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Research Article

Humanitarian Logistics Management After A Disaster: An Earthquake Case

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ABSTRACT

Post-disaster relief logistics includes logistics activities in the shortest time. Inventory routing problems have decided routing decisions considering inventory levels during the planning horizon at minimum cost. In this study, an inventory routing problem for the distribution after the disaster has been proposed. The problem aims the distribution of the supplies needed considering available inventory levels at minimum time. Distribution amount and the routes under the constraints of routing and inventory amounts for affected people have been decided. An integer programming approach to solve the problem has been proposed and solved. The proposed model is solved for a case of Van earthquake which occurred at 2011 in Turkey. The results from the case study show us that determining the inventory and routing decisions simultaneously can provide less logistic activities. In addition to this, holding inventory in the central depot can ensure to respond the emergency needs safely and quickly.

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Introduction

Disasters are sudden, dangerous events and cause catastrophe in human life. They have affected nations in recent decades. Thus, to manage effective humanitarian operations is an important part of a disaster relief. Disaster management is the process of taking measures beforehand and inspecting the effects of a disaster. Humanitarian logistics is sub-part of logistics that is relevant of the disaster management. This area is suitable for mathematical approach and several applications.

Organizations pay more attention to increase the efficiency of logistics systems. They are aware that the inventory routing decisions based on their logistics network are critical. The inventory-routing problems (IRPs) have been one of the most important problems. Several applications of the IRP have been documented [1]. Humanitarian logistics is a good area for the applications of the IRP and it has received interest both from academics and the practitioners. It includes disaster relief and support for developing regions [2]. Quick response to the urgent need after disasters is critical for emergency logistics [3]. Managing the emergency logistics is difficult because of this critical structure. Disaster management has gained interest after the 1999 Marmara Earthquake in Turkey. Post disaster relief regulations were organized and distribution of aids to affected people was suitably ensured. This study has been carried out to decide the routes considering the inventory levels at minimum cost after a disaster.

Disaster management requires solving several problems to help the affected people. These problems include location, routing and inventory decisions. Many studies about location-inventory problems are conducted by many researchers. They use exact formulations or/and heuristic algorithms to solve the problem. A model is proposed that decides the location of distribution centres and supplies to be stocked at the centres [4]. The location-inventory problem of rescue services is investigated. In the post disaster, they assign the relief items between demand points and rescue centres [5]. A disaster planning of medical needs is provided. The model determines the storage location, inventory levels, and distribution decisions. The study is applied for an earthquake scenario [6]. A mixed integer model is developed for location inventory problem. They aim to minimize the response time. The model is established for 9 warehouses and 3 inventory levels [7]. A two stage approach is proposed for an earthquake. They firstly try to solve location inventory problem and then vehicle routing is handled. By the uncertain situations, they use robust approach. They also meta heuristic methods [8].

Disaster management also requires giving decisions about routing problems. Transportation of aids for the affected people is ensured by the effective routes. Many studies about routing/distribution problems are conducted by many researchers. A mathematical model is developed for emergency logistics planning. They integrate two network flow problems, the first one linear and the second one integer. They needed heuristic solutions for the second problem [9]. A problem is presented about bioterrorism emergencies. They decomposed the problem into two stages. In the first stage, they plan the routes in any emergency; in the second stage they decide the delivery quantity. They use mathematical formulations to solve the problems [10]. Many studies about location problems are conducted by many researchers. Humanitarian logistics network is designed under mixed uncertainty involving multiple warehouses, local distribution centres. In the first step, locations of warehouses and centres are determined and then, a distribution decision is given to minimize total distribution time, total cost of unused inventories. The study is applied in Tehran for potential earthquakes [11]. A location-allocation problem is proposed to minimize response time. Ambulance locations near demand points are positioned [12]. A humanitarian supply chain design is developed. They use a p-median model for small instances and a tabu heuristic for large instances. The heuristic method has given better results. The results also show that integration of post disaster decisions with pre disaster decisions is important [13]. A stochastic approach is proposed to decide inventory amounts before disaster and sufficient amounts after the disaster. The problem includes uncertain demand, so a scenario based model is provided [14]. A mixed integer programming approach is presented for blood supply. The model includes some constraints based on uncertain demands, perishability products. Minimum cost of supply chain, maximum demand meeting, minimum time between production and consumption are expected in the objectives [15]. A disaster planning problem is presented by multi objective programming. They aim to take the location, inventory, distribution decisions for a flood disaster in Mexico [16]. Location warehouses, inventory levels in the pre disaster are decided, routing decisions are given in the post disaster. They solve the problems by two meta heuristic approach [17]. A model for deciding the relief locations and transportation is formulated. They aim to minimize pre disaster costs and unmet demands [18]. Distribution and routing decisions are investigated for emergency conditions by meta heuristic approach [19]. A mixed integer linear programming model is formulated for location-routing problem. They solve the problem by different meta heuristics [20]. The military supply is investigated by integer programming. Total supply chain costs and inventory levels are decided in the model [21].

In the literature, inventory routing problems are mostly studied. However, in this study, the problem is applied firstly for the post-disaster relief logistics. The reasons for this are as follows:

Managing products inventory after disasters is critical to avoid the stock-out situation.

The inventory component carries a time dimension to the routing problems. In the humanitarian logistics, the distribution of the supplies needed considering available inventory levels at minimum time.

Materials and Methods

Inventory routing problem concerned in this paper includes two sub problems: transportation of aid products and controlling inventory levels to prevent stock out. The network of the paper comprises centre depots, supply nodes and emergency nodes shown in Figure 1. The centres must provide emergency products to the demand points.

In this study, in order to solve problems caused by the disaster, an inventory routing model is proposed. The proposed model solved the routes considering the inventory levels at minimum cost. As the greatest benefit, with this system, delivery of aid materials at emergency is markedly provided.

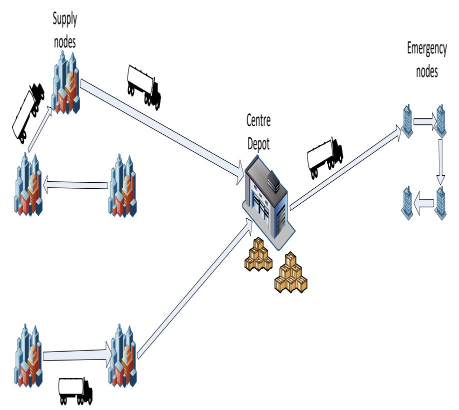


Figure 1. The proposed network in the problem

Mathematical model

The indices used for mathematical modelling of the problem are as follows;

Indices

i, j, v indices for supply or emergency nodes
E indice for emergency area
S indice for supply area
k index for supply or emergency vehicles
t index for periods
N_E set of emergency areas
N_s set of supply areas
K_E set of trucks for emergency areas
K_s set of trucks for supply areas
T set of periods in planning horizon $T_0 = T \cup \{0\}$

The parameters and decision variables used are as follows;

Parameters

$C_k^E\ (C_k^s)$: $Capacity\ of\ emergency\ (supply) vehicle\ k\ (unit)$
$l_i^E\ (l_i^s)$: $minimun\ inventory\ level\ of\ emergency\ (supply)\ node\ i\ (unit)$
$g_i^E (g_i^s)$ $maximum\ inventory\ level\ of\ emergency\ (supply) node\ i\ (unit)$
$f_k^E (f_k^s)$: $fixed\ usage\ cost\ for\ emergency (supply)\ vehicle\ k\ (money/period)$
p : $variable\ cost\ for\ transportation\ (money/distance)$
h : $holding\ cost\ for\ (money/(unit * period)$
$d_{ij}^E\ (d_{ij}^s)$: $distance\ between\ (i,j)\ emergency\ (supply) pair\ (distance)$
$D^E (D^s)$: $maximum\ tour\ length\ for\ emergency (supply)\ vehicles$
r_{it}: $demand\ of\ emergency\ node\ i\ at\ period\ t\ (unit)$
A(B): number of emergency (supply) nodes

Decision Variables

$I_{it}^S\ (I_{it}^E)$: $Inventory\ level\ on\ supplier\ (emergency) node\ i\ at\ period\ t\ (unit)$
$Q_{ikt}^S\ (Q_{ikt}^E)$: $Picked\ amount\ (delivery\ amount) from (to)\ supplier\ (supply)\ node\ i\ at\ period\ t\ with\ vehicle\ k\ (unit)$
$X_{ijkt}^E\ \left(X_{ijkt}^S\right)$: $Load\ on\ travelling\ (i,j)\ emergency\ \ (supplier) pair\ at\ period\ t\ with\ vehicle\ k\ (unit)$

$$Y_{ijkt}^S = \begin{cases} 1, if\ a\ delivery\ made\ to\ (i,j) supplier\ pair \\ \quad at\ period\ t\ with\ vehicle\ k \\ 0, \quad otherwise \end{cases}$$

$$U_{kt}^S = \begin{cases} 1, if\ vehicle\ k\ is\ used\ for\ supply\ on\ period\ t \\ 0, \quad otherwise \end{cases}$$

$$Y_{ijkt}^E = \begin{cases} 1, if\ a\ delivery\ made\ to\ (i,j) emergency\ pair \\ \quad at\ period\ t\ with\ vehicle\ k \\ 0, \quad otherwise \end{cases}$$

$$U_{kt}^E = \begin{cases} 1, if\ vehicle\ k\ is\ used\ for\ delivery\ on\ period\ t \\ 0, \quad otherwise \end{cases}$$

Model

$$\min z = \sum_{t=1}^{T}\sum_{k=1}^{Ke} f_k^E * U_{kt}^E + \sum_{t=1}^{T}\sum_{i=0}^{Ne}\sum_{\substack{j=0 \\ i\neq j}}^{Ne}\sum_{k=1}^{Ke} \mathrm{c} * l_{ij}^E * Y_{ijkt}^E + \sum_{t=1}^{T}\sum_{i=0}^{Ne} h * I_{it}^E$$
$$+ \sum_{t=1}^{T}\sum_{k=1}^{Ks} f_k^S * U_{kt}^S + \sum_{t=1}^{T}\sum_{i=0}^{Ns}\sum_{\substack{j=0 \\ i\neq j}}^{Ns}\sum_{k=1}^{Ks} \mathrm{c} * l_{ij}^S * Y_{ijkt}^S + \sum_{t=1}^{T}\sum_{i=0}^{Ns} h * I_{it}^S \tag{1}$$

$$I_{it}^E = I_{it-1}^E - r_{it}^E + \sum_{k=1}^{Ke} Q_{ikt}^E \qquad \mathrm{t} \in \{1..\mathrm{T}\}, \mathrm{i} \in \{1..\mathrm{Ne}\} \tag{2}$$

$$I_{0t}^S = I_{0t-1}^S - r_{0t}^E + \sum_{i=1}^{Ns}\sum_{k=1}^{Ks} Q_{ikt}^S - \sum_{i=1}^{Ne}\sum_{k=1}^{Ke} Q_{ikt}^E \qquad \mathrm{t} \in \{1..\mathrm{T}\} \tag{3}$$

$$X_{ijkt}^E \leq C_k^E * Y_{ijkt}^E \qquad \mathrm{i} \in \mathrm{Nc}, \mathrm{j} \in \mathrm{Nc} \mid \mathrm{i} \neq \mathrm{j}, \mathrm{t} \in \{1..\mathrm{T}\}, \mathrm{k} \in \mathrm{Ke} \tag{4}$$

$$\sum_{\substack{j=1 \\ i\neq j}}^{Ne} X_{jikt}^E - \sum_{\substack{v=1 \\ i\neq v}}^{Ne} X_{ivkt}^E = Q_{ikt}^E \qquad \mathrm{k} \in \mathrm{Ke}, \mathrm{t} \in \{1..\mathrm{T}\}, \mathrm{i} \in \{1..\mathrm{Ne}\} \tag{5}$$

$$\sum_{k=1}^{Ke}\sum_{j=1}^{Ne} X_{0jkt}^{E} - \sum_{k=1}^{Ke}\sum_{i=1}^{Ne} X_{i0kt}^{E} = \sum_{k=1}^{Ke}\sum_{v=0}^{Ne} Q_{vkt}^{E} \qquad t \in \{1..T\} \tag{6}$$

$$\sum_{\substack{j=1 \\ i\neq j}}^{Ne} Y_{ijkt}^{E} - \sum_{\substack{v=1 \\ i\neq v}}^{Ne} Y_{jvkt}^{E} = 0 \qquad k \in Ke, t \in \{1..T\}, i \in Ne \tag{7}$$

$$\sum_{i=0}^{Ne}\sum_{\substack{j=0 \\ i\neq j}}^{Ne} Y_{ijkt}^{E} * d_{ij}^{E} \le D^{E} * U_{kt}^{E} \qquad k \in Ke, t \in \{1..T\} \tag{8}$$

$$\sum_{i=1}^{Ne} Y_{0ikt}^{E} = U_{kt}^{E} \qquad k \in Ke, t \in \{1..T\} \tag{9}$$

$$\sum_{i=1}^{Ne} Y_{i0kt}^{E} = U_{kt}^{E} \qquad k \in Ke, t \in \{1..T\} \tag{10}$$

$$W_{ikt}^{E} - W_{jkt}^{E} + A * Y_{ijkt}^{E} \le A - 1 \qquad i \in \{1..Ne\}, j \in \{1..Ne\}, t \in T, k \in Ke \tag{11}$$

$$l_{i}^{E} \le I_{it}^{E} \le g_{i}^{E} \qquad t \in T, i \in Ne \tag{12}$$

$$I_{0t}^{E} = I_{0t}^{S} \qquad t \in T \tag{13}$$

$$I_{it}^{S} = I_{it-1}^{S} - \sum_{k=1}^{Ks} Q_{ikt}^{S} \qquad t \in \{1..T\}, i \in \{1..Ns\} \tag{14}$$

$$\sum_{\substack{j=1 \\ i\neq j}}^{Ns} X_{jikt}^{S} - \sum_{\substack{v=1 \\ i\neq v}}^{Ns} X_{ivkt}^{S} = -Q_{ikt}^{S} \qquad k \in Ks, t \in \{1..T\}, i \in \{1..Ns\} \tag{15}$$

$$\sum_{k=1}^{Ks}\sum_{j=1}^{Ns} X_{0jkt}^{S} - \sum_{k=1}^{Ks}\sum_{i=1}^{Ns} X_{i0kt}^{S} = \sum_{k=1}^{Ks}\sum_{v=0}^{Ns} -Q_{vkt}^{S} \qquad t \in \{1..T\} \tag{16}$$

$$X_{ijkt}^{S} \le C_{k}^{S} * Y_{ijkt}^{S} \qquad i \in Ns, j \in Ns \mid i \neq j, t \in \{1..T\}, k \in Ks \tag{17}$$

$$\sum_{\substack{j=1 \\ i\neq j}}^{Ns} Y_{ijkt}^{S} - \sum_{\substack{v=1 \\ i\neq v}}^{Ns} Y_{jvkt}^{S} = 0 \qquad k \in Ks, t \in \{1..T\}, i \in Ns \tag{18}$$

$$\sum_{i=0}^{Ns}\sum_{\substack{j=0 \\ i\neq j}}^{Ns} Y_{ijkt}^{S} * d_{ij}^{s} \le D^{s} * U_{kt}^{S} \qquad k \in Ks, t \in \{1..T\} \tag{19}$$

$$\sum_{i=1}^{Ns} Y_{0ikt}^{S} = U_{kt}^{S} \qquad k \in Ks, t \in \{1..T\} \tag{20}$$

$$\sum_{i=1}^{Ns} Y_{i0kt}^{S} = U_{kt}^{S} \qquad k \in Ks, t \in \{1..T\} \tag{21}$$

$$W_{ikt}^{S} - W_{jkt}^{S} + B * Y_{ijkt}^{S} \le B - 1 \qquad i \in \{1..Ns\}, j \in \{1..Ns\}, t \in T, k \in Ks \tag{22}$$

$$l_{i}^{S} \le I_{it}^{S} \le g_{i}^{S} \qquad t \in T, i \in Ns \tag{23}$$

The objective function (Eq. 1) minimizes the total costs consist of fixed usage costs of vehicles, transportation and holding costs of both emergency and supply area. Inventory balances regarding incoming products and outgoing demands are ensured by Eq. 2 and 3. The Eq. 2 allows the balancing the inventory amount by considering the needs occurred in the disaster region. The Eq. 3 calculates the amount from the supply area sent to the disaster area and the need finally. The Eq. 4 ensures that the vehicle capacity couldn’t be exceeded. Eq. 5 and Eq. 6 allow the balancing of the helps distributed. While Eq. 5 ensures the distribution carried out for each point by vehicle, Eq. 6 allows the total distribution by the depot. Eq. 7-10 ensures the routing constraints. Eq. 7 allows the routing. Eq.8 provides that the route length cannot exceed the maximum tour length. Eq.9

and 10 ensure that the tour must start in the depot and finish in the same depot. Eq. 11 is a sub tour elimination constraint. Eq. 12 holds the inventory levels between the upper and lower limits. Eq. 13 is a transfer constraint which provides to transfer main supply depot's inventory levels to main emergency node's inventory level. Eq. 14 balances the inventory levels on supply nodes. Eq. 15 and 16 provide the pick-up amounts for supply nodes and main depot, respectively. Eq. 17-22 are routing constraints for supply nodes. While Eq. 17 forces to avoid from exceed capacity, Eq.19 forces to avoid from exceed of the maximum tour length. While Eq. 18 provides the routes, Eq. 20 and 21 ensures the tour must be start and end of the main depot. Eq. 22 is a sub-tour elimination constraint for supply nodes. Finally, Eq. 23 ensures the held inventory levels should be in a range of lower and upper limits.

Results and discussion

Van Province in Turkey is examined for post disaster management. After the earthquake, several rescue operations, aids are provided shown in Table 1. The staffs include search and rescue staffs and health personals. For first 24 hours, %81 of all the staffs is sent to the region. The vehicles sent to the region are trucks, ambulances and airplanes. For first 24 hours, %94 of all the vehicles is sent to the region. The materials are tents, blankets and stoves which are sent to the region for first 24 hours with % 77 rate. The relief work after the Van earthquake in 2011 is took place for the solution of the model. The proposed mathematical model is solved in GAMS mathematical modelling language on computers with 3.6 GHz processor and 16 GB RAM.

Table 1. The provided post disaster activities (AFAD report)

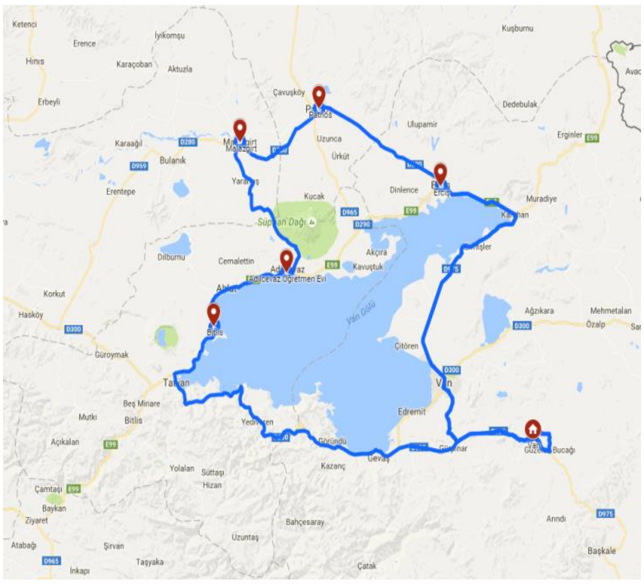
Post disaster activities	For first 24 hours	For first 72 hours
Number of staffs	3221	4615
Number of total vehicles	523	794
Number of materials	37585	103021

Accordingly, the model for the first 72 hours of relief work (3 days) is resolved. The results are given in Table 2, Figures 2-3.

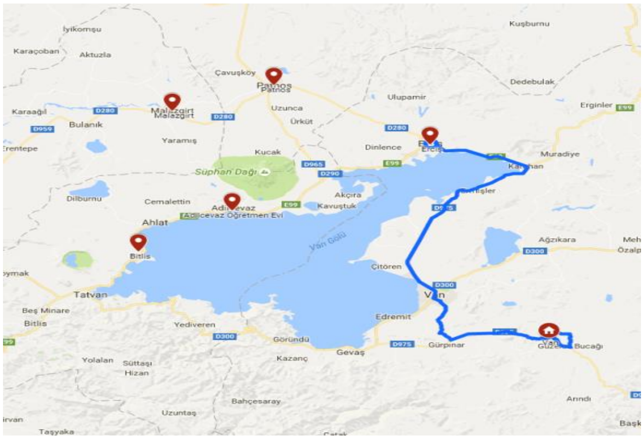
Table 2. Inventory levels on emergency nodes

Node	Period 1	Period 2
Malazgirt	16	5
Bitlis	16	5
Patnos	12	4
Adilcevaz	48	16
Erciş	97	699

Table 1 shows the amount of inventory at each point. When these quantities are evaluated, due to the inventory being kept, the demand that will be generated on the third day can be met from the stock and thus the lower logistics costs are ensured with the solution of the model.



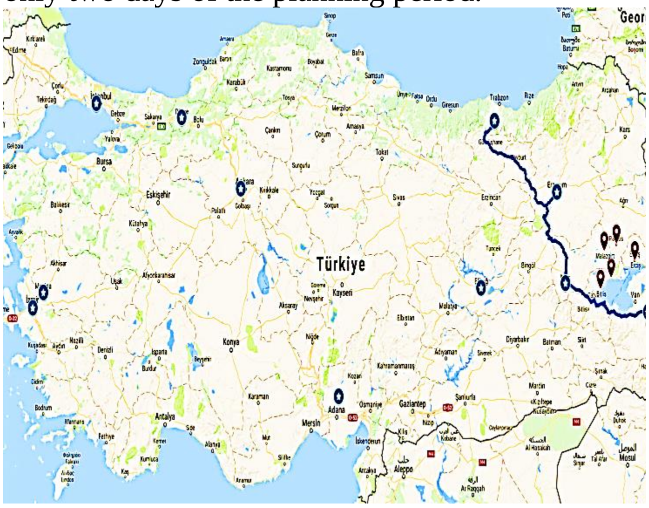
(a)



(b)

Figure 2. Routes on emergency nodes at (a) first period and (b) second period.

Figure 2 shows routes created between emergency points. The most important contribution of inventory keeping is seen in the formation of routes. Routes have been created only two days of the planning period.



(a)

(b)

(c)

Figure 3. Routes on supply nodes at (a) first period (b) second period and (c) last period.

Figure 3 shows routes between supply points. Considering the inventory quantities in each period, the needs are met from the nearest points. The result of establishing routes together between need and supply points is seen in the results. According to this, while there is no routing in the last period, supply is provided for the central depot requirement. Thus, it is possible to reduce the cost of routing.

Sensitivity analysis

Model parameters are estimated in this section. Measuring the sensitivity of the model against possible forecast errors is important. For this reason, the sensitivity of the model to the following conditions is examined:

• Emergency vehicle capacity
• Supply vehicle capacity
• Emergency tour length
• Supply tour length
• Holding cost / routing cost

Emergency vehicle capacity and supply vehicle capacity values are set to 1000. A graph of the variation of this value between 500 and 1500 is shown in Figure 4. Accordingly, it is seen that the change in the value of Supply Vehicle capacity is more effective on the solution. This is an expected situation because long distances can be transported to these distribution points. Emergency vehicle capacity does not react very much to change. From the perspective of the solution times, it can be said that the decrease of vehicle capacities reduces the solution time.

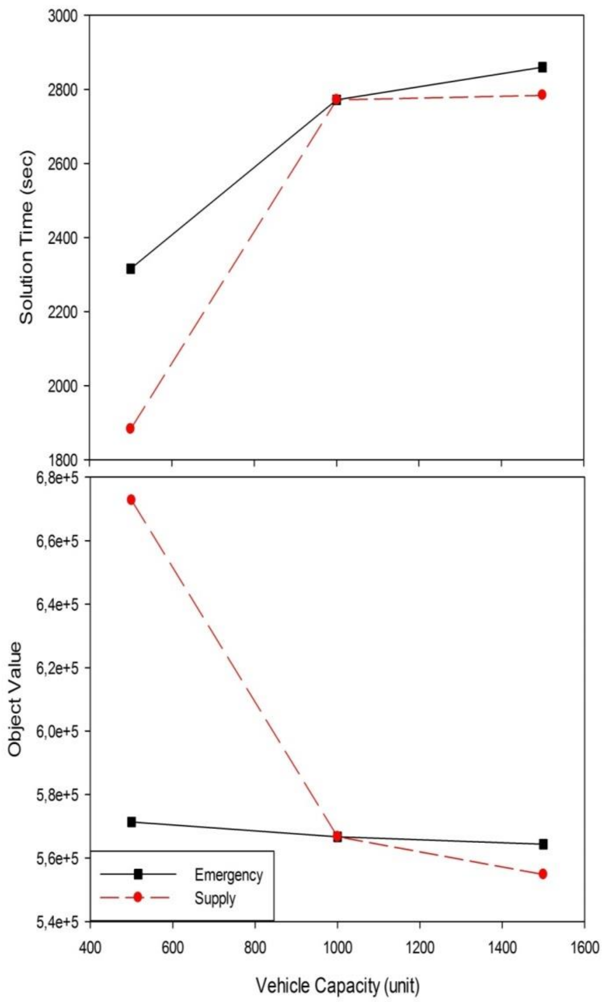


Figure 4. The effect of changes in the vehicle capacities to the solution times

Figure 5 shows the influence of the tour length on the resolution time. Accordingly, increasing the tour length does not change the solution for the emergency vehicle. However, shortening the length of the tour increases the costs for supply vehicles. This is why a vehicle must travel a longer way when the tour lengths shorter. When the duration of the solution is examined, the increase in the length of the emergency tour increases the duration of the solution significantly. In terms of supply vehicles, it increases firstly and then decreases.

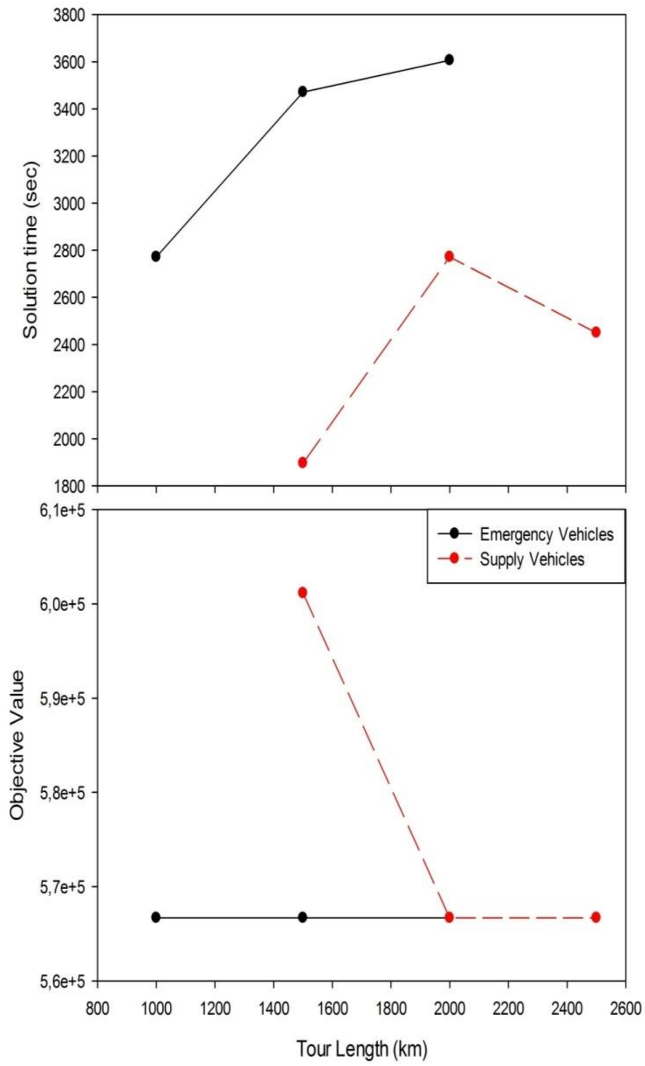


Figure 5. The effect of tour lengths to the solution

When the parameter effects of the parameters are examined, the last parameter is the ratio of the holding and routing costs. This ratio is one of the most important parameters in terms of solution duration of holding or transportation in every period. When the results presented in Figure 6 are examined, objective function cost increases. However, when the solution durations are examined, it is observed that the increase does not affect the solution times after a significant reduction in the solution at a certain point. This point can be considered as the point at which the balance between holding and routing is completely broken.

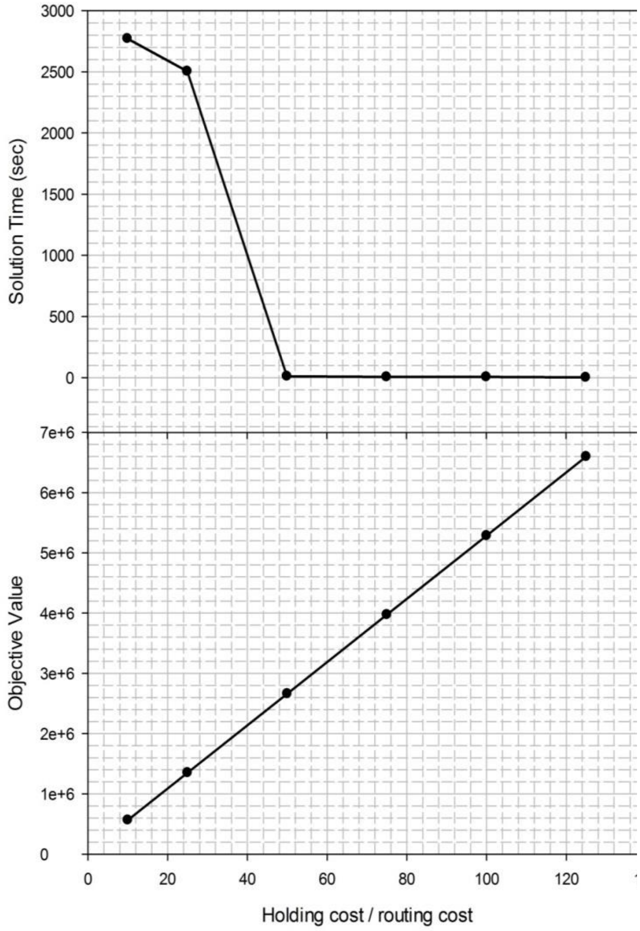


Figure 6. The effect of holding cost / routing cost rate to the solution.

Conclusion

Post disaster management is vital and includes several processes such as materials needed by affected people in the earthquake. Accurate planning of the processes requires a routing decision to distribute the materials timely and an inventory decision to hold the materials for the needs. This study aims to provide a mathematical model approach for realizing these activities. Model is applied for a real case study in a Van Province. Results are given by routes on emergency nodes and supply nodes, inventory levels on emergency nodes. A sensitivity analysis is also given to see the sensitivity of the model against the changes.

This study presents a mathematical model approach, for larger applications heuristic methods can be applied. Some uncertain conditions require stochastic or fuzzy approaches. Future works should address long-term economic development programs. Also, mitigation, preparation, response and recovery phases of the emergency management should be handled to reduce the impact of the hazards. Limitation of the study is that the model developed is only applied for a region and for post disaster processes. Future work may include national preparedness in the pre disaster stage and the results may be generalized for whole country.

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