respectively. Constraints (14) and (15) do not allow residual flows in the routes, making the returning flow of each route to the depot (1st-level) and to each satellite (2nd-level) equal to 0. Constraint (18) assigns each customer to one and only one satellite, while constraints (16) and (17) indicate that there is only one 2nd-level route passing through each customer. At the same time, they impose the condition that a 2nd-level route departs from a satellite k to deliver freight to a customer if and only if the customer's freight is assigned to the satellite itself. Constraints (19) allow a 2nd-level route to start from a satellite k only if a 1st-level route has served it. The relation between $x_{ij}$ and $y_{ij}$ is peresented by Equations (20) and (21). They indicate that if some first level vehicles are used in a path ($x_{ij}$>0), that path should be selected ($y_{ij}$=1) and should not be selected otherwise. The maximum allowable emissions constraints are formulated in (22) and (23), for the 1st-level and the 2nd-level routes, respectively. Constraints (24) guarantee maximum allowable travel time for perishable good. Finally, Equations (25)-(30) are also sign limitations for model's variables.

## 4. PROBLEM SOLUTION

Considering the small size of proposed model, the suggested integer model was solved by GAMS software and its optimal answer was obtained. For solving proposed bi-objective model, Simple Additive Weighting (SAW) method has been used. SAW method is a simple method for forming a combining fitness function. The purpose of SAW method is minimizing the total weighted existing objective functions. The objectives weights are determined by decision maker. Therefore, the overall function will be as follows:

$$Z = \alpha \times Z_1 + \beta \times Z_2 \tag{31}$$

So that $\alpha + \beta = 1$

$z$: The overall objective function, sum of weighted objectives.

$z_1$: The first objective function which minimizes the total travel costs.

$z_2$: The second objective function which minimizes the total customers waiting time.

### 4. 1. Case Study

This section presents an implementation of the proposed model on the distribution operations of a supermarket chain operating in the Netherlands. The data for this case study is taken from[4] which is a real case. The underlying transportation network includes one depot, two satellites and 16 supermarket branches (customers). The depot is located in Zaandam. The customers are located in the city center of Utrecht, and satellites (S1-S2) are located at the boundary of the city. There exist two types of vehicles. Two large vehicles are used for the deliveries between the depot and the satellites, each with a capacity of 20 tonnes. Four small vehicles are used for the deliveries between the satellites and the customers, each with a capacity of 10 tonnes. Vehicles travel at a fixed speed of 80km/h between the depot and the satellites. Delivery starts simultaneously in both satellites. In the second level, vehicles travel at an average speed of 35km/h. The randomly generated Demand (kg) for the base case is, (2000, 4500, 1500, 3500, 1500, 2500, 1000, 3000, 1500, 3000, 4000, 1000, 500, 1000, 500 and 2000) for customers C1–C16, respectively.

Distances between nodes are calculated using Google Maps. Handling cost at satellites one and two are 3 and 2 €/tonne, respectively. Service times at customer nodes are assumed to be related with the amount of demands. $st_j = (d_j/1000) + 15$, base on minutes. Both satellites have the same capacity of 2 vehicles and the same service time of 45 minutes. It is assumed that each first level and second level vehicle has a 0.9 and 0.5 kg/km $CO_2$ emissions, respectively. Maximum allowable Carbon emissions in 1st level routes and each second level route is considered 110 and 18.5 kg, respectively.

Along with changing allocated weight to each objective function, the optimal value of weighted objective function and the optimal routes of each level are shown in Table1. In this Table, "1" is the depot, "2 and 3" are the satellites and "4-19" the customers. According to the results shown in Table 1 the rows (1)-(3) and (4)-(7) have the same optimal solution.

It can be observed that by increasing α value, i.e. the importance factor of total travel cost objective function, the amount of $Z_1^*$ is reduced. Also, by decreasing β value, i.e. the importance of total customers waiting time objective function, $Z_2^*$ is increased. Ergo, based on the degree of importance of each objective over the other, different Pareto solutions can be achieved. An optimal solution for the case (α,β)=(0.5,0.5) is schematically shown in Figure 2.

Figures 3-a and 3-b show the amount of $Z_1^*$ and $Z_2^*$ for different cases of Table 1, respectively. In Figure 3-a, it can be clearly observed that by increasing α and decreasing β, the amount of first objective function $Z_1^*$ is reduced. When α is 0.9, the first objective is most important and will receive the least amount. Figure 4-b shows that by decreasing β and increasing α, the amount of second objective function $Z_2^*$ is increased.

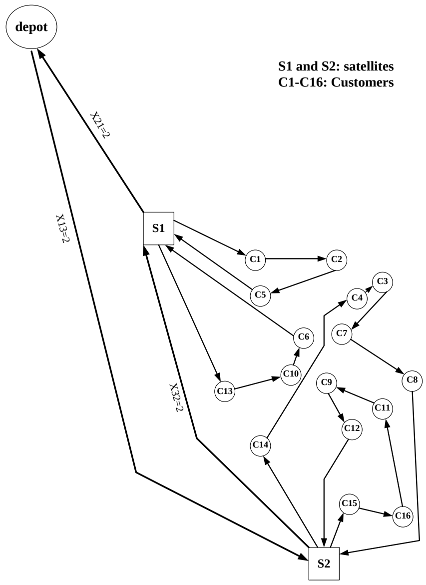



**Figure 2.** An optimal solution for the case (α,β)= (0.5,0.5)

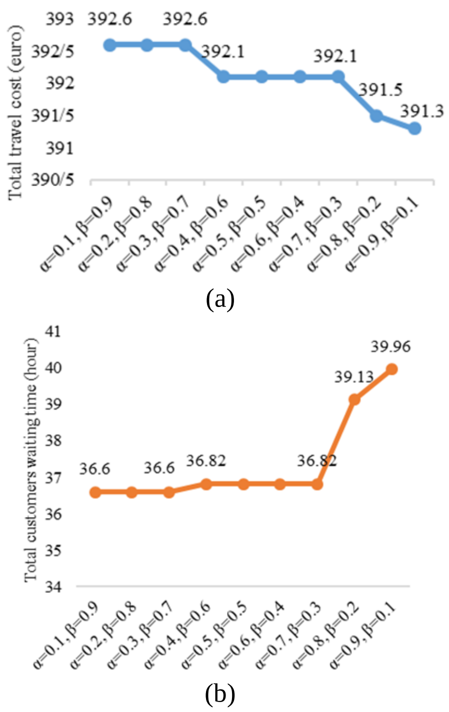



**Figure 3.** (a) Total travel cost $Z_1^*$ for different values of $(\alpha,\beta)$, (b) Total customers waiting time $Z_2^*$ for different values of $(\alpha,\beta)$

When β is 0.9, the second objective is most important and will receive the least amount.

**4. 2. Analysis and Discussion** This section presents sensitivity analysis for the model with respect to changes in the maximum allowable $co_2$ emissions for first and second level routes. We consider three values of $(\alpha,\beta)$, equal to (0.1, 0.9), (0.5, 0.5) and (0.9, 0.1). To show the effect of change in the maximum allowable $co_2$ emissions which is the environmental consideration of the problem, two scenarios are analysed as follows.

**(i)** **Scenario G1**: maximum allowable emissions for first level routes and each satellite routes in second level is taken as 110 and 18.5 kg, respectively.

In fact, the case study conditions are considered as the first scenario. The results are shown in Table 2.

**(ii)** **Scenario G1**: maximum allowable emissions for first level routes and each satellite routes in second level is taken as 110 and 18.5 kg, respectively.

Figures 4-a and 4-b show the objective values achieved under scenarios G1 and G2, respectively. As it is shown in Figure 4-a, the value in scenario G1 is more than that in scenario G2 in different cases. however, compared with scenario G1, the total travel cost has improved due to the change in maximum allowable emissions.

It can be concluded that tighter environmental restrictions causes more travel cost. It is obvious in each scenario by increasing α, $Z_1$* is reduced because its importance grows. Figure 4-b shows that in Scenario G1 $Z_2$* is equalor more compared to scenario G2 in different cases. So, it can be concluded that tighter environmental restriction causes more customers waiting time.

**TABLE 1.** Optimal value of weighted objective function

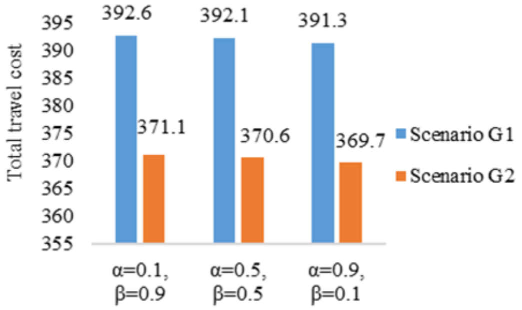
| row | $\alpha$ | $\beta$ | Final tour | $Z^*$ | $Z_1^*$ | $Z_2^*$ |
|---|---|---|---|---|---|---|
| 1 | 0.1 | 0.9 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,8,5,4),(2,16,13,9),(3,17,7,6,10,11),(3,18,19,14,12,15) | 72.20 | 392.6 | 36.60 |
| 2 | 0.2 | 0.8 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,8,5,4),(2,16,13,9),(3,17,7,6,10,11),(3,18,19,14,12,15) | 107.80 | 392.6 | 36.60 |
| 3 | 0.3 | 0.7 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,8,5,4),(2,16,13,9),(3,17,7,6,10,11),(3,18,19,14,12,15) | 143.40 | 392.6 | 36.60 |
| 4 | 0.4 | 0.6 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,4,5,8),(2,16,13,9),(3,17,7,6,10,11),(3,18,19,14,12,15) | 178.93 | 392.1 | 36.82 |
| 5 | 0.5 | 0.5 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,4,5,8),(2,16,13,9),(3,17,7,6,10,11),(3,18,19,14,12,15) | 214.46 | 392.1 | 36.82 |
| 6 | 0.6 | 0.4 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,4,5,8),(2,16,13,9),(3,17,7,6,10,11),(3,18,19,14,12,15) | 249.98 | 392.1 | 36.82 |
| 7 | 0.7 | 0.3 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,4,5,8),(2,16,13,9),(3,17,7,6,10,11),(3,18,19,14,12,15) | 285.51 | 392.1 | 36.82 |
| 8 | 0.8 | 0.2 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,4,8),(2,7,6,5),(3,16,13,9,10,11),(3,18,19,15,14,12,17) | 321.02 | 391.5 | 39.13 |
| 9 | 0.9 | 0.1 | 1st: (1,3,2) and (1,3,2)<br>2nd:(2,4,8),(2,7,6,5),(3,14,12, 13,16,17),(3,18,19,9,10,11,15) | 356.16 | 391.3 | 39.96 |

As it is seen, in each scenario by decreasing β, $Z_2$* is increased. The amount of emissions for each scenario and for each level are shown in Table 3. ent1 shows first level emissions. The second level emissions originate from satellite S1 and S2 i.e. nodes 2 and 3. Each satellite has some routes, and in general, has total emissions (Total ent2). In column "total emissions", the amount of total emissions that is sum of ent1 and total ent2 is shown. The results for total emissions under different scenarios are shown in Figure 5. It can be seen that the amount of emissions in scenario G2 is more compared to scenario G1. This is due to looser environmental restriction in this scenario for first and second level routes emissions .

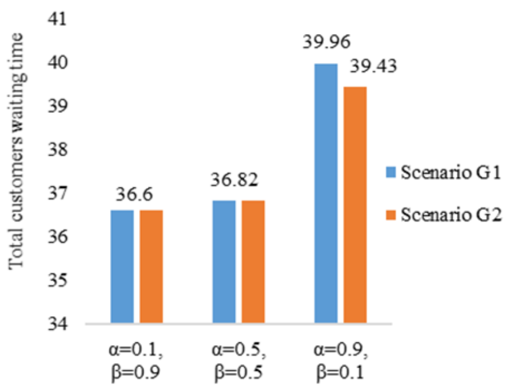
**TABLE 2.** Final results of second scenario

$\max GH_1 = 220 \quad \max GH_2 = 20$

| α | β | $Z^*$ | $Z_1^*$ | $Z_2^*$ |
|---|---|---|---|---|
| 0.1 | 0.9 | 70.05 | 371.1 | 36.60 |
| 0.5 | 0.5 | 203.71 | 370.6 | 36.82 |
| 0.9 | 0.1 | 336.67 | 369.7 | 39.43 |




(a)




(b)

**Figure 4.** The amount of $Z_1^*$ and $Z_2^*$ for different values of $(\alpha, \beta)$ in two scenarios, (a) Total travel cost $Z_1^*$ for different values of $(\alpha, \beta)$ in two scenarios, (b) Total customers waiting time $Z_2^*$ for different values of $(\alpha, \beta)$ in two scenarios

**TABLE 3.** The amount of emissions

| Scenario | α | β | ent1 | ent2(k) | Total ent2 | Total emissions |
|---|---|---|---|---|---|---|
| G1 | 0.1 | 0.9 | 107.91 | S1:18.3 S2:18.1 | 36.4 | 144.31 |
| | 0.5 | 0.5 | 107.91 | S1:18.05 S2:18.1 | 36.15 | 144.06 |
| | 0.9 | 0.1 | 107.91 | S1:18.1 S2:18.15 | 36.25 | 144.16 |
| G2 | 0.1 | 0.9 | 196.47 | S1:18.3 S2:18.1 | 36.4 | 232.87 |
| | 0.5 | 0.5 | 196.47 | S1:18.05 S2:18.1 | 36.15 | 232.62 |
| | 0.9 | 0.1 | 196.47 | S1:17.1 S2:18.85 | 35.95 | 232.42 |

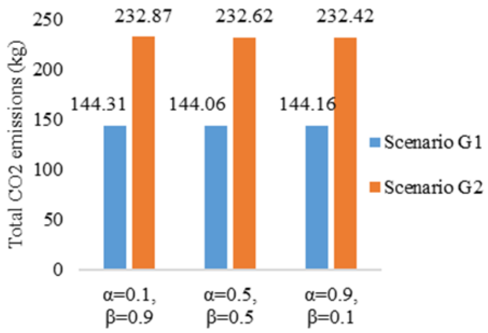



**Figure 5.** Total emissions for different values of $(\alpha, \beta)$ in two scenarios

In general, by considering two different scenarios with respect to changes in the maximum allowable emissions for first and second level routes, these results are obtained. By tightening the maximum allowable emissions restriction, the amount of total travel cost and total customers waiting time will worsen, but, the amount of total emissions will improve. So, there is a conflict between environmental considerations and our two objective functions.

Depending on the importance of each goal, decision makers must adopt optimal decision.

## 5. CONCLUSION AND FUTURE RESEARCH

This paper proposed a novel bi-objective two-echelon capacitated vehicle routing problem with environmental consideration for perishable goods delivery. The objectives are minimization of total travel cost and minimization of customers waiting time in the second echelon. The proposed mixed integer programming model, also simultaneously maximizes customer satisfaction which is inversely proportional with customers waiting time. Environmental consideration is incurred by restricting the allowable $CO_2$ emissions on each route. The proposed model was finally applied to a supermarket chain problem. The results emphasize the good performance of the model in respect to each objective function. Furthermore, the sensitivity analysis performed on the model reveals that less restrictive policies on carbon emissions lead to more total emissions but less total travel cost and customers waiting time.

For future studies, heuristic methods can be used for solving the problem in large sizes. This model is appropriate for instances with at most two satellites. Moreover, by considering each route traffic load and using different vehicle speeds between nodes (instead of their distance), the model can be promoted for minimizing the time of vehicle servicing. Another extension could be the inclusion of more real-life constraints such as uncertainty in demands. Our study aims at minimizing total customers waiting time in second level only, while it can be considered for both levels. Considering other constraints such as time windows, can also be effective in model outputs being more realistic.

## 6. REFERENCES


1. Gonzalez-Feliu, J., Perboli, G., Tadei, R. and Vigo, D., "The two-echelon capacitated vehicle routing problem", DEIS OR.INGCE 2007/2(R), Bologna, Italy (2008).
2. Jabali, O., Woensel, T. and de Kok, A., "Analysis of travel times and $CO_2$ emissions in time-dependent vehicle routing", ***Production and Operations Management***, Vol. 21, No. 6, (2012), 1060-1074.
3. Kritikos, M.N. and Ioannou, G., "The heterogeneous fleet vehicle routing problem with overloads and time windows", ***International Journal of Production Economics***, Vol. 144, No. 1, (2013), 68-75.
4. Soysal, M., Bloemhof-Ruwaard, J.M. and Bektaş, T., "The time-dependent two-echelon capacitated vehicle routing problem with environmental considerations", ***International Journal of Production Economics***, Vol. 164, No.12, (2015), 366-378.
5. Perboli, G., Tadei, R. and Vigo, D., "The two-echelon capacitated vehicle routing problem: Models and math-based heuristics", ***Transportation Science***, Vol. 45, No. 3, (2011), 364-380.
6. Cuda, R., Guastaroba, G. and Speranza, M.G., "A survey on two-echelon routing problems", ***Computers & Operations Research***, Vol. 55, No.2, (2015), 185-199.
7. Lin, C., Choy, K.L., Ho, G.T., Chung, S. and Lam, H., "Survey of green vehicle routing problem: Past and future trends", ***Expert Systems with Applications***, Vol. 41, No. 4, (2014), 1118-1138.
8. Touati, N. and Jost, V., "On green routing and scheduling problem", ***arXiv preprint arXiv:1203.1604***, (2012).
9. Toro, O., Eliana, M., Escobar, Z., Antonio, H. and Granada, E., "Literature review on the vehicle routing problem in the green transportation context", ***Luna Azul***, Vol., No. 42, (2016), 362-387.
10. Sadegheih, A., Drake, P., Li, D. and Sribenjachot, S., "Global supply chain management under the carbon emission trading program using mixed integer programming and genetic algorithm", ***International Journal of Engineering, Transactions B: Applications***, Vol. 24, No. 1, (2011), 37-53.
11. Khanghah, P.A.a.J., A, "Modeling integrated production-inventory routing problem in a green supply chain", University of science and culture, industrial engineering, master, (2016),
12. Chen, H.-K., Hsueh, C.-F. and Chang, M.-S., "Production scheduling and vehicle routing with time windows for perishable food products", ***Computers & Operations Research***, Vol. 36, No. 7, (2009), 2311-2319.
13. Song, B.D. and Ko, Y.D., "A vehicle routing problem of both refrigerated-and general-type vehicles for perishable food products delivery", ***Journal of Food Engineering***, Vol. 169, No.3, (2016), 61-71.
14. Angel-Bello, F., Martínez-Salazar, I. and Alvarez, A., "Minimizing waiting times in a route design problem with multiple use of a single vehicle", ***Electronic Notes in Discrete Mathematics***, Vol. 41, No.8, (2013), 269-276.

# A new Bi-Objective model for a Two-Echelon Capacitated Vehicle Routing Problem for Perishable products with the Environmental Factor

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**چکیده**

در استراتژی توزیع چند سطحی بار به مشتریان از طریق انبارهای میانی تحویل داده می‌شود. این استراتژی نسبت به حمل و انتقال مستقیم یک استراتژی به طور فزاینده‌ای محبوب در تدارکات شهری است. این امر در درجه اول به دلیل کاهش پیامدهای محیطی (برای مثال مصرف انرژی و ازدحام) و اجتماعی (نظیر آلودگی هوای مرتبط با ترافیک، تصادفات و سروصدا) عملیات تدارک است. در این پژوهش یک مدل مسیریابی وسیله نقلیه‌ی دو سطحی را توسعه می‌دهیم که در آن برای اولین بار رضایت مشتریان و مسائل محیطی، برای تحویل اقلام فاسد شدنی در نظر گرفته شده‌اند. ما یک مدل دو هدفه‌ی جدیدی را ارائه می‌کنیم که در آن ۱) مجموع زمان‌های انتظار مشتریان و ۲) مجموع هزینه‌ی سفر حداقل باشد. یک محدودیت بر حداکثر مقدار مجاز انتشارات کربن دی اکسید حاصل از هر مسیر بعنوان موضوع محیطی در مسأله در نظر گرفته شده است. مدل پیشنهادی با شیوه‌ی مجموع وزنی ساده حل شده است. در انتها، مدل پیشنهادی برای یک مورد مطالعاتی در زنجیره سوپرمارکت پیاده سازی شده است. نتایج به دست آمده توسط نرم افزار گمز، اعتبار و عملکرد بالای مدل را با توجه به اهمیت قائل شده برای هر یک از توابع هدف تایید می‌کند. نتایج تحلیل حساسیت نیز بیان می‌کند که هرچه محدودیت محیطی آزادتر باشد، میزان انتشارات بیشتری خواهیم داشت در حالیکه مجموع هزینه‌ی سفر و مجموع زمان‌های انتظار مشتریان کمتر خواهند شد.

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