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A BI-LEVEL PROGRAMMING MODEL FOR ALLOCATING PRIVATE AND EMERGENCY VEHICLE FLOWS IN SEISMIC DISASTER AREAS

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Abstract: When a severe earthquake takes place, the road network system often suffers serious destruction and results in the malfunctioning of lifeline network systems. In particular, impassable roads and streets block transportation in evacuation, rescue and restoration. How to maintain traffic functions to facilitate rescue missions and save more lives turns out to be an essential task during the post-quake period. This paper aims at developing a decision-making tool that can potentially be used in managing the emergency vehicles and controlling the private vehicle flows in earthquake disasters. Methodologically, the problem to be addressed is formulated as a multi-commodity, two-modal network flow problem based on the concept of bi-level programming and network optimization theory. To prove the feasibility, this paper has conducted a numerical case study using a small sample data from the earthquake-raided areas. To solve the model efficiently, the genetic algorithm (GA) been applied to solve the model. A numerical example shows that this study can create an effective way to implement traffic regulation during earthquake disaster.

Key Words: traffic demand management, bi-level programming, emergency vehicles, genetic algorithm, CDA (combined distribution/assignment model)

1. INTRODUCTION

Natural disasters like earthquakes often cause a high degree of damage. Especially in highly inhabited urban areas, impassable roads and streets block transportation in evacuation, restoration and rescue. Thousands of people may be affected or killed. The most important aspect, which helps determine the total number of fatalities after an earthquake, is the performance of search and rescue in the first few days. Thus, during a disaster emergency, transportation is critical in minimizing the loss of life and maximizing the efficiency of the rescue operations, even when only part of the road network is damaged.

While much attention has been paid to understanding and predicting the performance of transport system under seismic loading, only recently have researchers begun to model traffic flow management in disaster areas. Haghani et al. (1996) formulated a complex multi-commodity, multi-modal network flow problem with time windows in the context of disaster relief management, which could be solved relatively easily. This model dealt with the problem of determining the routing and scheduling of emergency vehicles but did not formulate the OD traffic volume for private vehicle flows. Masuya et al. (1996) and Kurauchi et al. (1997) calculated the maximum trip generation and attraction volume that can be borne by that part of the network remaining intact after an earthquake. Nojima (1997) proposed road traffic capacity as a basic post-earthquake performance measure for highway systems, where capacity consists of the aggregate flow capacity of links connecting a specific origin-destination pair of nodes. Werner et al. (1997) modeled bridge damage, network traffic flows, and the costs associated with travel time delays. Results showed that moderate traffic demand control is needed in an emergency, however these models didn't consider emergency vehicles.

Since damage to urban road network can cause congestion in other parts of the network, efficient disaster traffic management is essential (Odani et al., 1996; Nakagawa et al., 1996). It is necessary to balance travel demand (traffic on a link) and traffic supply (the capacity of a network) in tackling traffic congestion (Tomita et al., 1995). This paper discusses the determination of allowable private vehicle flows aimed at ensuring that travel demand does not exceed road network capacity under deterioration of traffic function in the road network. The purposes of this study include three folds. First, it tries to deal with the question of how to reduce damages in earthquake-raided areas. Secondly, it hopes to provide quick and effective means to return chaos to normal situations post earthquakes. Finally, it provides appropriate approaches to reach the goal of supporting sustainable development of the affected areas in the future. Since road network capacities will be decreased due to severe damages on the main roads and bridges post earthquakes, how to maintain the basic road functions through traffic control/management becomes an important issue.

2. TRAFFIC CONTROL ISSUES IN SEISMIC AREAS

In the past, earthquake researchers in the sector of transportation only focused on transportation engineering designs and rescue scheduling. Few studies paid attention to the traffic control management in earthquake disaster areas. IIDA（1995）presented traffic management system against major earthquakes in the IATSS research, which developed a good study platform of traffic management system for the Great Hansin-Awaji Earthquake. A bi-level programming model seeking effective traffic control/management was developed in that paper, and the model focused only on the needs of victims. This focus could be extended to consider both the needs of victims and those who come to rescue. Because of the dual concerns, this research attempts to build a dynamic strategic model, based on a bi-level programming technique, to improve the traffic control management. In addition, this study tries to integrate the Combined Distribution/Assignment Model to solve the problem, which is proposed by Boyce and Janson in1980 and constructed by Suh and Kim in 1992.

Masuya et al (1999) developed a decision making tool to deal with the problem of controlling private vehicle flows. In his paper, the problem to be addressed is formulated as a multi-commodity, two-model network flow problem based on the concept of network flow theory and integer linear programming. Since the traffic control decision process is similar to the static two person Stackelberg game (G.P. Papavassilopoulos, 1982), it can be modified or extended by using bi-level programming approaches for solving interactive decision processes in reasonably large organizations.

2.1 Actual Traffic Conditions Post Earthquake

According to the statistics issued by Post-921 Reconstruction Commission organized by the Executive Yuan, Taiwan, Chi-Chi Earthquake occurred at a magnitude of 7.3 in 1999, left 2,400 deads, and more than 10,000 injured. More than 30,000 housing units were destroyed, 25,000 housing units were damaged on different levels, and 100,000 people became homeless. This natural disaster not just caused impacts on transportation systems, but also on public safety. Many towns and villages in central Taiwan were hurt seriously.

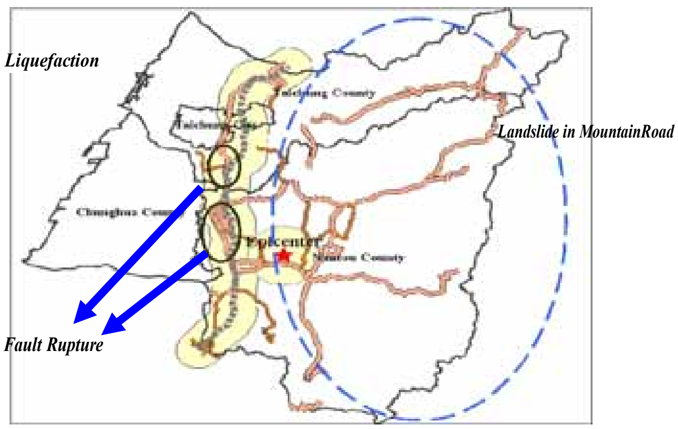

Figure1 Distribution of Major Reasons for Highway Damage

The highway transportation disruption in this great quake resulted primarily from landslide, fault rupture and liquefaction. Highway traffic was closed on 156 sites for provincial road and on 112 sites for county road. There were 290 sites having the road surface displacements and landslides. The locations of these damaged sites could be seen in Figure 1.

2.2 Traffic Control Problem Analysis

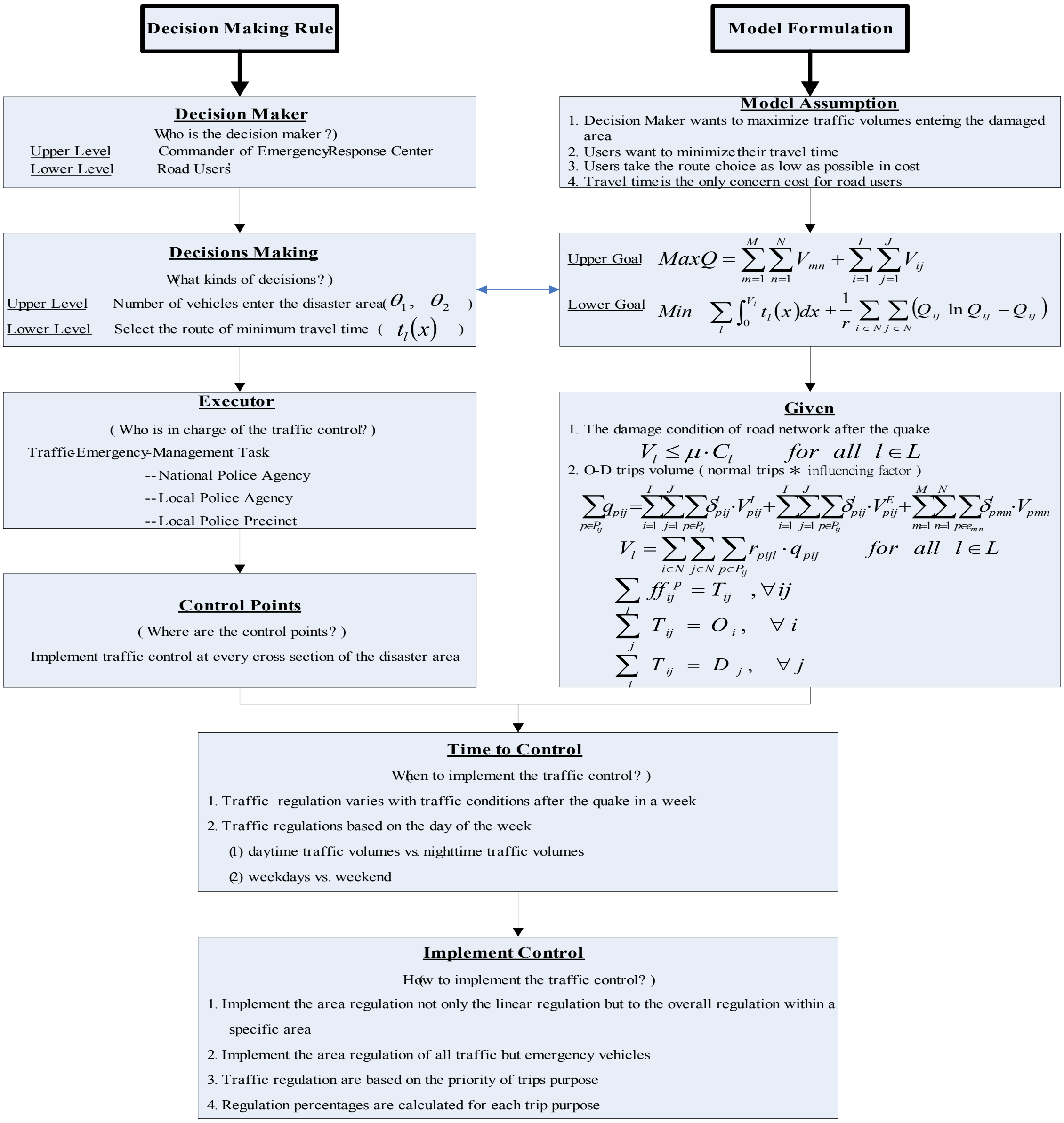

Figure 2 Traffic Control Decision-making Concept and Model Formulation

Lessons were learned form rescue operations in Chi-Chi Earthquake, show us that although both government and private organizations had tried their best to rescue the victims, but the results turned out not as good as expected. There is a room to improve if it can be done again. The main difficulty is insufficient information while an earthquake occurs. Without real time information of the damages on roadway networks, it is impossible to perform a good traffic control management, and of course it will affect the rescue performance. Experience implies that the following problems need to be explored:

1. Roadway damage information collection systems are in short.
2. Real transportation behaviors including choice of destinations, traveling frequency and mode choice cannot be easily obtained by means of regular surveillance systems.

3. Existing command and decision-making systems are not able to control vehicles in or out of the disaster areas rationally.
4. For real time controlling and diverging of traffic flows to facilitate on-site rescue operation, a dynamic traffic control mechanism is urgently needed.

Since the traffic control problem involves interactive decision processes, the bi-level optimization model is a practical and useful tool for solving the decision problems in a hierarchical system. We are concern about "who is the decision maker?", "what kinds of decision?", "who is in charge of the traffic control?", "where are the traffic control points?", "when to implement traffic control?", and "how to implement traffic control?" All these problem analyses and basic concepts of bi-level programming model formulation are illustrated in Figure 2.

The upper level decision maker (commander of Emergency-Response Center) makes his or her decision (number of vehicles ($MaxQ$) entering into the disaster area) in respect of different disaster period, time frames and location first with full information about traffic condition in disaster area. The second level decision maker (road user) makes his or her decision (selecting the route of minimum travel time $t_l(x)$) based on the first level's decision. Then the three levels of the Traffic-Emergency-Management Task Force, based on the traffic condition after the quake and the priority of trip objectives, implement control on all traffic except emergency vehicles at every cross section within the disaster area.

3. MODEL FORMULATION

Despite there is only little progress on predicting earthquakes, contingency study efforts can never be over-emphasized. This is particularly true in the case of Chi-Chi Earthquake. In the first couple of days everything was in chaos. There was no enough experience to deal with such a disaster. Policy makers could only rely on limited information and resources in hands. Therefore, rescue operation was not in a smooth process at the beginning. This study, after reviewing related literatures on earthquake operations, has explored various traffic-control measures in contingency and their effects. The study especially pays attention to how to make preparedness against unpredictable natural disasters, and tries to introduce useful ideas for traffic control and rescue. By presenting the strategy of traffic control in contingency, the study hopes to improve effectiveness and efficiency of rescue and restoration post disasters. The problem to be addressed is formulated as a multi-commodity, two-model (private vehicle flows and emergency vehicles) bi-level programming problem based on the concept of network flow theory.

3.1 Classification of Private Vehicle Flows and Consideration for Emergency Vehicles

It is necessary to control traffic demand to maintain traffic flow immediately after an earthquake and to understand the extent to which private vehicle flows can be generated in and attracted to a degraded road network. Analysis of changes in origin to destination (OD) traffic volume for automobiles within road networks of disaster area after the earthquake has revealed that: The OD ratio of short-distance trips increased greatly. The OD ratio of long-distance trips, which originated outside of the disaster area and ordinarily passed through it, decreased. The OD ratio of trips originating inside the disaster area to points outside decreased. The OD ratio of trips originating outside the disaster area to points inside increased greatly.

This paper discusses the OD traffic volume based on the classification of private vehicle flows considering OD traffic patterns. The OD trips of vehicle flows are classified into two categories (Yuzo MASUYA, 1999). One is the private vehicle flows that need to be controlled when travel demand exceeds the capacity of a network. The other category is emergency vehicles carrying supplies and relief personnel, which are not controlled during a disaster emergency. The private vehicle flows are also formulated considering the classification of OD trips, namely internal-internal trip, internal-external trip, external-internal trip and through trip (external-external trip). Three types of private vehicle flows excluding the through trip are considered as the OD traffic pattern representing the relative ratio of OD pair with origins and/or destinations inside the disaster area. Together with classification of private vehicle flows, a multi-commodity two-model network flow problem is formulated with bi-level programming given the highest priority of emergency vehicles used in evacuation, rescue and restoration.

3.2 Bi-level Interactive Algorithm

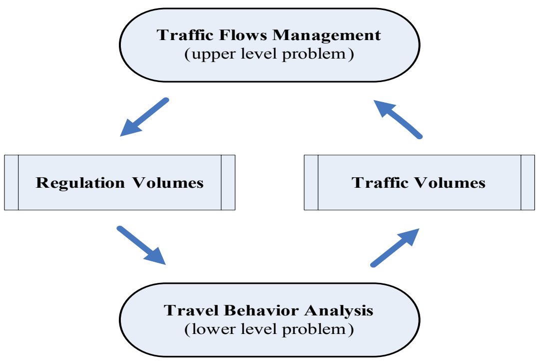

Figure 3 Bi-level Interactive Decision Processes

A multi-level optimization model is proposed to solve both the top decision makers' and road users' interactive decision process. The decision is executed in a top-down sequential manner, and the lower decision-makers do have freedom to make their decisions within the broad range set by the top decision-makers. Furthermore, the outcome depends on the degree of interaction or cooperation between the two levels, which are somewhat similar to the static two-person Stackelberg game and the interactive decision-making process (E. Stanley Lee, 2001). The decision process of this traffic control problem is illustrated as Figure 3.

To illustrate the basic characteristics of this duo-poly process, let us consider its decision is carried out in the following manner. The upper-level decision-maker makes his or her decision first with full information about both levels, and then the second level decision-maker makes his or her decision in isolation and based on the first level's decision. Notice that although the second level cannot control the decision of the first level, the final decision of the lower does eventually influence the upper level and the overall results. Ideally, this mutually interactive decision process is continued until a satisfactory solution or comprise is reached.

3.3 Conceptual Model Structure

The traffic control problem reflects an interactive decision process, and the bi-level optimization model is a practical and useful tool for solving decision problems in a hierarchical system. The model assumes the commanders of Emergency-Response Center at the county and city government levels in earthquake-raided areas are the decision makers. The decision-making objective is to meet the emergency and victims' needs. The upper level objective in the model is to allow traffic to go through the disaster areas as much as possible and not to exceed the reduced roadway capacity, so that victims can feel satisfied with the traveling. While the lower level objective is to both meet the emergency rescue needs and combine road network assignment and trip distribution concept (CDA model suggested by Evens, 1976) to analyze the traffic flows, which not only meets the requirements of the entropy model, but also more practically reflects users' travel behavior. The model assumes that road users will always choose the shortest route in respect of travel time. Traffic control zones are designated by decision makers in accordance with the degrees of damages on the roads. The bi-level programming conceptual model is shown as below.

Upper Level Objective $$MaxQ = \sum_{m=1}^{M}\sum_{n=1}^{N} V_{mn} + \sum_{i=1}^{I}\sum_{j=1}^{J} V_{ij} \qquad (3.1)$$

Equation 3.1 illustrates that the upper level objective is to maximize the number of vehicles entering the regulated areas. In the objective function (Max Q) there are two parts. The first part of the equation represents all the emergency vehicles that can be allowed to enter the seismic disaster areas. The second part of the equation represents the maximum number of private vehicles allowed to enter the seismic disaster areas under traffic control. Adding the two parts together represents the entire traffic flows subject to traffic control.

Upper Level Constraints

$$\sum_{p\in P_{ij}} V^{I}_{pij} = r_{ij} \cdot Q_d \qquad (i \in I_i,\ \ j \in J_i) \qquad (3.2)$$

Equation 3.2 represents the origin and destination flow conservation constraint for internal-internal trips.

$$\sum_{p\in P_{ij}} V^{E}_{pij} = \theta \cdot s_{ij} \cdot Q_i \qquad \begin{pmatrix} i \in I_i,\ \ j \in J_o \\ i \in I_o,\ \ j \in J_i \end{pmatrix} \qquad (3.3)$$

Equation 3.3 represents the origin and destination flow conservation constraint for internal-external or external-internal trips.

$$V_{ij} = \sum_{p\in P_{ij}} V^{I}_{pij} + \sum_{p\in P_{ij}} V^{E}_{pij} \qquad (i \in I_i,\ \ j \in J_o) \qquad (3.4)$$

Equation 3.4 represents all the private vehicles between OD pairs.

$$\sum_{m=1}^{M} V_{mn} \geq V_n \qquad (n = 1,\ \ 2,.....N) \qquad (3.5)$$

Equation 3.5 implies that the constraints with respect to the total number of emergency vehicles necessary for rescue missions at each demand node n.

$$\sum_{n=1}^{N} V_{mn} \leq d_m \cdot V_m \qquad (m = 1,\ \ 2,......M) \qquad (3.6)$$

Equation 3.6 implies that the constraints with respect to the total number of emergency vehicles from the rescue depot m.

$$\sum_{m=1}^{M} d_m \leq D \qquad (3.7)$$

Equation 3.7 says that at most D depots can be located.

$$V_l \leq \mu \cdot C_l \qquad (3.8)$$

Equation 3.8 implies that total amount of vehicles (emergency and private vehicles) entering the regulated disaster areas (including those already inside the areas) could not exceed the reduced roadway capacity.

Lower Level Objective $\quad Min \ \sum_{l} \int_0^{V_l} t_l(x)dx + \frac{1}{\gamma} \sum_{i=1}^{I} \sum_{j=1}^{J} \left(T_{ij} \ln T_{ij} - T_{ij}\right) \qquad (3.9)$

Equation 3.9 illustrates that the lower level objective is to minimize the total travel time from the users' perspective. The first item in this equation represents road network assignment and the second item of the equation analyzes the trip distribution.

Lower Level Constraints

$$\sum_{p\in P_{ij}} q_{pij} = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p\in P_{ij}} \delta_{pij}^{l}\cdot V_{pij}^{I} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p\in P_{ij}} \delta_{pij}^{l}\cdot V_{pij}^{E} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{p\in E_{mn}} \delta_{pmn}^{l}\cdot V_{pmn} \qquad (3.10)$$

Equation 3.10 represents the link capacity constraints that consider the emergency and private vehicles.

$$V_l = \sum_{i\in I}\sum_{j\in J}\sum_{p\in P_{ij}} r_{pij}^{l}\cdot q_{pij} \qquad for \quad all \quad l\in L \qquad (3.11)$$

Equation 3.11 represents the traffic flows on every road section (V_l). Parameter r_{pij}^{l} is a dummy variable, which will be marked as 1 if vehicles pass link l on path p, otherwise as 0.

$$\sum_{p\in P_{ij}} ff_{pij} = T_{ij} \qquad \forall ij \qquad (3.12)$$

Equation 3.12 represents total amount of trips passing through path p.

$$\sum_{j\in J} T_{ij} = O_i \qquad \forall i \qquad (3.13) \qquad\qquad \sum_{i\in I} T_{ij} = D_j \qquad \forall j \qquad (3.14)$$

Equation 3.13 and Equation 3.14 represents the total amount of starting trips and ending trips, both are the outcome of trip distribution that should meet the principle of entropy model.

$$q_{pij} \ge 0 \qquad for \quad all \quad p\in P_{ij},\ \ i\in I,\ \ j\in J \qquad (3.15)$$

Equation 3.15 is to assure the volume of p path will always be positive.

$$ff_{pij} \ge 0 \qquad (3.16) \qquad\qquad V_{pij}^{I} \ge 0 \qquad (3.17) \qquad\qquad V_{pij}^{E} \ge 0 \qquad (3.18)$$

$$V_{pmn} \ge 0 \qquad (m = 1,\ \ 2,\ldots.M \qquad n = 1,\ \ 2,\ldots.N;\ \ p\in e_{mn}) \qquad (3.19)$$

$$V_{mn} \ge 0 \qquad (m = 1,\ \ 2,\ldots.M \qquad n = 1,\ \ 2,\ldots.N) \qquad (3.20)$$

Equation 3.16 to Equation 3.20 is to guarantee the amounts of different objective trips passing through path p will not be negative.

3.4 Variable Definitions

1. Controllable Variables

V_{mn} : number of emergency vehicles from rescue depot m to demand node n

V_m : total number of emergency vehicles from rescue depot m

V_n : total number of emergency vehicles

D : number of depots to locate

to demand node n

J : set of attraction zones ($J = J_i \cup J_o$)

I_i : set of generation zones inside the disaster area

I_o : set of generation zones outside the disaster area

M : number of rescue depots

E_{mn} : a set of paths for emergency vehicle mn between OD pair ij

C_l : capacity flow on link l

I : set of generation zones ($I = I_i \cup I_o$)

N : number of demand nodes

J_i : set of attraction zones inside the disaster area

J_o : set of attraction zones outside the disaster area

L : a set of links

P_{ij} : a set of paths for OD pair ij

μ : allowable congestion level

γ : dispersion parameter

2. Uncontrollable Variables

Q_d : maximum traffic demand of disaster area

V_{pij}^{I} : the p-th path traffic volume on an internal-internal OD pair ij

θ : traffic control ratios

V_{pmn} : the p-th path emergency vehicles between OD pair ij

V_l : traffic flow on link l

q_p : p-th path flow between OD pair ij

O_i : number of trips from i

ff_{ij}^{p} : number of trips for p-th path

r_{ij} : unit OD traffic volume on an OD pair ij generated in or attracted to the zone inside the disaster area

d_m : if we locate at candidate depot m then 1, otherwise 0

r_{pij}^{l} : if the p-th path between OD pair ij is included on link l then 1, otherwise 0

V_{ij} : number of private vehicles between OD pair ij

V_{pij}^{E} : the p-th path traffic volume on an internal-external or external-internal OD pair

Q_i : total amount of OD traffic volume generated from zone i

Q_{ij} : traffic volume between OD pair ij

$t_l(x)$: travel time function on link l

D_j : number of trips to j

T_{ij} : number of OD pair ij

s_{ij} : destination choice ratio on an internal-external or external-internal OD pair ij

δ_{pij}^{l} : if the p-th path between OD pair ij is included on link l then 1, otherwise 0

δ_{pmn}^{l} : if the p-th path between OD pair mn is on link l then 1, otherwise 0

4. NUMERICAL EXAMPLES

4.1 A Hypothetical Network

A hypothetical network is used for the numerical example in this study, as shown in Figure 4. The road network has 11 nodes and 28 links, of which there are 5 centroids (3 centroids inside the disaster area and 2 centroids outside the disaster area). Each link is assumed to have two types of costs: one corresponds to the cost in the normal state of road and the other is in the degraded state of road. The OD traffic volumes under normal conditions are listed in Table 1. The road network capacity under each OD traffic volume is 2940 trips. Different scenarios are assumed based on the different road capacity such as the capacity is decreased by 60% (link 01, 02, 09, 10, 23, 24 of road network), or 70% (link 04, 06, 11, 13, 20, 21 of road network) and the others by 80% compared with the normal road network. Calculation of the road network capacity on the degraded road network generates 2178 trips, 74% of the normal network capacity.

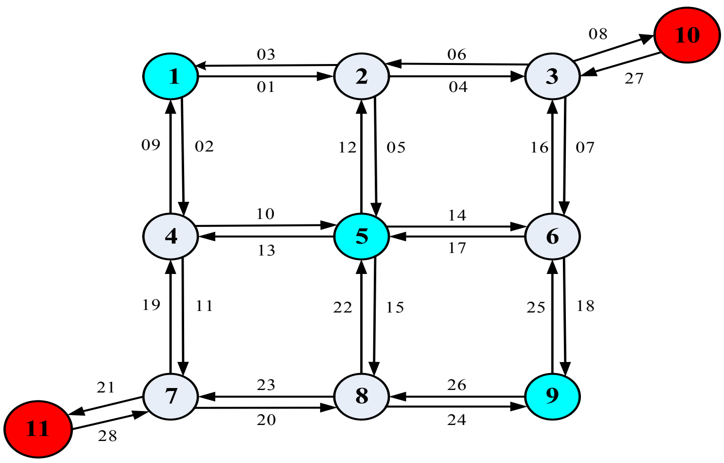

Figure 4 Test road network. All links are two-directional.

The estimated maximum demand of passenger car trip after seismic disaster under 72 hours is 4040 trips, and the assumed rescue depots of emergency vehicles (such as ambulance, rescue and restoration flows) are located at two centroids (node 10, 11) outside the disaster area as illustrated in Figure 4. It is assumed that each demand node (node 1, 5, 9) needs to have 200 emergency vehicles, such as that the total number of emergency vehicles from each rescue depot is 600 trips. The emergency vehicles V_{mn} are assigned to the shortest path between rescue depot m and demand node n. Then the total amount of OD traffic demand is calculated as illustrated in Table 1. The link travel time function used in the user equilibrium model is as follows:

$$t(V_l) = t(0)\left[1 + 0.15\left(\frac{V_l}{C_l}\right)^4\right] \qquad (4.1)$$

In the example, every reasonable path for the OD pair is assumed to be known. The path flows are determined in the assignment model, and the traffic volume on a link is obtained after the path flows are obtained.

Table 1 Link data for the example road network

Link No.	Start Node	End Node	Free Flow Travel Time	Link Capacity (normal)	Link Capacity (degraded)	Link Traffic Flow (normal)	Max. Traffic Demand
01	1	2	2	100	60	80	100
02	1	4	2	100	60	80	100
03	2	1	3	100	80	80	200
04	2	3	3	100	70	80	100
05	2	5	3	80	64	60	130
06	3	2	2	100	70	80	100
07	3	6	2	100	80	80	100
08	3	10	4	100	80	80	100
09	4	1	3	100	60	80	200
10	4	5	3	80	48	60	130
11	4	7	3	100	70	80	100
12	5	2	2	80	64	60	80
13	5	4	2	80	56	60	80
14	5	6	2	80	64	60	80
15	5	8	2	80	64	60	80
16	6	3	3	100	80	80	100
17	6	5	3	80	64	60	130
18	6	9	3	100	80	80	200
19	7	4	2	100	80	80	100
20	7	8	2	100	70	80	100
21	7	11	2	100	70	80	100
22	8	5	3	80	64	60	130
23	8	7	3	100	60	80	100
24	8	9	3	100	60	80	200
25	9	6	2	100	80	80	100
26	9	8	2	100	80	80	100
27	10	3	4	250	200	160	500
28	11	7	4	250	200	160	500

4.2 Numerical Results

To prove the feasibility, this paper has conducted a numerical case study using a small sample data from the earthquake-raided areas. To solve the model efficiently, the genetic algorithm been applied to solve the model. A computer program coded with Visual Basic.NET was performed on a PentiumⅣ personal computer with 32M RAM. Since we assumed that each demand node needs to have 200 emergency vehicles, and the same condition as the previous hypothetical road network. The numerical result through the bi-level programming and user equilibrium assignment, the total number of vehicles on the road network inside the disaster area is 2178. Although the traffic volumes after the traffic control indicates that there remains some road network capacity, it is better to give the first priority to accommodate all emergency rescue vehicles (600 vehicles) from outside into the regulated area, and passenger cars are permitted to enter the regulated area are about 466 vehicles as illustrated in Figure 5.

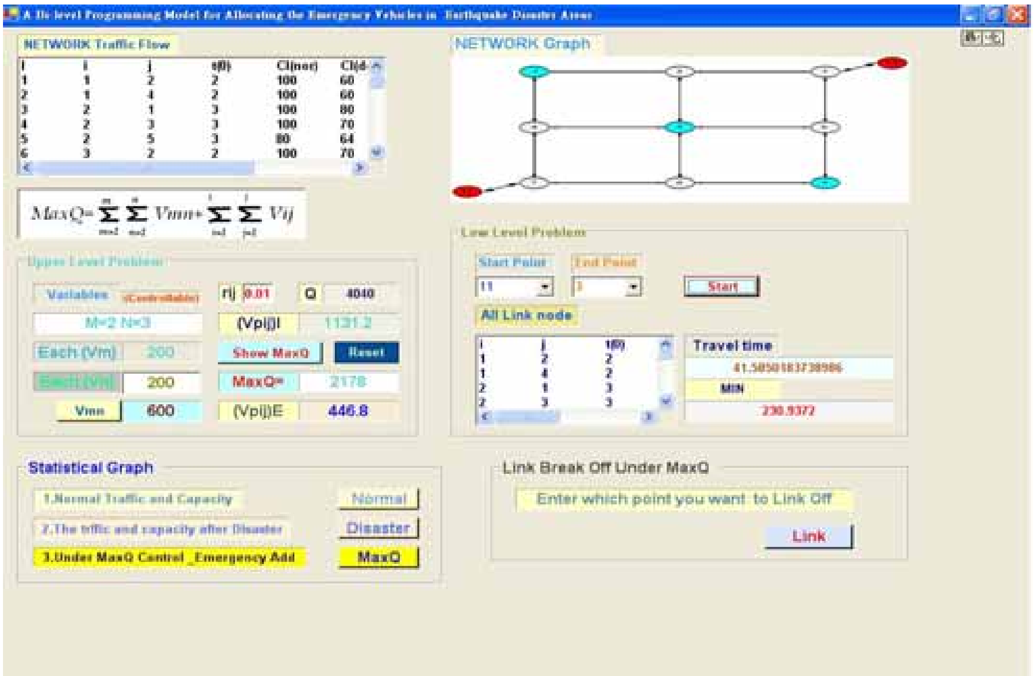

Figure 5 Total numbers of vehicle are permitted to enter the regulated area

Figure 6 indicates that there remains a certain amount of road network capacity (red bar chart) left to accommodate emergency and passenger cars. The commuting trips or personal safety confirmation trips should be given a lower priority to enter the disaster area in order to meet the needs of emergency vehicles.

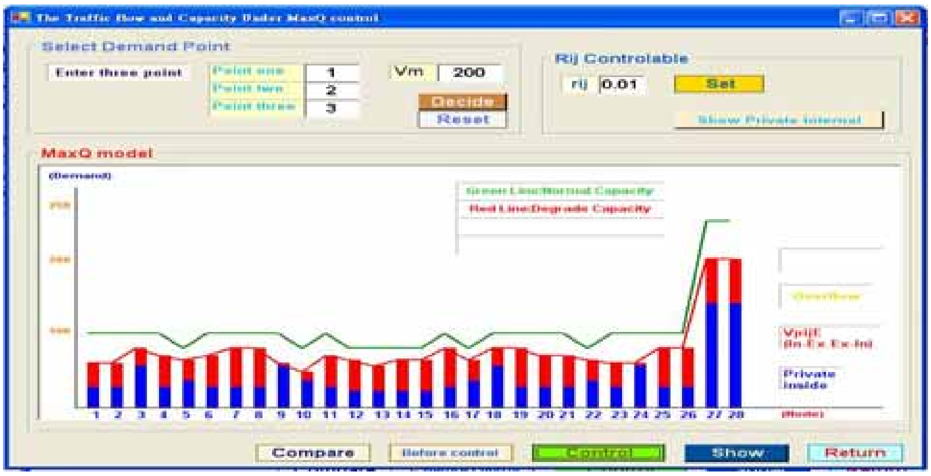

Figure 6 Determination of allowable vehicle flows under degraded road network capacity

Figure 7 shows the scenarios that when the demand of passenger cars (yellow bar chart) exceeds the degraded road network capacity in the disaster area, all the passenger cars should not be allowed to enter the disaster area. Figure 8 depicts the other scenarios that the total amount of emergency vehicles (green bar chart) from each location of rescue depot to enter the regulation area under the degraded road network capacity.

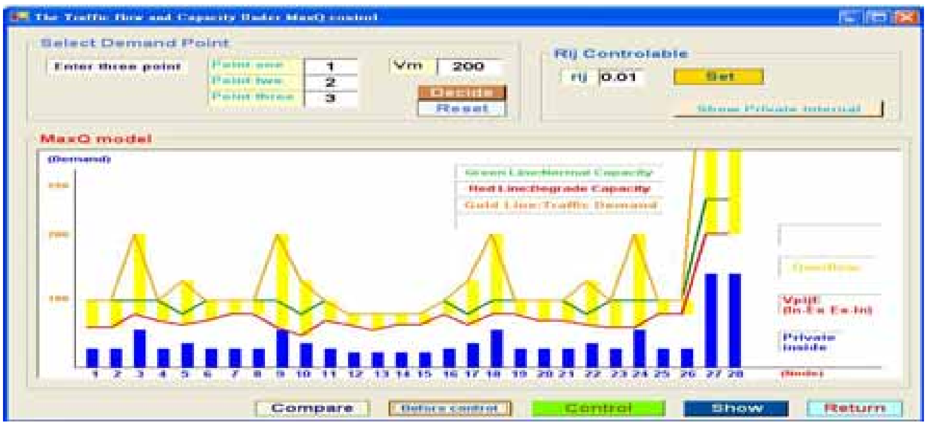

Figure 7 Traffic demand over degraded road network capacity

Figure 9 indicates that when unit OD traffic volumes on an OD pair ij inside the disaster area increase, some emergency vehicles (red bar chart) exceeds the degraded road network capacity should be regulated. These results imply that the total amount of passenger cars entering into the regulated area is different depending on the number of emergency rescue vehicles and location of the rescue depots.

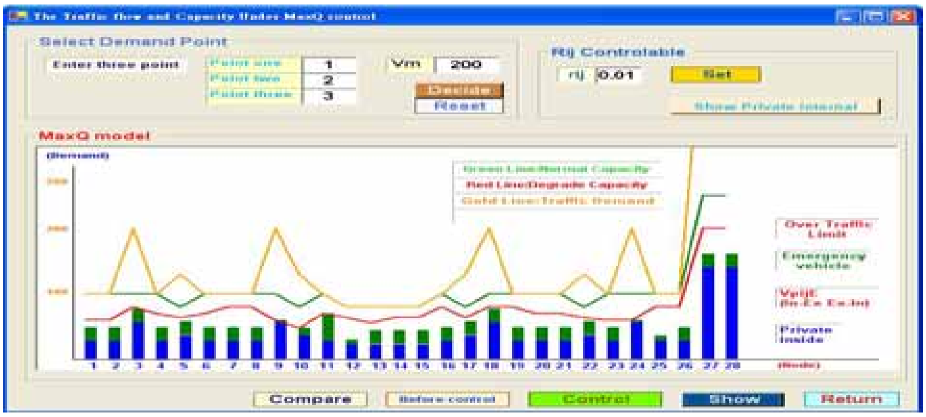

Figure 8 Allowable emergency vehicles under degraded road network capacity

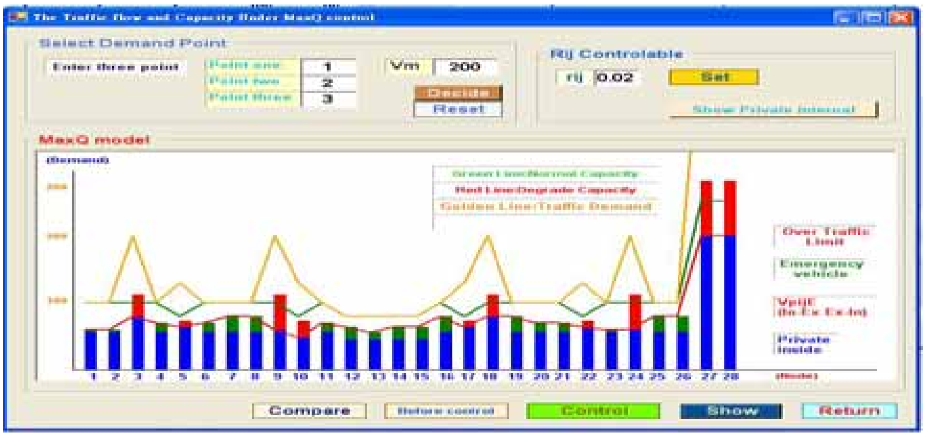

Figure 9 Some emergency vehicles exceed degraded road network capacity

5. CONCLUSIONS AND RECOMMENDATIONS

Using the bi-level programming model, this study attempts to build a dynamic traffic control strategy to deal with needs of restoring order from chaos as soon as possible after an earthquake. To be specific, the strategy is trying to satisfy the unusual traffic conditions in various post-earthquake periods, and to assist decision makers to make the appropriate decisions considering different objectives and traffic situations. To prove the feasibility of the proposed conceptual models, the study has conducted a numerical case study using a small sample data from the earthquake-raided areas. To solve the model efficiently, the genetic algorithm been applied to solve the model. A numerical example shows that this study can create an effective way to implement traffic regulation during earthquake disaster.

The bi-level programming model can be proved to be flexible and effective in solving the problem of traffic control decision-making. The multi-objective bi-level programming approach indeed provides a powerful interactive decision environment, allowing the decision-makers to learn about the problem before committing to a final decision. However, there are some limitations and recommendations of this study worth being addressed in future studies. First, the collection of sufficient data to reflect the real damages in earthquake-raided areas to prove the feasibility of the models is still a difficult task at this stage. Secondly, incorporating temporal dimension into the model such that the dynamics of flow variations over time could be better considered. Thirdly, instead of establishing comprehensive contingency plans for some unexpected disasters, the study suggests that developing an efficient information analyzing and decision support system will be worthwhile. Particularly, it is believed that the usage of ITS technology will help in improving existing traffic management systems. In that case, some limitations of applying the proposed model might not be a problem in the future. The contributions of our work are as follows:

1. We have brought out how mathematical and interactive decision environment and traffic control issues by formulating the modeling approach that can be proved to be flexible and effective in solving the problem.
2. We have shown how a bi-level programming model in improving existing traffic management systems to control vehicles in or out of the disaster areas rationally.
3. We have demonstrated that, by utilizing the "Taiwan Earthquake Loss Estimation System" simulation data and employing the bi-level programming model technique, which can implement a dynamic traffic control mechanism for real time management.

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