CHAPTER 1 INTRODUCTION

1.1 Research Background

The Chi-Chi Earthquake that occurred in Nantou, Taiwan, on September 21, 1999, caused serious damage to the infrastructures in the disaster areas. Transportation network, gas, water and electric power systems were badly impacted. There were road blockage and traffic congestion, making it difficult to access the disaster areas. These posed challenges to on-site operators in charge of delivering supplies, evacuation, rescue and restoration.

Congestion caused by damaged urban road networks called for efficient disaster traffic management. In addition, severe damages on main roads and bridges after the earthquake decreased road network capacities. Thus, it is undoubtedly important to maintain the basic functions of road systems through traffic regulation/management.

A review of the literature shows that most previous attempts to solving the above problem focused mainly on engineering designs and rescue scheduling. Little attention had been paid to the importance of traffic regulation and management in earthquake disaster areas. However, efforts on contingency study can never be over-emphasized; not to mention the little advance made in earthquake prediction. This is particularly true in the case of the Chi-Chi Earthquake. In the first couple of days, everything was in chaos. People were hardly prepared to deal with such a disaster. Policy-makers could only rely on limited information and resources available. Therefore, rescue operation was haphazard and disorganized in the beginning. How to maintain a balance between traffic demand and supply in the aftermath of an earthquake was of grave concern.

1.2 Research Motivations and Objectives

In the aftermath of a disaster, efficient traffic management is critical to minimizing the loss of life and maximizing the efficiency of rescue operations. There is a vital need to balance travel demand (traffic on a link) and traffic supply (the capacity of a link) when in tackling traffic congestion (Tomita *et al*., 1995). The motivation of this research is to develop a decision-making tool that can provide determining variables for private vehicle flows to ensure that travel demand does not exceed road network capacity when traffic function in the road network deteriorates.

The objectives of this study are three-fold. First, it tries to deal with the question of how we can reduce damages in earthquake-raided areas. Second, it attempts to provide a quick and effective means to return chaos to normal in the aftermath of an earthquake period. Finally, it develops an appropriate decision-making tool using traffic regulation model formulation to a achieve traffic control strategies in disaster areas.

1.3 Research Scope

In the past, research on post-earthquake transportation focused mainly on transportation engineering designs and rescue scheduling. Few studies have paid attention to the traffic regulation management in earthquake disaster areas.（Iida, 1995）presented a traffic management system against major earthquakes. A bi-level programming model seeking effective traffic regulation/management was developed. However, the model focused only on the needs of victims, neglecting the needs of those who come to rescue. In view of the dual concerns, this research attempts to build a dynamic strategic model using a bi-level programming technique to improve traffic regulation management.

To fulfill the goals mentioned above, this study explores the case of the Chi-Chi Earthquake that occurred in Nantou, Taiwan, in 1999. Data obtained for this study include the road network damage situations, nature of traffic involved, and regulation measures adopted during that incident. With these data, this study compares the empirical experiences adopted in Japan and the United States with those in Taiwan. The study hopes to develop a better set of traffic management strategies in urban road network so that future earthquakes can be more efficiently coped with.

To facilitate the formulation of traffic regulation model formulation and implement the traffic regulation strategies, this research addresses the urban road network in the main with focuses on the emergency road network system of Taipei City. In order to accommodate the traffic situation in the post-earthquake period, this research employs the simulated data of the Taiwan Earthquake Loss Estimation System (TELES) for its hypothetical scenario analysis. To test the feasibility of this traffic regulation model, we assume that the commander of the Emergency Response Center in county or city governments inside the earthquake-raided areas is the main decision-maker. The areas affected by earthquakes constitute the space where regulation control is to be implemented. Policemen are the main actors. Among the developed approaches regarding traffic-flow assignment and distribution, the principle of user equivalent assumption is adequate if congestion is the main factor to be considered when choosing traffic routes.

1.4 Research Method

This study, after reviewing related literature on earthquake operations, has explored various traffic-regulation measures in contingency and their effects. Special attention is paid to how to make preparation against unpredictable natural disasters, and useful ideas for traffic regulation and rescue are introduced. By presenting the strategy of traffic regulation in contingency, this study hopes to improve effectiveness and efficiency of rescue and restoration in the post-disaster period. The problem to be addressed is formulated as a multi-objective, two-model (private vehicle flows and emergency vehicles) bi-level programming problem using the concept of network flow theory.

If a disaster lasts longer, blockage of roads will be pose problems to evacuation, restoration and rescue. As it is necessary to balance travel demand and service supply in order to relieve traffic congestion, this study proposes a multi-level optimization model when it presents the interactive decision process between roadway control decision-makers and road-users. It is assumed that the decision is executed in a top-down hierarchy, because low-level decision-makers often make their choices under certain conditions determined by the high-level decision-makers. The problem discussed above is similar to the static two-person Stackelberg game and the interactive decision-making process (Lee, 2001). This type of decision process is well known and has been studied extensively under the topic of bi-level programming problem.

To set up a strategy of traffic regulation in earthquake-affected areas, this research adopts literature analysis by integrating related studies both local and abroad with a view to understanding properly the characteristics of the means of transport taken by the population and the potential effect of earthquakes on traffic. This research attempts to derive a better contingency plan for traffic regulation strategy using traffic regulation model formulation. In addition, with a view to gaining the knowledge of the practicability and feasibility of the model, this research executes a case study and scenario analysis of the Taipei City.

A. Literature Review

This research starts from a review of literature by exploring traffic regulation contingency systems for dealing with earthquakes, looking into earthquake-related damages and analyzing strength and weakness of contingency measures adopted by various countries. It seeks to fully understand difficulties and challenges faced by different countries with different traffic regulation contingency measures coming into play so that we can foresee the future trend of traffic regulation contingency measures in Taiwan. With this, it is hoped that we can develop an overall strategy of traffic regulation contingency measures by integrating proper concept, method and technologies of disaster prevention and by systematic execution and forward-looking programming.

B. Model Formulation

This research constructs a traffic regulation contingency model using the bi-level programming method. This programming is justified because whenever earthquakes occur, the decision-making of contingency units in charge of traffic programming and regulation as well as the choice-making of general road-users for routes are characterized by a mutually interactive process.

C. Case Study and Scenario Analysis

It is understood that the current technology cannot predict the scale of earthquakes and the consequent damages they cause, but it is for sure that the probability of an earthquake with the exactly the same epicenter is pretty low; especially for strong earthquakes. In view of this, the present research develops a model of traffic regulation strategy and analyzes its feasibility using simulated data in the context of hypothetical scenarios.

1.5 Dissertation Framework

This dissertation is organized as follows. Chapter 1 is the introduction, which gives an overview of this research in terms of background, motivation and objective, research scope, methodologies and approach, and the framework of this dissertation. Chapter 2 contains a review of past researches for traffic regulation strategy in disaster areas, the features of bi-level programming, and the solution algorithm of methodologies. Chapter 3 illustrates the methodology of fuzzy interactive algorithm and genetic algorithm. Chapter 4 depicts the traffic control strategies and the decision-making framework of traffic regulation. The formulation of the Basic Model and its detailed solving algorithm using fuzzy interactive programming and genetic algorithm will also be described. Then, the Revised Model is developed and elaborated in Chapter 5. Case studies of real emergency rescue road-network traffic control strategy for Taipei city with different scenarios are presented in Chapter 6 to demonstrate the feasibility and efficiency of the models. The final Chapter concludes the research and provides suggestions for future empirical studies. The flow chart of this dissertation is shown in Figure 1.2.

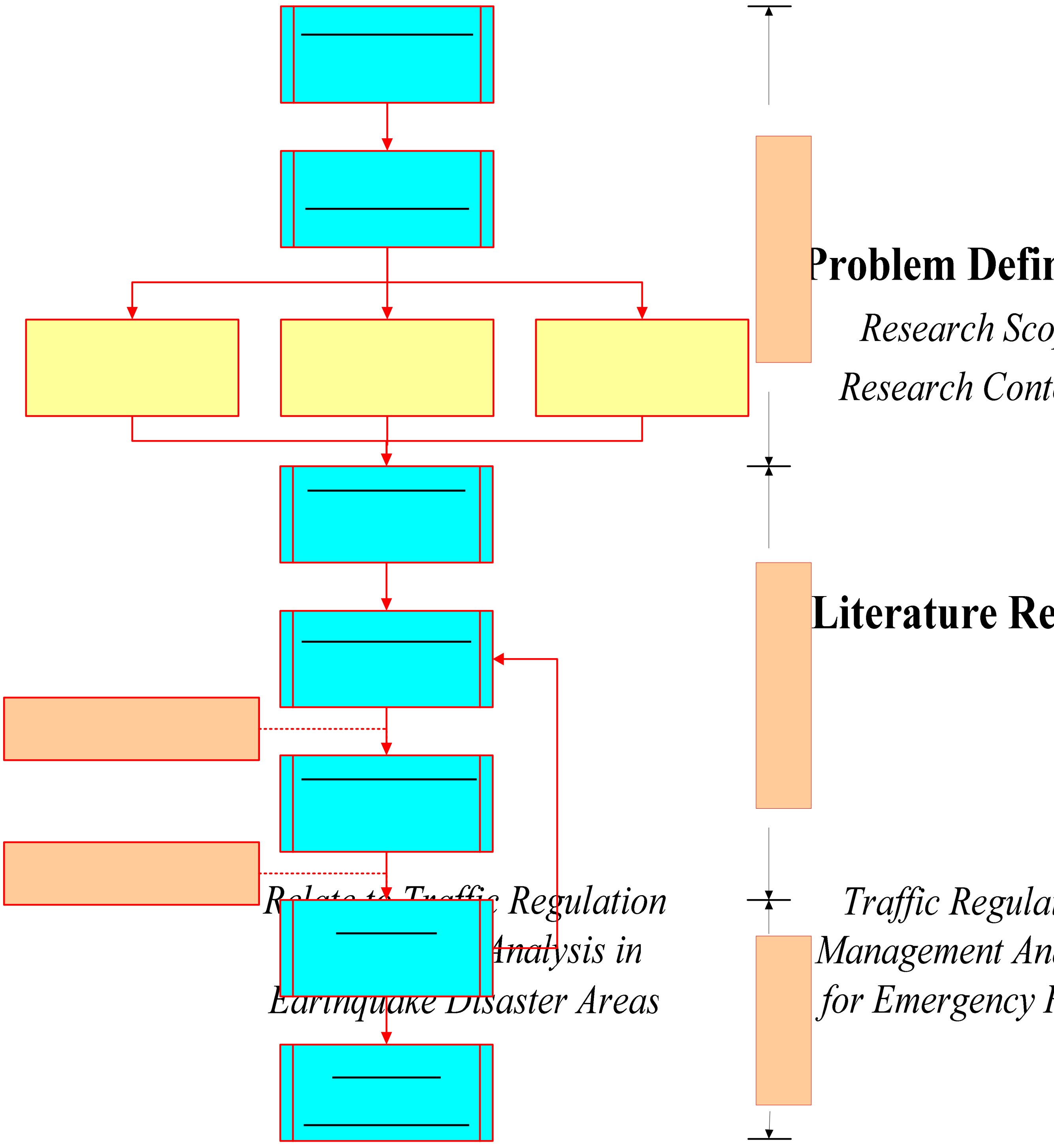


Figure 1.2 Flow-Chart of Dissertation

CHAPTER 2 LITERATURE REVIEW

The Chi-Chi Earthquake that occurred in Nantou, Taiwan, in 1999 jeopardized not only transportation systems, but also public safety. Many towns and villages in central Taiwan were seriously affected. Highway systems were significantly damaged in this disaster. The Chi-Chi Earthquake has been the most serious earthquake disaster of Taiwan in recent years. Figure 2.1 shows the major areas affected, which include Taichung City, Taichung County, Chunghua County and Nantou County.

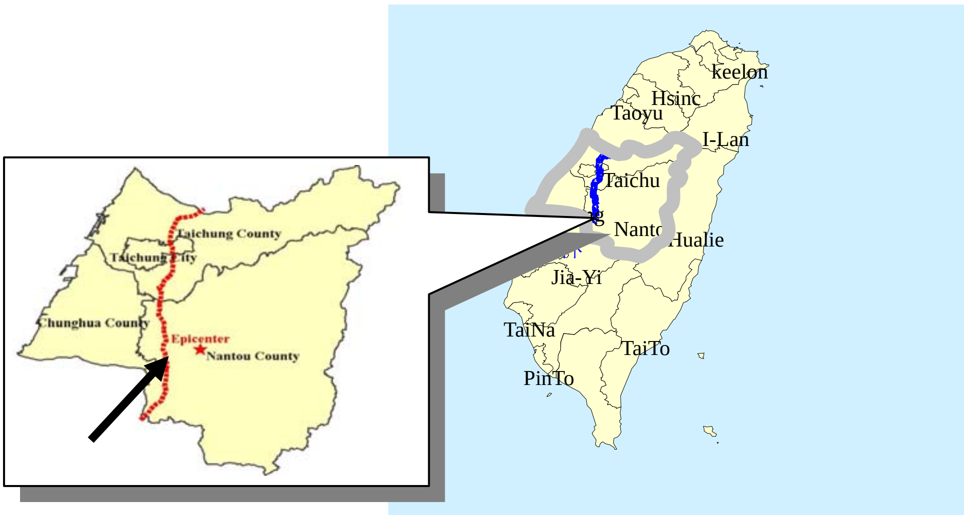


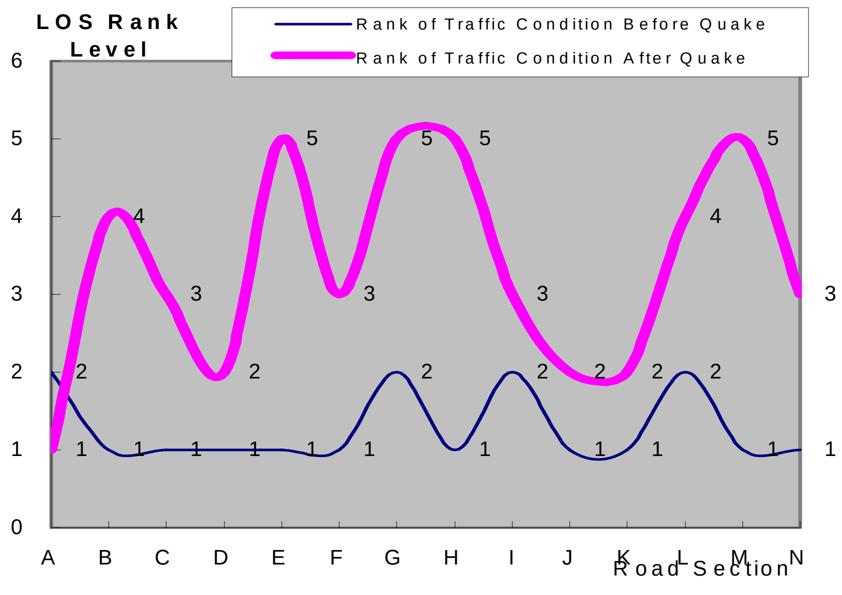
Figure 2.1 Distributions of Major Disaster Areas

The 921 earthquake exposes certain earthquake-related problems in Taiwan that requires attention. The contingency mechanism for dealing with earthquake-related damage controls needs to be enhanced. This research looks into issues on traffic regulation in earthquake-affected areas. By reviewing earthquake-related damages, analyzing cases and exploring mathematic programming methods, it seeks to establish a theoretical and pragmatic basis for traffic regulation strategy model.

2.1 Damages of Road Network System in Earthquake Disaster

2.1.1 Road Network Conditions after Chi-Chi Earthquake

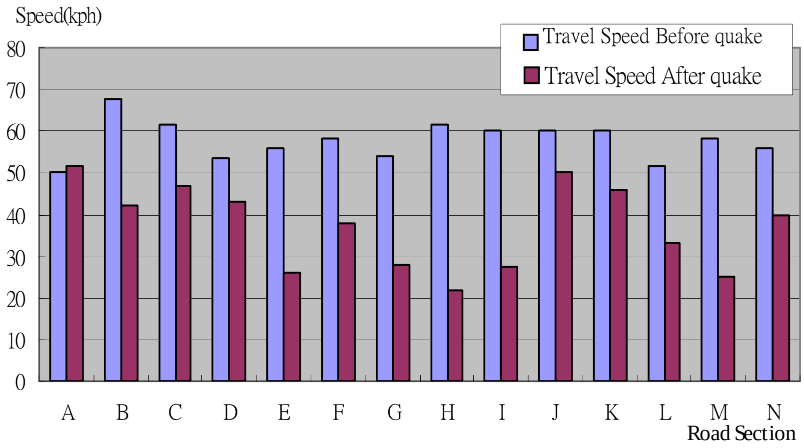
According to the statistics issued by Post-921 Reconstruction Commission organized by the Executive Yuan, Taiwan, the Chi-Chi Earthquake occurred at a magnitude of 7.3 in 1999, left 2,400 dead, and more than 10,000 injured. More than 30,000 house units were destroyed, 25,000 house units were damaged to various extents, and 100,000 people became homeless. Collapsed buildings resulted in roadway damage and blockage, which in turn degraded the level of service (LOS) on those affected roadways. Figure 2.2 illustrates the changes in LOS on roadways before and after the Chi-Chi Earthquake in Tsaotuan Village. Figure 2.3 displays the changes in traffic speed in the disaster areas.



Road Section	
A	(No. 3)
B	Chung-Tou Road
C	(No. 14)
D	(No. 148)
E	(No. 3)
F	(No. 3-1)
G	(No. 14-2)
H	(No. 14)
I	(No. 14-4)
J	(No. 139)
K	(No. 150)
L	(No. 3)
M	(No. 139)
N	(No. 14-2)

Figure 2.2 Changing LOS Before/After Chi-Chi Earthquake

Source: Chinese Institute of Transportation, 2000.



Road Section	
A	(No. 3)
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I	(No. 14-4)
J	(No. 139)
K	(No. 150)
L	(No. 3)
M	(No. 139)
N	(No. 14-2)

Figure 2.3 Changing Travel Speed Before/After Chi-Chi Earthquake

Source: Chinese Institute of Transportation, 2000.

This study probes into the LOS of roadways through a questionnaire survey. Traffic congestion is classified into five different levels, from the best to the worst. Level 1 represents “very few cars on the road and high driving speed”, Level 2 means “many cars on the road and moderate driving speed” and Level 3 shows “slow but acceptable driving speed”. It need to be pointed out that Level 4 (congested with slower speed) means traffic moves slowly, and Level 5 (road space occupied with very slow speed) shows that the traffic almost stops due to decrease in lane width and / or road closure. The best traffic condition scores 1 point, while the worst one scores 5 points. Averaging all the scores of a specific link given by the respondents yields the final scores for that link. If the final score is between 1 and 1.5, the LOS of the specific link is set to be Level A, representing “a comfortable traffic situation with a high average travel speed”. If the final score is between 1.5 and 2.5, then its LOS is set to be Level B, representing “a smooth traffic situation with a moderate average travel speed”. If the final score is between 2.5 and 3.5, then its LOS is set to be Level C, representing “a fair traffic situation with an acceptable average travel speed”. If the final score is between 3.5 and 4.5, then its LOS is set to be Level D, representing “a congested situation with a low average traffic speed”. If the final score is between 4.5 and 5, then its LOS is set to be Level E, representing “a seriously congested situation with an unbearable travel speed”.

Results of data analysis results show that the LOS of the highways connecting Nantou City and Tsaotuan Village ranged from Levels A to B before the earthquake. However, after the earthquake, it ranged from Levels A to E, implying significant damage done. Only four highway segments retained the same LOS, and the other four highway segments all degraded to Level E.

Figure 2.3 illustrates the change in traffic speeds before and after the earthquake. As can be seen, the travel speeds before the disaster were relatively high, ranging from 50-kph to the highest of 67.8 kph. However, all travel speeds were decreased after the earthquake, with the greatest reduction of 65%.

2.1.2 Road Network Conditions after Hanshin-Awaji Earthquake

On January 17, 1995 the Hanshin-Awaji Earthquake occurred on western Honshu Island in southern Hyogo prefecture, Japan. The earthquake was assigned a JMA magnitude of 7.2 by the Japan Meteorological Agency (JMA). According to the survey done by Tzeng and Chang, the earthquake claimed more than 5,000 casualties with over 30,000 people hurt and 70,000 strong buildings reported as severely damaged. Those affected included 33 spots in the railroad station, 300 vehicles, 10 railway lines, 1 section on the highway, 4 collapsed bridges, 180 half-collapsed bridges, 300 mildly damaged bridges and 2000 sections of the general road system. Financially, net losses as the result of the earthquake amounted to US$100 billion, which were 10 times of that caused by the Northridge earthquake that occurred on January 17, 1994, California.

The adverse effects on traffic caused by the Hanshin-Awaji Earthquake are as follows:

1. Severe traffic congestion in the post-earthquake period;
2. Significant decline in transportation capacities;
3. Bridges located on soft soil surface and on reclaimed lands were seriously damaged;
4. MTR road systems including bridges and underground sub-systems were reported damaged for the first time in the history of Japan;
5. Most bridges that were seriously damaged were built before the 1970s. This provides evidence that accumulated experience in conditioning earthquakes in the past and advances in techniques for coping with them help reduce the extent of damages caused by earthquakes.

However, the great severity of damage as the result of the Hyogo Ken Nanbu Earthquake destroyed, at least partially, Japanese overconfidence in their skill of coping with earthquakes. It called the attention of the Japanese people to effective management of emergency rescues and damage controls. They became aware of the needs to establish speedier, more reliable information system in peacetime and to have better crisis management and more effective contingency capability during and after the occurrence of earthquakes.

2.1.3 Road Network Conditions after Northridge Earthquake

On January 17, 1994, an earthquake of magnitude 6.8 occurred at 0431 hours in Los Angeles. The earthquake's epicenter was in Northridge, San Fernando Valley, 20 miles northwest of Los Angeles. Despite lasting for 40 seconds only, it claimed 57 lives with 5,000 people injured, 25,000 homeless, and financial losses amounted to $47 billion. The earthquake brought about a disconnected web of highways in California as the result of more than 10 collapsed bridges on the highways. The disconnected roads included state-government roads such as nos. 5, 10, 405 and highways such as nos. 1, 14, 118, and 210. The traffic authorities in California estimated that recovery would take 12 to 18 months. Local traffic of California was seriously affected.

Nevertheless, despite the serious damage in the aftermath of the Northridge earthquake, the traffic authorities exemplified great efficiency and effectiveness in dealing with the crisis. Within 12 hours after the occurrence of the earthquake, the state authorities in charge of traffic succeeded in striking a contract to recover 50 percent of transportation capacity by removing 15 main roads and constructing alternative routes. The factors contributing to the success of the US in the rescue mission after the Northridge earthquake are as follows:

1. A speedy mobilization of rescue systems;
2. A timely launch of traffic control;
3. A timely set-up of rescue command center.

The above responses, prompt and efficient, make possible a timely damage control in place, thus minimizing the unexpected effect from the earthquake.

2.2 Post-Earthquake Traffic Regulation Issues

Lessons learned from rescue operations in the Chi-Chi Earthquake reveal that although both government and private organizations had tried their best to rescue the victims, the results turned out to be not as good as expected. This implies that there is much room for improvement. The main difficulty is insufficient information after an earthquake occurs. Without real-time information of the damages on roadway networks, it is difficult, if not impossible, to perform a good traffic regulation management, thus undermining the effectiveness of the rescue operations. Previous experience has indicated that the following problems need to be explored.

1. Current contingency plans are unsatisfactory. Government agencies lack professional institutions and staff to support their field operations.
2. Roadway damage information collection systems are inadequate.
3. Real transportation behaviors including choice of destinations and means of transportation as well as frequency of travel cannot be easily obtained by means of regular surveillance systems.
4. Existing command and decision-making systems cannot provide rational control of vehicles entering or leaving the disaster areas.
5. Current transportation network design lacks the function of contingency operation. The roles of main service routes and their alternative routes are not clearly defined.
6. The need for real-time control and divergence of traffic flows so as to facilitate on-site rescue operation calls for a dynamic traffic regulation mechanism.

2.2.1 The Characteristics of Travel Behavior

The unexpected nature of an earthquake makes it impossible to predict its exact time of occurrence or the location of its epicenter. To avoid its indirect damage on human lives and properties, we need to adopt or develop an effective policy for traffic diversion and regulation. However, such would depend on the information regarding the behavioral of the victims in the affected areas. Therefore, this research analyzes the behavior of the people in the disaster areas and their need. The findings thus obtained will form the basis for formulating policy of traffic regulation.

Judging from the experience accumulated from earthquakes data on traffic behavior in the post-earthquake period, we can divide the people to be studied into two groups: those leaving the disaster areas and those entering. People leaving the disaster areas include those whose houses are damaged, forcing them to find refuge from their relatives, while those evacuated and those physically jeopardized that have to be treated other places, tourists, commuters and students coming outside the areas concerned. On the other hand, people entering the disaster areas include emergency units such as the military, police, firefighting, medical, supplies and international rescues units. There is also engineering personnel that maintain road systems, maintenance and communications. Reviewing the different needs and purposes for traffic behavior in pre- and post-earthquake periods, we categorize them into seven types as follows:

1. **Emergency Rescues**: assistances offered by the military, police, firefighting, medical and supply units;
2. **System Maintenance**: maintaining road system and utilities such as gas line, water and electricity;
3. **Rehabilitation**: the effort of tearing down those architectures that are identified as dangerous and constructing permanent housing or temporary shelters;
4. **Commuting**: traffic provided to office workers and students;
5. **Funeral and Burial**: management of dead bodies of those who perished in the earthquakes;
6. **Disaster Exploration**: providing access to the media, government officials and researchers so that the damage situation can be further explored and understood;
7. **Safety Verification**: activities that confirm the safety of relatives and friends.

2.2.2 Priority of Trip Purpose in Different Post-Earthquake States

According to Table 2.1 provided by IATSS Research Report (1998), which followed the seven purposes of traveling in/out of the disaster areas and issued questionnaires, enquiring about relative priorities of varied phases in the post-earthquake period, recovery of systems and prompt rescues are the major efforts at the initial phase of the post-earthquake period. The first 72 hours are the golden period to life recovery too. At the second phase, rescue activities, aside from being continuous with contingent responses as the first phase, there is a need to rescue utility systems with a view to stabilizing public psychology as well as avoiding damages due to after-shocks. Contents of other phases are dependent upon objectives of rescues and extent of damages. They can come with various but related needs of communication, undertakings and rehabilitations.

Table 2.1 Priority of Trip Purposes Post-Earthquake

Time / Priority	**1st Stage (0-3 day)**	**2nd Stage (4-10 day)**	**3rd Stage (11-20 day)**	**4th Stage (21-30 day)**
1	System Maintenance	Emergency Rescue	System Maintenance	Commuting
2	Emergency Rescue	System Maintenance	Funeral and Burial	System Maintenance
3	Funeral and Burial	Disaster Exploration	Disaster Exploration	Rehabilitation
4	Disaster Exploration	Funeral and Burial	Rehabilitation	Funeral and Burial
5	Rehabilitation	Rehabilitation	Commuting	Disaster Exploration
6	Commuting	Safety Verification	Safety Verification	Emergency Rescue
7	Safety Verification	Commuting	Emergency Rescue	Safety Verification

Resource: IATSS Research Report, 2000.

2.2.3 Development of ITS Technology Against Major Earthquake

In order to keep traffic function normal and effective when managing natural disasters, we have to put high-tech into use. In the following sub-sections, we will illustrate the application of technology and construction of traffic control mechanisms, which can serve as useful references for improvements in technology for natural disaster management.

A. Comprehensive Communication Network Installation

Well before the 921 Earthquake, the National Fire Agency, Ministry of the Interior, Taiwan, had laid its hand on programming functioning networks such as firefighting, first-aid rescue, channeled and radio communications. After the occurrence of the 921 Earthquake, the authorities concerned brought up plans such as contingency radio networks and satellite systems to make the previous programs more comprehensive. Objectives of the effort are to link agencies in charge of policing, water systems, hygiene, environmental protection, social politics, weather conditions, electricity, telecommunication, engineering matters so that there is a comprehensive governing network. The plans are also integrated with systems such as mobilization of reserves and civil defense. These networking efforts are designed to meet a higher requirement that we can have smooth and speedy engineering process from notification of disaster to activation of contingent responses.

B. Integrated Emergency Traffic Management System Installation

In order to enhance the effectiveness of the traffic systems in the post-earthquake period, there is a need to bring up contingency plan for traffic regulations. However, traffic regulation as a responsive measure is dependent upon the severity of damage in the affected areas and traffic conditions during the post-earthquake periods. There is therefore a need to bring forth a plan to assure the execution of area regulation and time regulation. In other words, a traffic regulation system for dealing with contingent need during the post-earthquake period is urgently needed. Figure 2.3 illustrates the related conceptual structure with a view to ensure proper functioning of traffic frameworks in the post-earthquake period. As there is a need to build up up-to-date shock-resistant traffic infrastructures, so is there a need as well to have a comprehensive approach to constructing highly reliable and hierarchic road networks. These road networks are important shock-resistant infrastructures that, ideally speaking, can weather heavy damages. More importantly, their design is to serve as emergent traffic rescue and management centers, providing needs for speedy recovery and emergency transportations.

Since damages of earthquakes can expand over a large area, there is also a need to integrate various means of transportation. Moreover, the mutual impact between physical infrastructures and conceptual systems can be complicated. Integrated systems should be developed comprehensively, rather than separately, so as to enhance the overall effectiveness of the post-earthquake traffic management. On the other hand, with the thriving development of Intelligence Traffic System (ITS), availability of time and precision of data have become vital variables in post-earthquake traffic management. They can help with data such as time, options, and locations of contingency operations regarding traffic. Dynamic calculation methods are also getting mature these days. We can directly get data regarding traffic transition in any given time period so that overall traveling data such as originating and destination of trips, rates of O-D trips, and traffic capacity can be deducted.

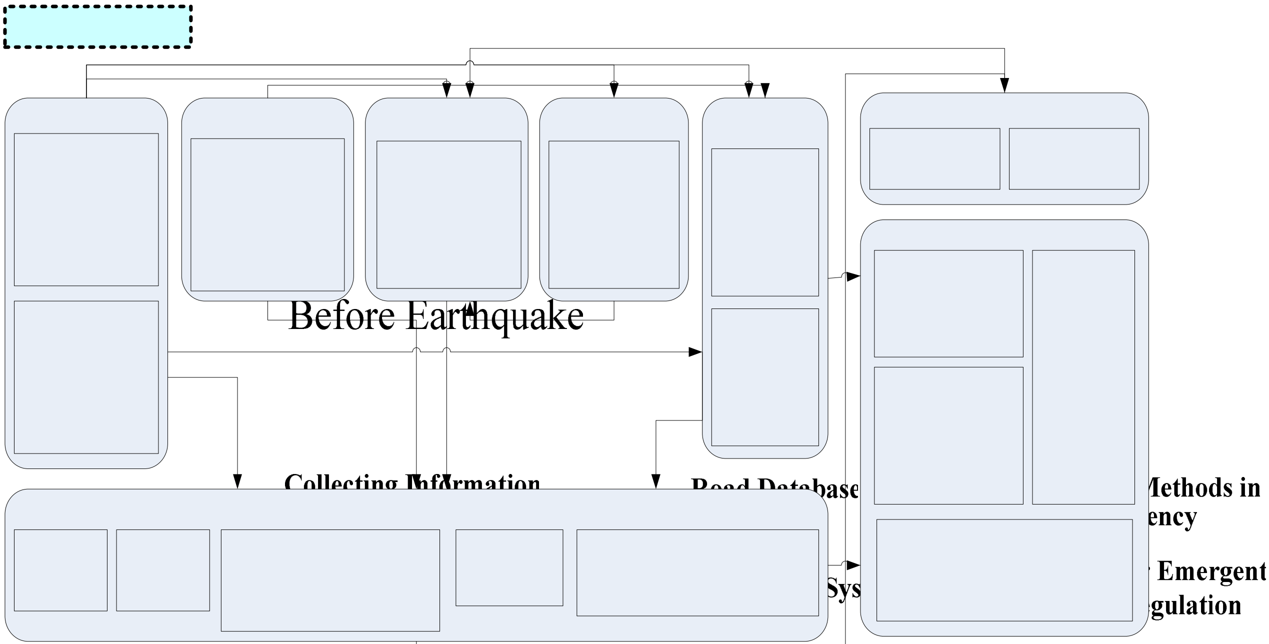


Figure 2.4 Basic Framework of Road Traffic Regulation Management System Post-Earthquake

Source: *Yasunori Iida, Fumitaka Kurauchi, Hirofumi Shimada (2000)*

2.3 Past Researches on Traffic Regulation Strategy in Disaster Area

2.3.1 Comparison of Emergency Response Operations

Table 2.2 shows the statistics of earthquakes taking place in Chi-Chi, Hanshin-Awaji, and Northridge. In terms of scale of damage, the Chi-Chi Earthquake is roughly the same as the Hanshin-Awaji Earthquake, but there is a huge gap in casualties. This is because Great Hanshin-Awaji is a metropolitan area, which led to damage unmatched in Japanese history—financial loss up to US$100 billion and casualties claimed 50,000. Financial loss as the result of the Chi-Chi earthquake is US$9.2 billion, relatively lower than that in the Great Hanshin-Awaji. Nevertheless, the loss constitutes 3.3 percent of the Gross Domestic Production, which has been the highest ever. The Northridge earthquake, on the other hand, is a well-known natural disaster in American history that led to a loss of US$47 billion. What made it worse is the fire as the result of the earthquake. Given these data, how to bring forth an effective traffic regulation strategy to cope with rescue need in the post-earthquake period turns out to be an urgent call.

While there has been so far no significant progress in the prediction of earthquake, response measures for traffic regulation during the post-earthquake period have become vitally important. Within a few days after the Chi-Chi Earthquake, there was no exact traffic regulation measure put into place. This resulted in dysfunction in crisis management with central controls. Decision-makers in charge of traffic regulation, without data on the extent of traffic being damaged and effective traffic regulation measures, could solely rely on intuitive responses and personal preferences. This weakness had caused serious traffic congestion due to heavy traffic demand not for rescue, but ironically for visit and sightseeing at the early post-earthquake period.

The Great Hanshin-Awaji earthquake in Japan, on the other hand, did miss the golden phase for rescue activities due to governing patterns and local sense of dignity. The locals were hesitant about intervention from the Central Government. Aids from the outside and many bottlenecks across the roads between cities and prefectures were major complaints of the people. However, after the consensus had been reached between the local and the Central Government, all the contingency measures became in order. Significant dimensions that are worthwhile for Taiwan to make reference to; include control of total amount of traffic, classification of road functions and construction of emergent supportive system for disseminating related information.

Take the United States for instance. Transportation agencies in the United States have made surveys and come up with the Disaster Transportation Management

System that is characterized by a Time-phased Force and Deployment List and Movement Coordination Center. The Time-phased Force and Deployment List seeks to deploy needed means of transportation as prioritized by the Federal Government to the disaster areas within the shortest notice. The Movement Coordination Center helps facilitate the purchase of means of transportation and to trace the conditions of traffic resources in the disaster areas. In other words, with the assistance of the Disaster Transportation Management System, the US government can guarantee effective traffic service and timely deployment of transportation means. The major government unit in charge of the post-disaster traffic is the Ministry of Communications. It is responsible not only for providing means of transportation, but also assessing traffic infrastructures being damaged, analyzing the impact of the earthquake on traffic routes, and providing necessary technical assistance in traffic matters. All these data are important for selecting traffic networks that are most needed, identifying key elements in traffic resources and integrating requirements for means of transportation issued by the lower units. Supportive units in the main include the Ministries of Defense, Ministry of Foreign Affairs, and Federal Emergency Management Agency. The Ministry of Defense is in charge of providing means of transportation for inland waterways and harbors, and recovering of basic structures of traffic and supports of military vehicles. The Ministry of Foreign Affairs is in charge of coordinating with foreign countries that come to aid with more means of transportation. The Federal Emergency Management Agency monitors the deployment of rescue teams, arranges the list of deployed units and also staffs the Movement Coordination Center. That said, whether it is the overall structural design, share of workload among related bureaucratic units, or their coordination and integration, the US case shows us a good example of contingency programming in traffic regulation during the post-earthquake period.

Table 2.2 Comparison of Emergency Response Operation and Loss in Major Earthquake

Quakes Contents	*Chi-Chi Quake*	*Hanshin-Awaji Quake*	*Northridge Quake*
Time of Happen	1999/09/21	1995/01/17	1994/01/17
Depth of Quake	1.0 km	14 km	17.7 km
Scale of Quake	7.3	7.2	6.8
Populations	2,500,000	3,600,000	—
Number of Disaster Victims	320,000	320,000	—
Emergency Act Implement	≤ 2 hr.	≤ 6 hr.	≤ 15 min.
Injured Person	11,122	50,215	11,918
Dead Person	2,321	6,430	72
Number of ruin House	82,238 households 51000 buildings	460000 households 250000 buildings	114000 buildings
Estimate loss of Economics	USD 0.92 billions	USD 100 billions	USD 47 billions
Loss of GDP	3.3 %	2 %	0.7 %
Emergency Response Organization	This refers to a temporary but moonlight three-level organization consisting of central government, city/county, and town administrations that take National Fire Agency, Ministry of the Interior and the fire department of each city and county as the backbones and command policing forces of cities and counties.	This refers to a temporary but moonlight three-level organization consisting of central government, prefectures, and municipal administrations.	FEMA is a constant organization with professional quality and efficiency better than those of Japan and Taiwan. This is especially significant in horizontal connection and resource integration.
Emergency Response Operations	Traffic regulation only applies to transportation routes in disaster areas. This leaves the criticisms that there is no comprehensive plan, professional know-how, or emergency communication systems. On the other hand, regulation measures cannot be adaptable to missions at different stages.	Regulation only applies to single disaster area without comprehensive scheming. However, there are strict and precise regulation measures on railroad and highway systems at initial phase of the contingency.	FEMA is in direct charge of traffic regulation of the national traffic network. A comprehensive plan is required.
Influence of Political Background	Owing to inadequate rescues equipment, insufficient team members and incomprehensive laws related to the contingency need in the Chi-Chi Earthquake, there was no unified commend and coordination in traffic regulation. What made it worse was that the earthquake took place during the hectic presidential election. This made rescue effort a political bargaining chip while units handling the post-earthquake matters, no matter they are at which level, often shunned their due responsibilities.	Local politics, clans' power and national dignity made the central government hesitant to intervene into the rescues, which delayed the foreign aid and bottlenecked the traffic among prefectures and municipal areas. Whereas no consensus brought about loss of golden time for rescue, later effort came into effect immediately after a consensus is reached.	FEMA is supposed to take charge of the disaster areas in the post-earthquake period. This decision is made without political factors at work.

Source: Ciou, "Disaster Management Science-Earthquake Sections", 2000

2.3.2 Traffic Regulation Strategies in Disaster Area

The strategy of traffic regulation developed depends heavily on the traffic situations. The regulated areas should not be limited to only a specific section of roadways. Instead, contingency plans should cover a more comprehensive area. According to the Law of Disaster Relief newly issued by the government of Taiwan in May 2002, it is mandatory for the contingency plans of disaster relief to stipulate a defined area, where all personnel and vehicles are to be controlled. That is, the contingent traffic regulation should not only facilitate rescue and recovery missions, but also prevent disasters from getting worse. The law also indicates that contingency traffic regulation plans are not restricted to the affected local areas, which can be extended to cover a more comprehensive area if necessary.

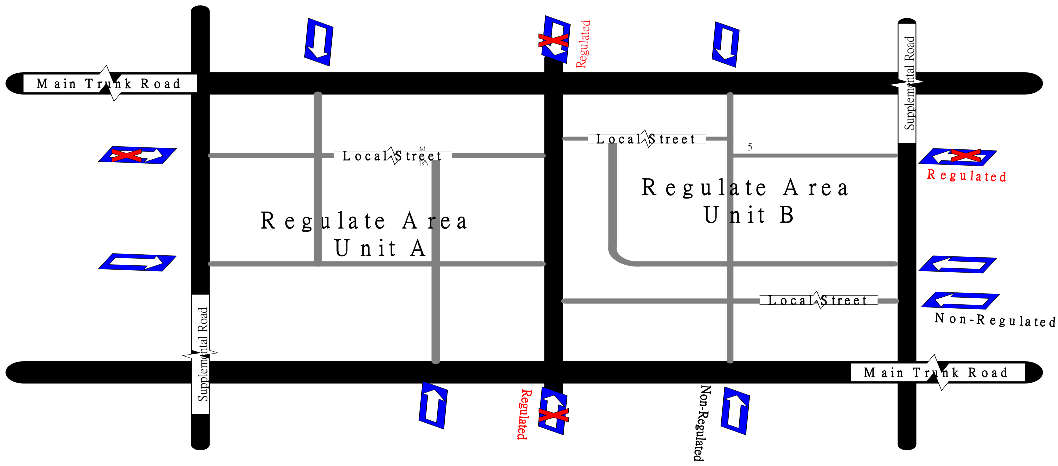


Figure 2.5 Examples of Regulated Areas

Yasunori Iida, Fumitaka Kurauchi, and Hirofumi Shimada develop the area regulation concept for control traffic. An ideal way is to define the control areas before earthquakes. This is important because it will become a difficult task in the aftermath. The pre-determined traffic regulation plan should reflect different degrees of damage on roadways. The major arterial roads and supplementary arterial roads must be defined clearly, and then the basic reaction unit locations surrounding them can be identified beforehand. Figure 2.5 shows the conceptual relationship between two regulated areas.

The strategy of traffic regulation should vary with different traffic situations at different periods. Generally speaking, there are three periods ranging from the day that the Chi-Chi Earthquake occurred to the day of fully recovery (see Figure 2.6). It can be called “Chaotic” for the first three days, during which various activities including fire-fighting, emergency rescues and evacuations take place simultaneously. The strategy of traffic regulation during this period is to satisfy the objective of “life saving first”. From the third day to two weeks later, it can be called the period of “Rescue and Stabilization”, when efforts of rescue, engineering recovering and material supplies are emphasized. In this period, traffic regulation decision should be made with two perspectives, i.e., accelerating the delivery of supplies and meeting the needs of traveling victims. The final phase is the period of “Rehabilitation”, starting from the end of the second week to the end of the first month. Major efforts of traffic regulation during this period should focus on maintaining smooth traffic so that rehabilitation and recovery works can be carried out efficiently and people can resume their normal life as soon as possible.

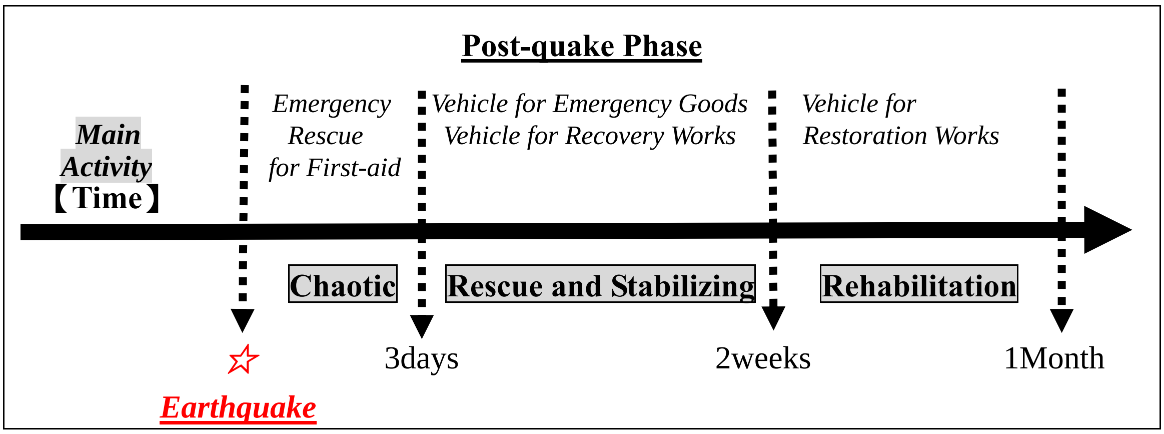


Figure 2.6 Traffic State on Earthquake Disaster Areas

Lessons gained from earthquake-raided areas including Osaka, Kobe, Los Angeles and Chi-Chi show that it could be helpful to identify different patterns of traffic flows before making any suggestions. There are three patterns of traffic flows distinguished by different time frames, i.e., daytime in weekdays (06:00-18:00), midnight (00:00-06:00) and evening time (18:00-24:00) and all day holidays. Different time frames are characterized by different situations that have to be addressed by different traffic regulation strategies. This means that a strategy of traffic regulation has to be dynamic and correspond to different post-earthquake periods and different daily time frames. Strategy of traffic regulation can be more meaningful if “network capacity” is considered. The model can estimate the maximum flow in each zone and compare it with the traffic flows in normal situations. Such estimation can shed light on the allowed traffic flows to each zone.

CHAPTER 3 RESEARCH METHODOLOGY

In this research, the related emergency response traffic regulation measures of Japan and the United States serves as our references. Since the property of emergency rescue operation problem in response stage is part of the traffic regulation interactive decision process between "decision-makers" and "road users", we employed the bi-level programming method to construct the traffic regulation decision model. Since the lower-level objectives of the model is to combine the traffic assignment and trip distribution and involve non-linear, non-convex and NP-hard problems, the heuristic method of genetic algorithm is employ to resolve the traffic regulation decision model.

The traditional approach to solving the duo-ploy decision problems are known as the bi-level programming problems (BLPPs). Bracken and McGill (1973) are the first researchers to investigate and to define this hierarchy decision problem as a generalized mathematical programming problem. In order to summarize the results, it is convenient to classify the problem according to both the structural complexity and the approach of the solution method. In terms of the approach involved, the solution methods can be classified into four categories, namely:(1) Extreme-point Search (k^{th} -best algorithm, Grid-search algorithm), (2) Transformation Approach (Complementary pivot, Branch-and- bound, Penalty function), (3) Descent and Heuristic (Descent method, Branch-and- bound, Cutting plane), and (4) Evolutionary Approach (Tabu search, Genetic algorithm). The first three categories are started relatively early and involve traditional optimization or decision concepts, while the last one involve more recent developments in decision-making.

Although Categories 1 and 2 can be extended or modified for non-linear problems, Category 3 is developed solely for discrete or non-linear BLPPs and involves existing search or heuristic decision-making approaches. In general, the problem is non-convex, thus optimality cannot be guaranteed even when the search procedure appears to be exhausted. Category 4 employs the recently developed evolutionary approaches, which is especially suited for solving NP-hard problems. This application is relatively new and has great potential. Most of the computational algorithms are developed for the simplest linear BLPPs. However, unfortunately, even for this simplest problem, there exist no simple solutions. In fact, it has been proved that even for this simplest two-level linear case, the problem is strongly NP-hard. Furthermore, the geometric properties of the bi-level linear problem are much more complicated than the usual mathematical programming problem and thus the set of feasible solution is non-convex and non-unique.

The difficulties in obtaining an effective solution for the multi-poly problems are two-fold: the complexity caused by the interactions of the various decision-makers in the various levels and the implicit nature caused by these interactions. Owing to the imbedding of the top-level problems into the lower levels, most optimization or decision-making techniques are too restrictive and cannot meet the flexibility demand. Furthermore, because of the limited freedom of the lower decision-makers, there exists no easy solution to the overall problem. In this research, we first use the fuzzy interactive algorithm to help the decision-makers to solve practical problems efficiently, and then employ genetic algorithm and based on hypothetical scenarios analysis to solve large organizational hierarchy system problems. Both the bi-level model formulation and detailed computational procedure and algorithm are described in the following section.

3.1 Bi-Level Programming

This research based on the demand of emergency disaster relief and accord with the different trip purpose of victims in different time periods in the aftermath of an earthquake. The bi-level programming approach is employed to construct the traffic regulation optimization model. This bi-level optimization model is proposed for solving the interactive decision process of both the top decision-makers and road-users. 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 (Lee, 2001). The decision process of this traffic regulation problem is displayed in Figure 3.1.

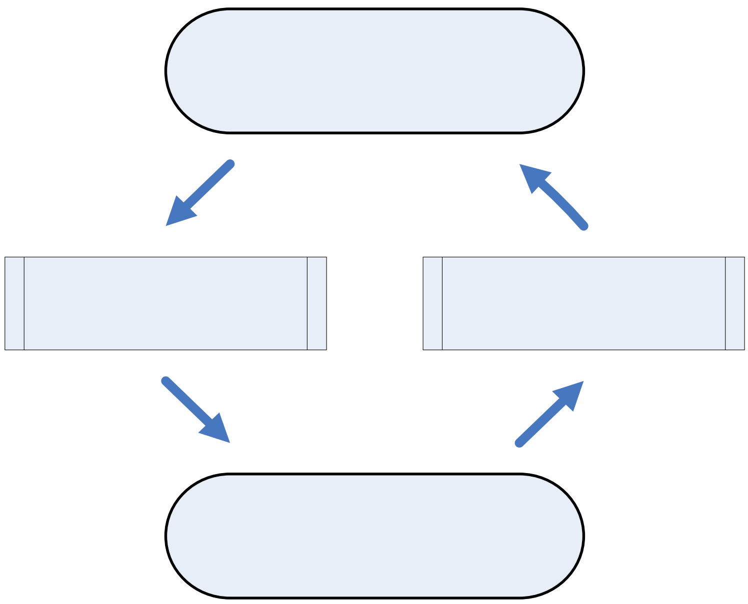


Figure 3.1 Bi-level Interactive Decision Processes

To illustrate the basic characteristics of this duo-poly process, let us consider its decision to be 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/her decision in isolation according to the

Traffic Flows
(upper leve

decision of the first level. Note that although the second level cannot control the decision of the first level, the final decision of the lower level does eventually influence the upper level and the overall results. Ideally, this mutually interactive decision process is repeated until a satisfactory solution or compromise is reached.

3.2 Fuzzy Interactive Algorithm

Most of the computational algorithms are developed for the simplest linear bi-level programming problems. Unfortunately, even for this simplest problem, there exist no simple solutions. In fact, it has been proved that even for this simplest two-level linear case the problem is strongly NP-hard and non-convex. Owing to the interactions of various decision-makers at various levels and the implicit nature due to these interactions, it is difficult to obtain an effective solution to duo-ploy problems.

In recent year, Lee and coworkers (Shih *et al*. 1996 and Shih and Lee 1999) have proposed a completely different approach by exploring the typical fuzziness, vagueness, or the not-well-defined nature of a large hierarchical organization using the fuzzy set theory. The fuzzy interactive sequential approach thus developed has been proved to be a powerful one and can help the decision-maker in large decentralized companies to solve practical problems encountered. In this research, we first apply the proposed approach, which allows various different degrees of regulation are ideally suited for traffic management. This approach has two advantages. Fist, the problem becomes much more simplified and thus it can be solved reasonably easily for fairly large practical problems; and second, the representation of the original problem is not only simplified but also much more realistic. In other words, since the real-world problems for large organizations are generally fuzzy or not well-defined, the existing classic algorithms are trying to solve a non-existing problem by assuming unrealistically accurate models and by ignoring the inherent fuzziness of large organizations.

When consider the fuzzy interactive decision-making process applied to a bi-level organization with a single follower. The upper-level decision-maker specifies the preferred values of his/her control variables and goals with certain amount of tolerance. This information is represented implicitly by the use of membership functions and is passed to the lower-level decision-maker. The lower-level decision-maker obtains his/her optimum according to the goals and preferences of the upper level and then presents the results to the upper level. If the upper level agrees with the proposed solutions, a final decision is reached and for the convenience of description, this decision or solution will be referred to as a satisfactory solution. If he or she rejects this proposal, the decision-makers of both levels will need to re-evaluate and changes the goals and decisions as well as their corresponding tolerances. This mutually interactive process is continued until a satisfactory solution is reached. This strategy is very flexible. Since the decision-makers of both levels first seek their optimal solutions in isolation, it does not violate the non-cooperate idea. However, the strategy does require a certain degree of coordination between the different levels.

The problem is formulated following the rules of bi-level programming, with two decision-makers of two different hierarchical levels. The algorithm for this bi-level programming problem is defined as follows. The decision variables (x_1, x_2) are vectors representing the actions taken by the two decision-makers, where the upper-level one has control over vector x_1 and the lower-level one has control over vector x_2. Mathematically, the upper-level decision can be made by solving the following problem.

$$Max \quad f_1(x_1, x_2) = c_{11}^T \cdot x_1 + c_{12}^T \cdot x_2 \qquad (3.1)$$

Subject to:

$$(x_1, x_2) \in F_1 = \{(x_1, x_2) | A_1 x_1 + A_2 x_2 \le b, \quad x_1, x_2 \ge 0\}$$

The solution can be presented as (x_1^U, x_2^U, f_1^U). On the other hand, the lower-level decision can be reached by solving the following problem.

$$Min \quad f_2(x_1, x_2) = c_{21}^T \cdot x_1 + c_{22}^T \cdot x_2 \qquad (3.2)$$

Subject to:

$$(x_1, x_2) \in F_2 = \{(x_1, x_2) | A_1 x_1 + A_2 x_2 \le b, \quad x_1, x_2 \ge 0\}$$

The solution can be presented as (x_1^L, x_2^L, f_2^L). If $(x_1^U, x_2^U) = (x_1^L, x_2^L)$, an optimal or preferred solution is reached. However, the two solutions are usually in conflict because of the nature of the two objectives.

The upper-level decision-maker understands that assuming the optimal decision x_1^U can also be the acceptable solution for the lower-level decision-maker is obviously not practical. It is more reasonable to have some tolerance that gives the lower-level decision-maker a room to search their optimal choice. The scope of the decision for vector x_1 can be described as "around x_1^U "with its maximum tolerance p_1. In other words, the most preferred decision is x_1^U and the worst acceptable decision is $(x_1^U - p_1)$ or $(x_1^U + p_1)$. The satisfaction or preference can be assumed as linearly increasing within the interval of $[x_1^U - p_1, x_1^U]$ and linearly decreasing within $[x_1^U, x_1^U + p_1]$. Decisions outside the interval $[x_1^U - p_1, x_1^U + p_1]$ are not acceptable. These assumptions can be formulated as the following membership function. The function follows the fuzzy set theory:

$$\mu_{x_1}(x_1) = \begin{cases} [x_1 - (x_1^U - p_1)] / p_1, & if \quad x_1^U - p_1 \le x_1 \le x_1^U \\ [(x_1^U + p_1) - x_1] / p_1, & if \quad x_1^U \le x_1 \le x_1^U + p_1 \\ 0, & otherwise \end{cases} \qquad (3.3)$$

The upper-level decision-maker must also reset his or her goal with some tolerance. The upper level may adopt a tolerance of $f_1^{'}$. Values of $f_1 > f_1^U$ are absolutely acceptable and values of $f_1 < f_1^{'}$ are absolutely unacceptable. The satisfaction or preference within the interval $\left[f_1^{'}, f_1^U\right]$ can be assumed as linearly increasing. The membership function can be formulated as follows:

$$\mu_{f_1}\left(f_1(x)\right) = \begin{cases} 1, & if \quad f_1(x) \geq f_1^U \\ \left[f_1(x) - f_1^{'}\right] / \left[f_1^U - f_1^{'}\right], & if \quad f_1^{'} \leq f_1(x) \leq f_1^U \\ 0, & if \quad f_1(x) \leq f_1^{'} \end{cases} \tag{3.4}$$

The lower-level decision-maker also reassesses his/her goal. According to his/her tolerance or preference level, the lowest tolerable goal for the lower level is $f_2^{'}$. Thus, we have the following membership function for the goal of the lower level:

$$\mu_{f_2}\left(f_2(x)\right) = \begin{cases} 1, & if \quad f_2(x) \geq f_2^L \\ \left[f_2(x) - f_2^{'}\right] / \left[f_2^L - f_2^{'}\right], & if \quad f_2^{'} \leq f_2(x) \leq f_2^L \\ 0, & if \quad f_2(x) \leq f_2^{'} \end{cases} \tag{3.5}$$

The lower-level decision-maker can now optimize his/her objective function under the new constraints of “x_1 is about x_1^U” and “f_1 is near or greater than f_1^U”. The discussion above can be represented as the following membership functions.

$$\begin{aligned} & Max \quad f_2(x_1, x_2) = c_{21}^T \cdot x_1 + c_{22}^T \cdot x_2 \\ & subject \quad to: \\ & \qquad A_1 x_1 + A_2 x_2 \leq b \\ & \qquad \mu_{f_1}\left(f_1(x)\right) \geq \alpha \\ & \qquad \mu_{x_1}(x_1) \geq \beta \\ & \qquad \alpha \in [0, \ 1] \\ & \qquad \beta \in [0, \ 1] \\ & \qquad x_1, x_2 \geq 0 \end{aligned} \tag{3.6}$$

3.3 Genetic Algorithm

The basic principles of GA were first proposed by Holland (Man, *et al.*, 1999). Thereafter, a series of literature and reports (Man, *et al.*, 1996, Liu, 1998, Sena, *et al.*, 2001) become available. GA is inspired by the mechanism of natural selection where stronger individuals are likely the winners in a competing environment. GA uses a direct analogy of such natural evolution. Through the genetic evolution method, an optimal solution can be found and represented by the final winner of the genetic game. In fact, GA has proved to be a unique approach for solving various mathematical intangible problems which other gradient type of mathematical optimizers have failed to solve.

GA presumes that the potential solution of any problem is an individual and can be represented by a set of parameters. These parameters are regarded as the genes of a chromosome and can be structured by a string of values in binary form. The positive value, generally known as a fitness value, is employed to reflect the degree of "goodness" of the chromosome for the problem, which would be highly related with its objective value. Throughout a genetic evolution, the fitter chromosome has the tendency to yield good-quality offspring, which means a better solution to any problem.

In a practical GA application, a population pool of chromosomes has to be installed and these can be randomly set initially. In each cycle of genetic operation, termed as an evolving process, a subsequent generation is created from the chromosomes in the current population. It is generally called "parents" or a collection term "mating pool" is selected via a specific selection routine. The genes of the parents are mixed and recombined for the production of offspring in the next generation. From this process of evolution, the "better" chromosome will create a larger number of offspring and emulating the survival-of-the-fittest mechanism in nature.

Thus far, the essence of the GA in both theoretical and practical domains has been well demonstrated. Since the concept of GA can be easily understood, the GA is full of transferability and is proved to be effective in solving such NP-hard problems. Considering the characteristics of the traffic regulation model in disaster area, the gene type, selection, crossover and mutation are re-defined for traffic management and illustrated as follows (Man, *et al*., 1999, Chipperfield, *et al*., 2000).

A. Gene Type (Chromosome Representation)

The coding of chromosome representation may vary according to the nature of the problem itself. In general, the bit string encoding is the most classic method used by GA researchers because of its simplicity and traceability. The traffic regulation problem in disaster area can be coded in a chromosome with a 20-bit long binary string for representing four different portions including the regulation points, passing links, traffic volume and travel time. A sequence of the gene layout is shown in Figure 3.2.

Regulation Points	***Links of Road Network***	***Traffic Volume***	***Travel Time***
1 7	**8 15**	**16 18**	**19 20**

Figure 3.2 Chromosome Coding

B. Selection

To generate good offspring, a good parent selection mechanism is necessary. The chance of selecting one chromosome as a parent should be directly proportional to the number of offspring produced. The selection algorithm should be achieving a zero bias whilst maintaining a minimum spread and not contributing to an increased time complexity of the GA. Many selection techniques employ Roulette Wheel Mechanism. It is one of the most common techniques being used for such a proportionate selection mechanism. The selection procedure is illustrated as follow:

1. Sum the fitness of all the population members, named as total fitness;
2. Generate a random number between 0 and total fitness;
3. Return the first population member whose fitness added to the fitness of the preceding population members, is greater than or equal to the random number.

In order to facilitate the GA evolution cycle, two fundamental operators: Crossover and Mutation are required.

C. Crossover

The preference for using which crossover techniques is still arguable. A general comment was that each of these crossovers was particularly useful for some classes of problems and quite poor for the others. The basic concept in crossover is to exchange gene information between chromosomes. An effective design of crossover operation would greatly increase the convergence rate of a problem. To further illustrate the operational procedure, a One-Point Crossover mechanism is depicted in Figure 3.3. A crossover point is randomly set. The portions of the two chromosomes beyond this cut-off point to the right are to be exchanged to form the offspring. An operation rate (p_c) with a typical value between 0.6 and 1.0 is normally used as the probability of crossover.

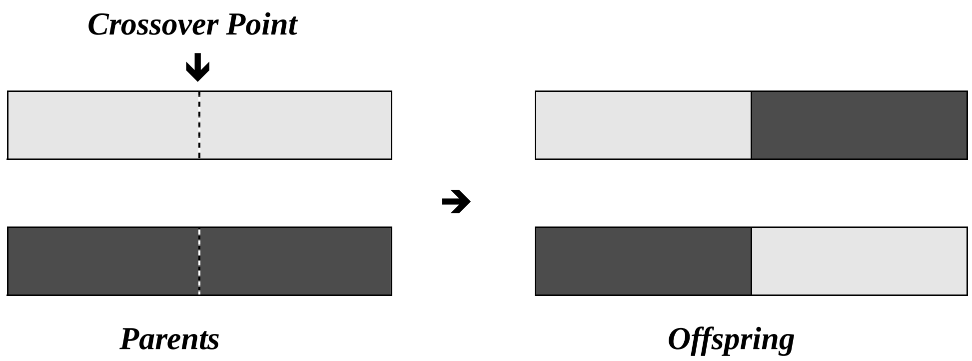


Figure 3.3 Example of One-Point Crossover

D. Mutation

Mutation is the other important genetic operation. This can prevent premature convergence from occurring. Since binary coding is adopted in the software, then, only bit mutation is implemented. However, the mutation is applied to each offspring individually after the crossover exercise. It alters each bit randomly with a small probability (p_m) with a typical value of less than 0.1. In general, the mutation process is to choose a gene randomly from the gene population. Then select a bit randomly from this gene and inversely transmitted to the offspring gene. This mutation process is illustrated in Figure 3.4.

Original Chromosome

0	1	1	0	**0**	0	0	1	0	1

↓

0	1	1	0	**1**	0	0	1	0	1

Offspring Chromosome

Figure 3.4 Bit Mutation on the Fifth Bit

The choice of mutation rate and crossover rate as the control parameters can be a complex nonlinear optimization problem. Furthermore, their settings are critically dependent upon the nature of the objective function. This selection issue still remains open to suggestion although some guidelines have been introduced. In general, for large population size (100), the crossover rate is 0.6 and mutation rate is 0.001. Then for small population size (30), the crossover rate is 0.9 and mutation rate is 0.01.

The cycle of evolution is repeated until a desired termination criterion is reached. This criterion can also be set by the number of evolution cycles (computational runs), or the amount of variation in individuals of different generations, or a predefined value of fitness. The conventional GA structure cycle is summarized in Figure 3.5 and the steps of the genetic algorithm approach are shown in Figure 3.6 (Man, *et al*., 1999).

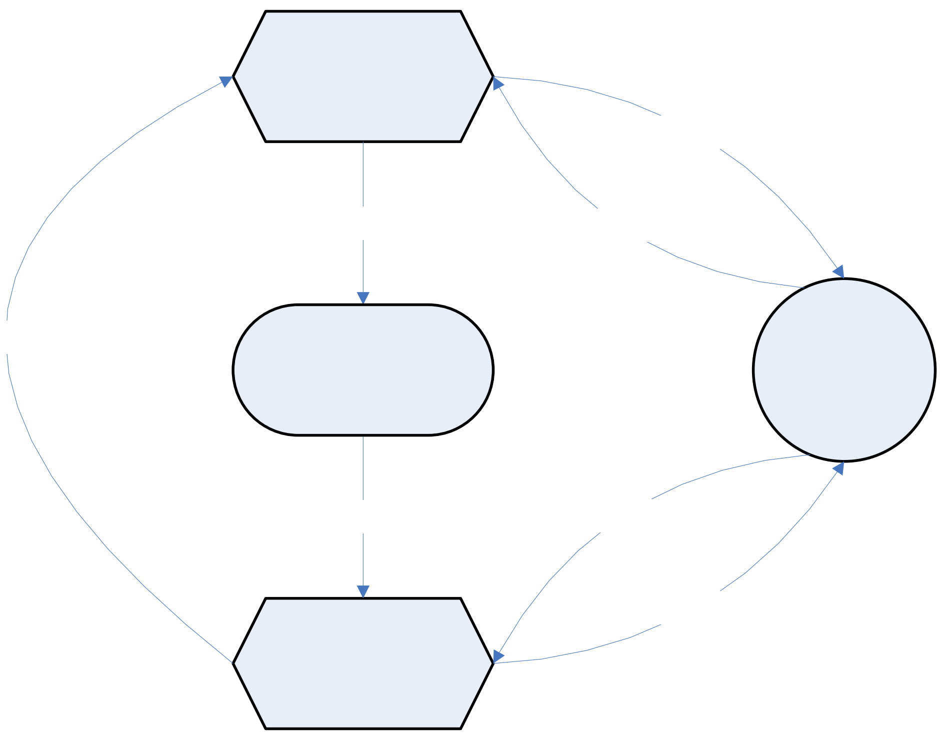


Figure 3.5 Conventional Genetic Algorithm Cycle

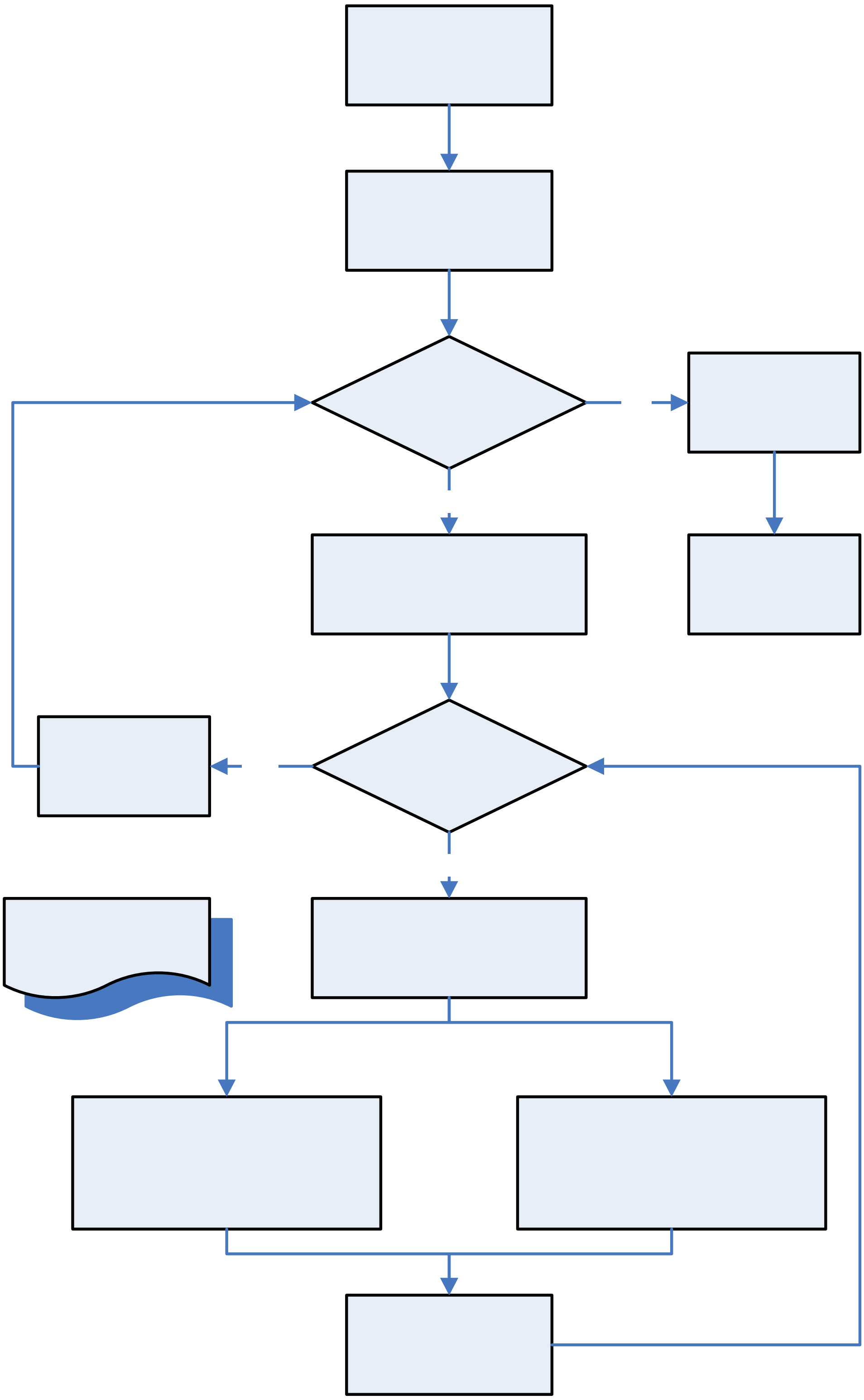


Figure 3.6 The Process of Genetic Algorithm Approach

E. Terminal Criteria

The evolution process is terminated when the maximum number of generations is reached. This figure is set by the user. In order to avoid long computation, the program stops after some generations have provided a good indicator towards the quality of the result. Or the specified appearance according to the fitness function is reached by all of the populations accounting for the choice of “average fitness”.

From the above discussion, it can be seen that the GA differs substantially from more traditional search and optimization methods. The four most significant differences are as follows:

1. GAs search a population of points in parallel, not a single point;
2. GAs do not require derivative information or other auxiliary knowledge, only the objective function and corresponding fitness levels influence the directions of search;
3. GAs use probabilistic transition rules, not deterministic ones;
4. GAs work on an encoding of the parameter set rather than the parameter set itself (except in where real-valued individuals are used).

It is important to note that the GA provides a number of potential solutions to a given problem and the choice of the final solution is left to the user. In this study, the problem does not have one individual solution; for example, a family of Pareto-optimal solutions, as is the case in this multi-objective optimization, then the GA is potentially useful for identifying these alternative solutions simultaneously.

3.4 Hypothetical Scenario Analysis

Following the model exemplified by the survey data on personal requirements for traffic at the Great Hanshin-Awaji Earthquake and the third Kyoto/Osaka/Kobe earthquakes, this research calculates the number of trips for commuting, procurement trips, personal safety verification trips and evacuation trips. The data on personal requirements for traffic during the post-earthquake period is meaningful as they represent a basis for traffic regulation in the aftermath of a disaster. According to the survey results, the traffic condition for private use in the first three days after the earthquake is as follows (Iida, 1998):

1. Verification of Personal Safety 32%;
2. Commuting 25%;
3. Evacuation 24%;
4. Purchase of Water 11%;
5. For Injury and Sickness no more than 8%.

In order to explore the impact of traffic regulation on private vehicles in the post-earthquake period, we need to assess the purposes of private-vehicle trips on the road networks as well as the regulation percentage of every purpose. However, it is highly unlikely for this research to collect real-time information of traffic in the post-earthquake period because we find it impossible to predict the occurrence of an earthquake and the damages caused. Normally, we can do pre-assessment by issuing questionnaires after the earthquakes. However, if we follow a scenario-simulation approach, producing models from data of personal trips, and assessing commuting trips, procurement trips, personal safety verification trips and evacuation trips throughout the controlled areas, we may be able to analyze the collected data by applying a traffic regulation model. Therefore, priority can be given according to trip purposes and rescue needs. For instance, traffic controls on evacuation and procurement are relevant to survivals of victims in the disaster areas; their priorities should be considered higher than the others'. Thus, various hypothetical scenarios yield related traffic data under observations, which can be instrumental and referential for earthquake management in the future.

CHAPTER 4 BASIC MODEL AND BI-LEVEL PROGRAMMING

When an earthquake disaster happens, whether road networks have the ability of anti-earthquake, substitution, complementary and robustness must be taken into consideration seriously beforehand. It can reduce the probability of road network being damaged and sustain the function of transportation in disaster areas, especially when rescue team and disaster relief goods from non-disaster areas enter disaster areas continuously. If there is no suitable traffic regulation program, for implementing traffic regulation and evacuation, there will be serious traffic congestion, thus influencing the efficiency of disaster relief and causing the loss of life and properties. Therefore, this research emphasizes how to construct the emergency response of traffic regulation model to implement traffic control strategies efficiently so as to promote the efficiency of disaster relief and decrease the loss caused by earthquake disaster.

4.1 Traffic Regulation Problems and Strategies

The Chi-Chi Earthquake has caused serious damage to the infrastructures in the disaster areas. Damages caused road closure and traffic jam, therefore the network capacities will be decreased due to severe damages on main roads and bridges after the earthquakes. Vehicles cannot get in or out of the affected areas easily (Odani et al., 1996; Nakagawa *et al*., 1996). It is a major concern for the on-site operators who are in charge of delivering supplies, evacuation, rescue and restoration. Because the transportation is critical to minimizing the loss of life and maximizing the efficiency of rescue operations, it is necessary to develop an efficient disaster traffic regulation model to balance travel demand (traffic on a link) and traffic supply (the capacity of a network) when tackling traffic congestion (Tomita *et al*., 1995).

4.1.1 Traffic Regulation Problems

We learned from the Chi-Chi Earthquake that the victims were not satisfied with the performance of the government agencies and civilian societies although they had responded to the catastrophe with all their strength. The main reason, also the difficulty, was that the related information concerning the earthquake, especially the damages of the transportation network essential to rescue operation could not be acquired immediately. Without enough information, the authorities in charge could not take efficient traffic regulation measures, thus resulting in congested traffic, which delays the timing for salvage. Reviewing earthquakes both domestic and abroad, this study identifies the following problems that remain to be solved.

1. The traffic contingency plan in the current Disaster Prevention and Response Act is neither comprehensive nor perfect. Moreover, the government at each level does not have an agency responsible for integrating traffic regulation measures in response to disasters, and could not devise strategies according to different scenarios.

2. We need to develop the Advanced Traffic Data Collection Systems because ordinary detection equipment may not collect information after the disasters, particularly those pertaining to the damages of infrastructure and the property of travel behavior (such as the trip purpose, the type of transportation tools, and so on.).

3. Although the newly revised “Disaster Prevention and Response Act” stipulates a “commanding establishment” to respond to emergencies, there still is neither a systematic “decision-making model” nor a unified system to regulate the vehicles. Therefore, the transportation network could not operate well and thus delay the timing for emergency response.

4. Most of roadway networks lack stratification and substitutability, and there is a

lack of mode-connectivity among transportation systems either, so it is impossible to sort out the stratification of the roadway networks (salvage, evacuation and so on) to be the alternatives prepared before the disasters and the basis for traffic regulation management after the disasters.

5. Strategies responding to different disasters scenarios are required for directing the traffic flow in good time, and avoiding congestion in order to assist the save and rescue operation.

From the above mentioned issues, this study sums up the related earthquake response and traffic regulation management literature, analyzes the psychology of the earthquake victims in their traffic behavior, formulates an overall traffic regulation management approach, combines the application of hi-technology with appropriate traffic policies, and develops a comprehensive traffic regulation management to cope with the earthquakes.

4.1.2 Traffic Regulation Strategies

This study is focuses on the post-quake traffic regulation management during the “response” stage in order to optimize transportation capacity, tackle congestion, carry out evacuations and avoid secondary damages. Learning from numerous major earthquakes around the world, we know that most of the rescue and save operations were conducted within the first post-quake 72 hours. Hence, the most efficient approach to alleviating the devastation of the earthquake zone is to keep the traffic smooth through effective and fast traffic regulation management within the golden 72 hours.

A. Time-based Regulation Strategy

Iida (1998) and his colleagues established a post-quake traffic control management system using details of personal trips investigation during the Great Hanshin-Awaji and the 3rd Kyoto/Osaka/Kobe Earthquake. They pointed out that the daytime traffic on Sundays had been rising until one month or so after the quake, and it was obviously heavier than the mean daytime traffic of each week. On the other hand, the nighttime traffic was busier than that of daytime, and this situation lasted for 3 months after the catastrophe. The difference between the nocturnal traffic on Sundays and the mean nocturnal traffic of each week compared considerably in visibility than that of daytime. This indicated that people traveled more transportation in nighttime and daytime on Sundays than the average of any other day of the week. Similarly, Lee, Ming-Je (2000) divided the post-quake traffic within one week into 3 time frames, i.e., (1) weekday daytime (06:00~18:00), (2) weekday nighttime (18:00~24:00) and weekends as well as holidays (06:00~24:00), (3) midnight (00:00~06:00). The time frames form the basis for this research on traffic regulation management.

As stated above, this study stresses that the traffic regulation management is focused on the golden 72 hours, and different rescue operations and traffic regulations are implemented in different time frames. In addition, depending on the situations, we can carry out traffic regulation according to the time frames as well as the priority of the trip purpose, to execute total quantity control in the disaster zone.

B. Area Traffic Regulation Strategy

As stated in Article 31 of the Disaster Prevention and Response Act, the command officer of the emergency operation center may designate a certain area to limit or restrict entry or clear the area, or designate an area among roads to restrict passage of vehicles. This study divides the disaster area according to the degree of devastation. That is, using the “major arterial” and “supplemental arterial” as the basic unit in the road network to separate the area. By doing so, it would be easier for people to understand the circumstances of the area, and much easier for those who execute the traffic regulation mission.

The area regulation concept introduced by Iida, et al. (1998) defines the regulation areas before earthquakes. The main trunk roads and supplementary roads must be defined clearly, and then the basic reaction unit locations surrounding them can be identified beforehand. Figure 2.5 shows the conceptual relationship between the two-stage regulated areas. These areas require regulation of all traffic but emergency vehicles, and not to linear regulation of traffic within specific segments or routes of road, but to the overall regulation of traffic within a particular area. In order to implement area regulation, we assumed that all the traffic regulation points lie on the cross-section of the main trunk routes, supplementary routes and accessory routes. It is also assumed that the commander of the Emergency Response Center in county or city government is the main decision-maker. The space of regulated area is decided according to the areas damaged by earthquakes. Through the use of hypothetical scenario analysis and using on the TELES simulation data, we can compare the values obtained from the model with those for generated and concentrated traffic volumes under normal conditions. Then calculations can be made concerning the extent to which traffic in each zone must be regulated.

4.2 Traffic regulation Decision-Making Systems Framework

In the field of transportation, previous earthquake studies only focus on engineering designs and rescue scheduling. Few studies have paid attention to the subject of traffic regulation and management in earthquake disaster areas. Haghani *et* *al*. (1996) formulated a complex multi-model network flow problem with time constraints reflecting the situation of disaster relief, which could be solved relatively easily. This model attempts to identify the best emergency vehicle route choice and dispatching schedule. However, the model does not consider the need of non-emergency traffic flow control on each link. Masuya *et al*. (1996) and Kurauchi *et al*. (1997) have proposed ways for measuring the maximum trip generation and attraction volume that can be catered by the remaining capacity of the network after the impact of an earthquake. Results show that appropriate traffic demand control is needed under emergent situations. However, these models does not distinct the needs of emergency vehicles.

Masuya *et al*. (1999) develop a decision-making tool to regulate the access of non-emergency vehicles to disaster areas. In this paper, the problem is formulated as a multi-objective, two-model network flow problem from the concept of network flow theory and integer linear programming. The traffic regulation decision process is similar to the static two-person Stackelberg game problem (Papavassilopoulos, 1982) and it can be transformed into a bi-level programming problem. In the IATSS research, Iida (1995) presents the idea of how to against major earthquakes by traffic management system. The study develops a good study platform of traffic management using the Great Hansin-Awaji Earthquake as the background. A bi-level programming model is developed by Iida, and the model can be extended to cover both the needs of victims and those who come to rescue them.

According to the emergent traffic regulation measures of domestic and international major earthquakes and accidents, and the Disaster Prevention and Response Act promulgated on July 19, 2000, this study formulates a decision-making system of the traffic regulation of the quake-affected regions. It reasonably specifies the decision-makers, the executive branch, the regulation strategy, the timing and the measures of traffic control in order to effectively regulate the disaster area. The decision-making flow-chart of this system is presented in Figure 4.1 and described as follow.

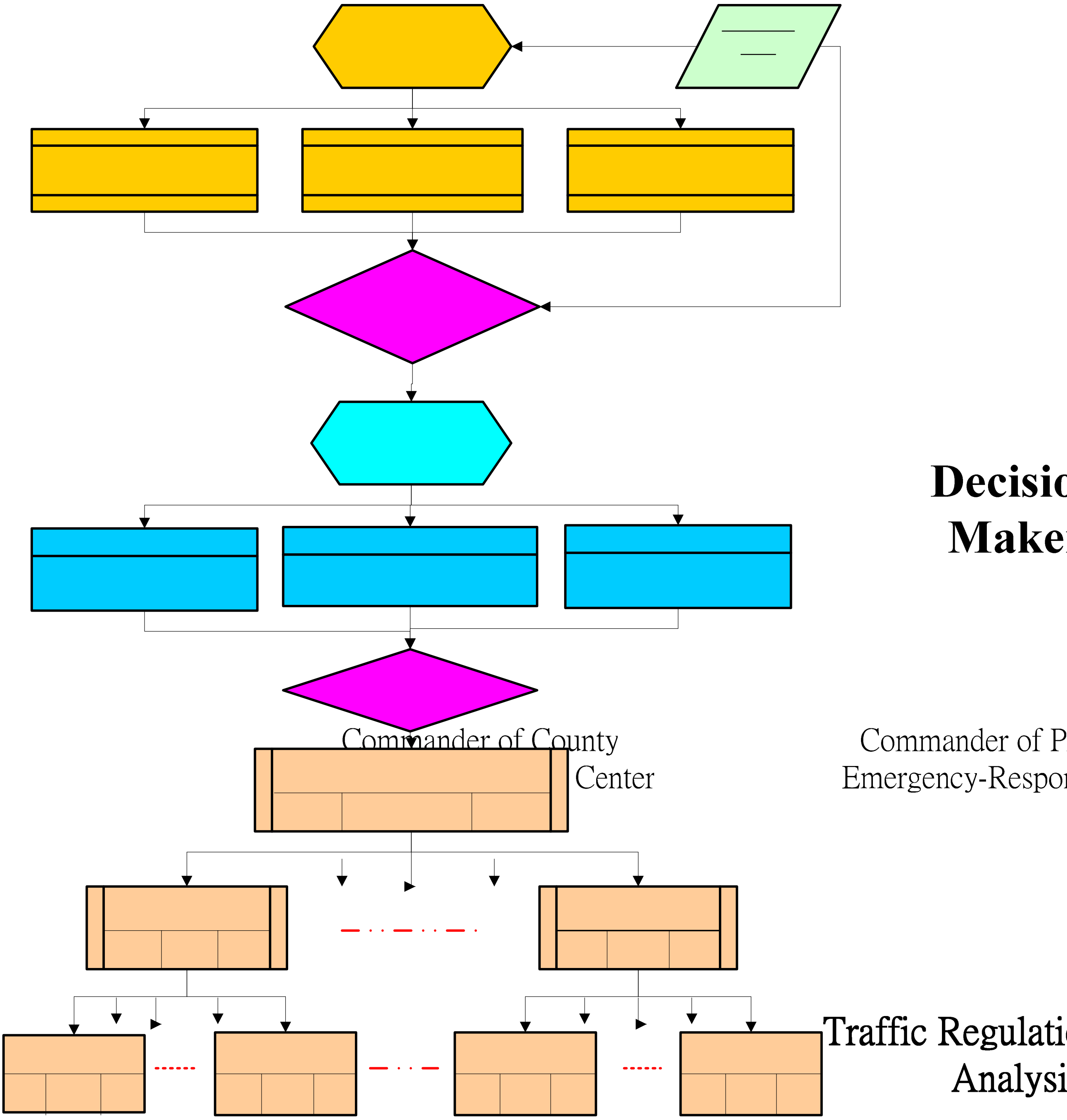


Figure 4.1 Traffic Regulation Decision-Making Systems

A. Units of Decision-Making

According to the Disaster Prevention and Response Act promulgated on July 19, 2000, the regulating authorities for disaster prevention and response at the central level shall be the Ministry of the Interior; municipality, the municipal government; and county/city, the county/city government, and they are responsible for carrying out disaster prevention and response and executing penalties. As stated in Article 3 of the abovementioned Act, the central government agencies such as the Ministry of Interior, Ministry of Defense and Environment Protection Agency are in charge of command, supervision and coordination among administrative agencies and civil utilities to carry out disaster prevention and response operation. All measures concerning disaster prevention, emergency response and rehabilitation as well as reconstruction require the government agencies to cooperate and coordinate, so the central and local governments and civil utilities concerned must carry out the work of disaster emergency action such as issuing warnings. Moreover, upon creating the emergency operation center at each level, the administrator of each government agency shall either in person or designates a representative to reside in the center to carry out the emergency actions. The command officer of the center shall be the highest-ranking official in charge of commanding, coordination and integration.

As indicated in our disaster prevention and response structure, in case of a major disaster or risk of such major disaster presents, the administrator of the regulating authorities of Disaster Prevention and Response shall immediately report it to the convener of the National Disaster Prevention and Response Council. In turn, the convener, depending on the gravity and nature of the disaster, may decide to create a Disaster Emergency Operation Center and appoint a command officer. Likewise, the promoter of the municipal, county/city, or town Disaster Prevention and Response Council shall, depending on the gravity of the disaster, create and direct an emergency operation center to prevent disaster or carry out effectively disaster emergency action and to be the command officer. To sum up, the decision-making unit of the traffic regulation model developed in this study is the Disaster Emergency Operation Center of each level, and the decision-maker is the command officer of the Disaster Emergency Operation Center.

B. Units of Execution

According to Article 14 of the Disaster Prevention and Response Act, to handle tasks related to Disaster Prevention and Response things and matters or support the disaster emergency operation center of each level in carrying out disaster emergency actions in case of a disaster or risk of an imminent disaster, any agency, division or civil utilities designated in the Disaster Prevention and Response operation plan and regional Disaster Prevention and Response plan shall create an emergency mission to carry out the emergency actions. These actions include providing temporary accommodation, supplying and allotting consumer products and potable water, sterilizing the disaster area, preventing crime, controlling traffic, maintaining order, taking actions required in coping with emergency and prevention of spread of disaster, and so on.

Therefore, the Traffic Response Unit under the Central Emergency Operation Center, the Ministry of the Interior as well as the Ministry of Communication and Transportation are responsible for implementing the traffic regulation management developed in this paper. At local level, the police chief heads the unit; its members comprise municipality/county/city/ police department and reserve military personnel. Similarly, the commander of police precinct at town/township level is the leader of the unit.

C. Regulation Area

Article 31 of the Disaster Prevention and Response Act stipulates that the command officer of the emergency operation center may, as required by emergency actions, make certain dispositions or injunctions. The second item of the same article elaborates further: “Designating a certain area to limit or restrict entry or clear the area, or designating an area among roads, on the surface, and/or an air altitude to restrict pass by vehicles, sea vessels and/or aircrafts.” Moreover, how to set up the parameter of the restricted area should be decided on a case-by-case basis depending on the situation and be announced individually. For adaptation to local conditions, the parameter established ought to be announced and enforced by municipality/county/city/ emergency operation center; and each agency in charge should carry out the task within the parameter designated.

D. Time of Regulation

Previous experience reveals that an earthquake below 6 on the Richter scale usually causes minor damages that would not hinder the save and rescue operations. According to the special research plan on the disaster prevention system sponsored by the Public Construction Commission of the Executive Yuan, it could be divided into three levels: “the alert level (magnitude over 4)”, “the alarm level (magnitude over 5)” and the “emergency level (magnitude over 6)”; the first two levels expect only minor damages and a short restriction or limitation of passage should be enforced. When a shallow earthquake measured over 6 on the Richter scale strikes an urban area, and the disaster area covers two or more counties/cities, the Emergency Operation Center should begin functioning in order to formulate and carry out long-term traffic regulation measures.

With reference to the time and medical care defined by the International Decade for Natural Disaster Reduction (IDNDR), the first 48 hours after the earthquake is the perfect period for search and rescue, and the post-quake 72 hours are categorized into Three T's (Triage, Treatment and Transportation). With the destruction of lifeline structure, interruption of information, devastation of infrastructure as well as chaos, the functioning of the whole medical system would be jeopardized. Statistics of previous major earthquakes reveal that during the first 48 hours after the quake, delaying one minute would cause one casualty. Therefore, the key to decreasing casualties is to maximize the capacity of emergency transportation within the first 72 hours after the disaster.

In view of the above, the timing for emergency traffic regulation management developed in this study is designed for urban areas suffering grave damages from any earthquake registered above 6 on the Richter scale. The Emergency Operation Center must begin functioning and conduct rescue operation.

E. Regulation Operations

(a) Total Traffic Volume Control in Disaster Area

In view of the overall damages caused by the earthquake, we must take the whole disaster area into account to effectively control abnormal traffic flow. In particular, we have to take a serious approach to dealing with the abrupt increase in post-earthquake trips within a short period of time. Thus, carrying out total capacity control in the disaster area is a pragmatic and effectual means of traffic regulation.

(b) Area Traffic Regulation Management

It is quite difficult to implement traffic regulation in the chaotic post-quake period. To carry out the task involves using the roadway network available as the basis for dividing the disaster area; that is, dividing the area using the “major arterial” and “supplemental arterial” as the basic unit in the roadway network. By doing so, it would be easier for those who execute the regulation to understand the circumstances of the area. Figure 2.5 illustrates the regulated area after being divided. Viewed in this light, the traffic regulation response not only facilitates rescue mission, rehabilitation work, and traffic order maintenance, but also prevents the consequences of the catastrophe from spreading beyond control.

(c) Trips Purpose Regulation

Reviewing the priority to the needs for transportation during the Chi-Chi Earthquake, we observe seven purposes of major trips. In order of priority, these trips were for “System Maintenance”, “Emergency Rescue”, “Funeral and Burial”, “Disaster Exploration”, “Rehabilitation”, “Commuting” and “Safety Verification”. The traffic regulation framework in an earthquake-raided area in terms of priority between time phases and trip purposes after the quake is illustrated in Figure 4.2.

Since damage to urban road network system causes congestion in many parts of the network, efficient traffic management is urgently needed (Odani *et al*., 1996; Nakagawa *et al*., 1996). Real-time traffic control is an interactive decision process. Bi-level optimization model is a practical and useful tool for solving decision problems in a hierarchical system. When solving the problem, several questions need to be answered, such as “who is the decision-maker”, “what kinds of decision will be made”, “who is in charge of traffic control”, “where are the traffic regulation points” are, “when to implement traffic regulation” and “how to implement traffic regulation”.

All these question analyses and the basic concepts of bi-level programming model formulation are illustrated in Figure 4.3.

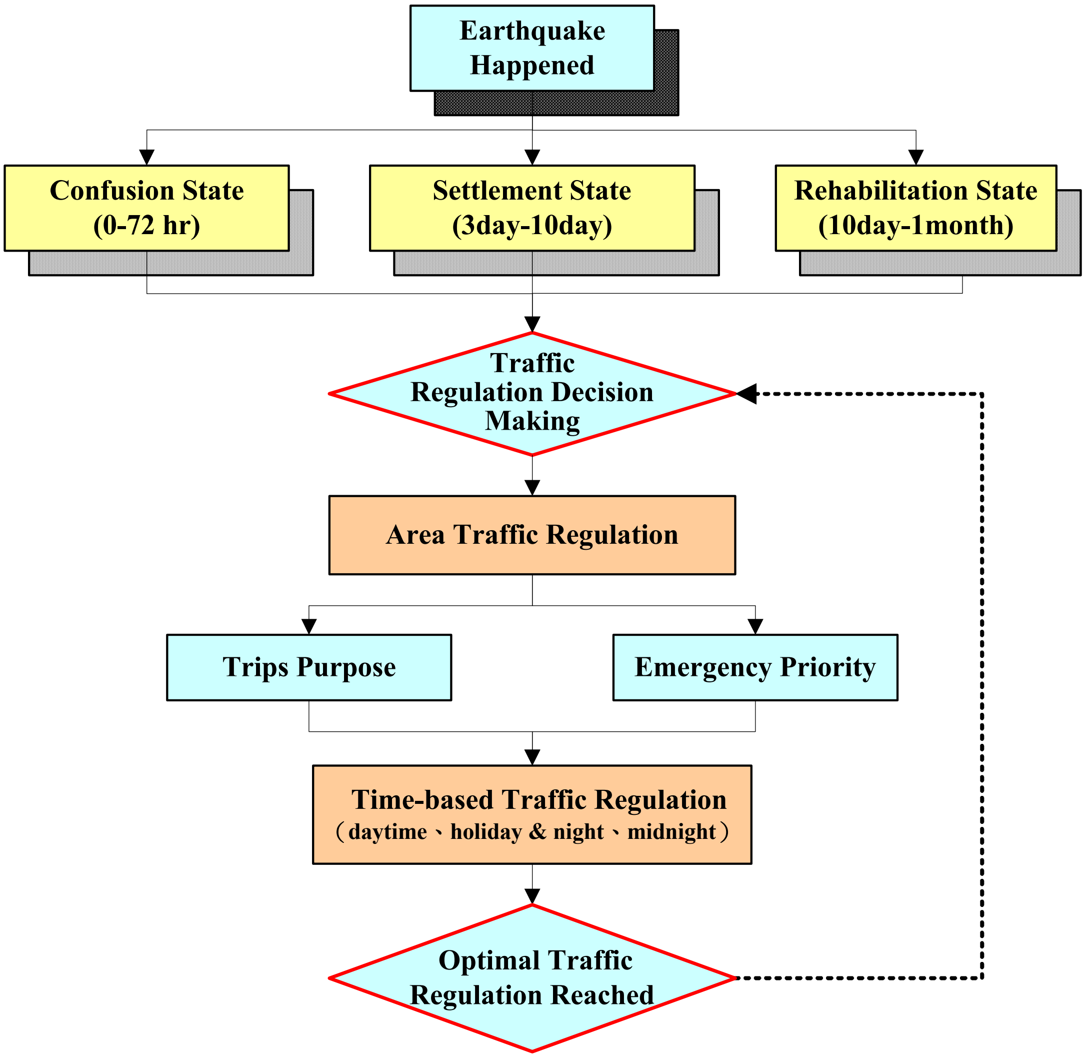


Figure 4.2 Traffic Regulation Frameworks in Earthquake-Raided Area

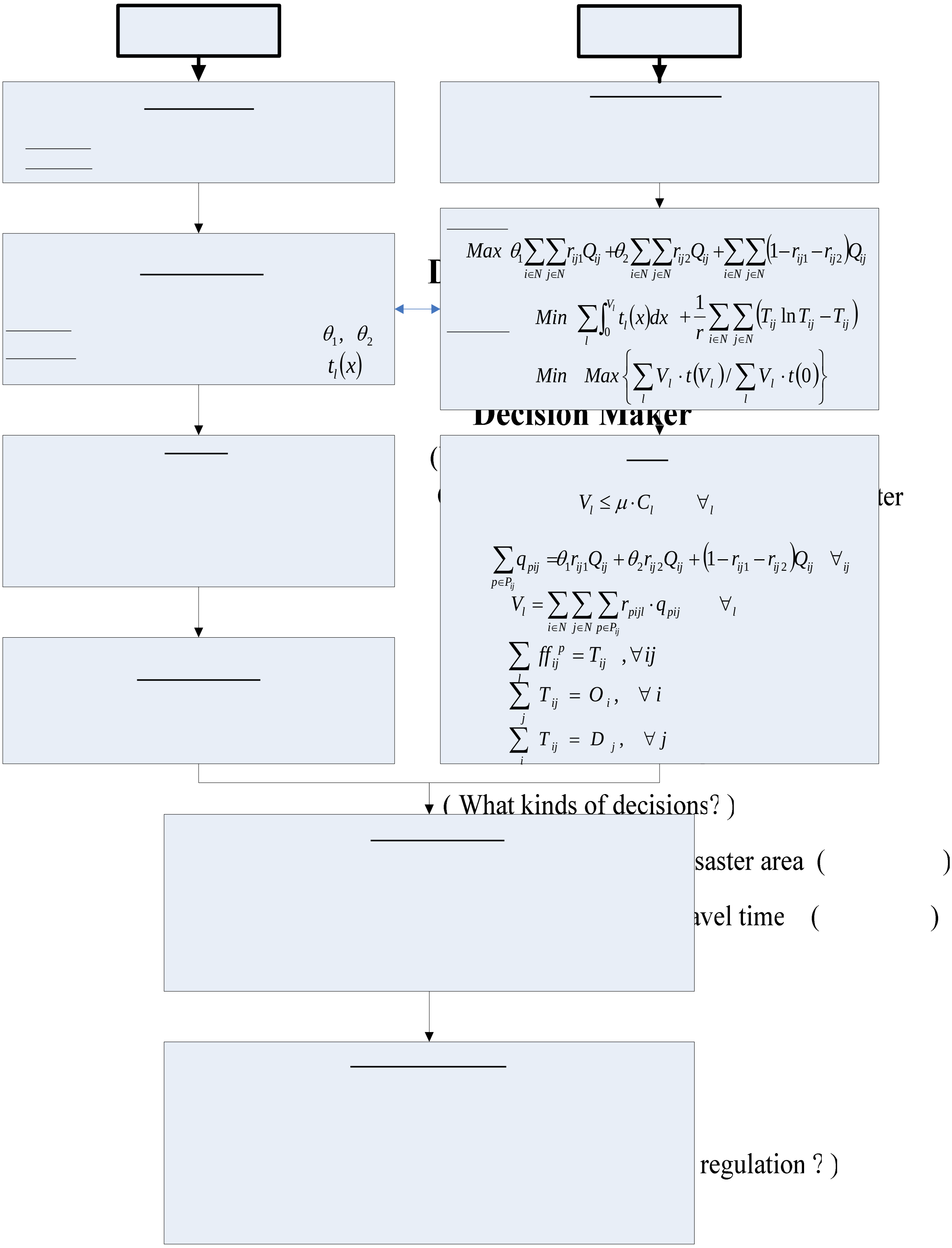


Figure 4.3 Traffic Regulation Decision-Making Concept and Model Formulation

-- National Police Agency

-- Local Police Agency

-- Local Police Precinct

4.3 Formulation of Basic Model

The Basic Model proposed in this thesis is developed from the traffic management system model of Iida (2000). The Basic Model examines different decision-making perspectives and follows the trip-analysis approach in order to strengthen the model's applicability and rationality. The two-stage model for traffic regulation can be demonstrated as below.

4.3.1 Model Assumption

The model assumes that the command officer of the Emergency Response Center in county or city governments inside the earthquake-raided areas is the main decision-maker. The size of regulated area is decided according to the areas damaged by earthquakes. Policemen are the main actors in the problem definition. It is also assumed that all the traffic regulation points lie on the cross-section of main trunk routes, supplementary routes and accessory routes.

Among the developed approaches regarding traffic-flow assignment and distribution, the principle of user equivalent assumption is found to be adequate if congestion is the main consideration for traffic route choice. The question becomes one of how these trips are distributed among the various destination nodes, an issue that is affected by motorists' choice of destination. The determination of motorists' choice of destination and the path used to get there is known as the joint distribution/assignment problem. In this problem, it is assumed that motorists' try to accomplish two goals: travel to the destination with the highest attraction measure while spending the least possible time in travel. Under this assumption the choice of destination is the result of a trade-off between attraction and travel time.

In this line of thinking, if the Basic Model can be seen as a model dealing with a two-phase traffic regulation area, and is a kind of non-linear traffic regulation models, it must follow the assumptions listed below:

1. In making route choice, road-users will try to minimize their travel cost;
2. Travel time is the only cost of concern to road-users;
3. The trip demand within a traffic zone will not be changed by other factors;
4. The congestion function is symmetrical and the travel time function is positively related to the link flow
5. There is only one kind of vehicle on the road networks.

If these assumptions can be fulfilled, then the model can be constructed as a bi-level programming problem. The decision variables for approaching the upper-level objective are traffic regulation ratios (θ_i), which decide how many vehicles can enter the earthquake-raided areas. Likewise, the other decision variables are link flows (V_l) for approaching the lower-level objective. According to this problem formulation, if the total cost of link flow can be minimized, then the road-user flow distribution will achieve equilibrium.

4.3.2 Model Formulation

The command officer of the Emergency Response Center of the government at the county and city levels in earthquake-raided areas is assumed to be the decision-maker. The decision-making objective is to meet the emergency operation. The upper-level objective in the model is to allow as much traffic as possible to go through the disaster areas so that victims can feel satisfied with the traveling. The lower-level objective is set to meet the emergency rescue needs while a combined road network assignment and trip distribution concept is integrated. According to this arrangement, the model not only can meet the requirements of the entropy model, but can also reflect practically users' travel behavior. It is assumed that road-users will always choose the shortest route with respect to travel time. Traffic regulation zones are designated by decision-makers with knowledge of the degrees of damages on roadways. The bi-level programming in the Basic Model is shown in Table 4.1 and the notation is summarized in Table 4.2.

Equation 4.1 in the Basic Model represents the upper-level objective, which tries to maximize the number of vehicles allowed to enter the regulated areas in order to satisfy the large number of short-distance trips (such as verification of the safety of relatives, evacuation of victims, and procurement of supplies). There are three parts in the objective function Max Q. The first part of the equation represents the maximum number of vehicles that can be allowed to enter the first encircled earthquake-raided zone under traffic regulation. The second part of the equation represents the maximum number of vehicles allowed to enter the second encircled earthquake-raided zone. The third part of the equation represents all traffic flows that are not subject to traffic regulation within the two zones mentioned above. Parameters r_{ij1} and r_{ij2} are dummy variables represented by 0 or 1. Vehicles traveling within the traffic regulation zones are mark 1 otherwise mark 0. Adding the three parts together represents the entire traffic flows subject to traffic regulation.

Equation 4.2 implies that the total amount of vehicles entering the regulated disaster areas (including those already inside the areas) could not exceed the reduced roadway capacity.

Equation 4.3 illustrates that the value of entry ratios ranges from 0 to 1.

Table 4.1 Conceptual Framework of Basic Model

<table>
<tr><td colspan="2">Bi-level Programming Model Formulation</td></tr>
<tr><td>Upper-level Decision Maker</td><td>Commander of Emergency-Response Center</td></tr>
<tr><td>Decision-Making Objective</td><td>Maximum Total Traffic Volumes</td></tr>
<tr><td colspan="2">

1. Objectives:

$$Max \quad \theta_1 \sum_{i\in N}\sum_{j\in N} r_{ij1}Q_{ij} + \theta_2 \sum_{i\in N}\sum_{j\in N} r_{ij2}Q_{ij} + \sum_{i\in N}\sum_{j\in N}(1-r_{ij1}-r_{ij2})Q_{ij} \tag{4.1}$$

2. Constraints: $V_l \le \mu_l \cdot C_l$ (4.2)

$$0 \le \theta_1, \theta_2 \le 1 \tag{4.3}$$

</td></tr>
<tr><td>Lower-level Decision Maker</td><td>Road Users'</td></tr>
<tr><td>Decision-Making Objective</td><td>1. Minimum user's total travel time（Victim's need）
2. Minimum path travel time (Emergency Rescue need)</td></tr>
<tr><td colspan="2">

1. Objectives:

$$Min \sum_l \int_0^{V_l} t_l(x)dx + \frac{1}{r}\sum_{i\in N}\sum_{j\in N}\left(T_{ij} \ln T_{ij} - T_{ij}\right) \tag{4.4}$$

$$Min \quad Max\left[\frac{\sum_l V_l \cdot t_l(V_l)}{\sum_l V_l \cdot t_l(0)}\right] \tag{4.5}$$

2. Constraints:

$$\sum_{p\in P_{ij}} q_{pij} = \theta_1 r_{ij1}Q_{ij} + \theta_2 r_{ij2}Q_{ij} + (1-r_{ij1}-r_{ij2})Q_{ij} \qquad \forall i,j \tag{4.6}$$

$$V_l = \sum_{i\in N}\sum_{j\in N}\sum_{p\in P_{ij}} r_{pij}^l \cdot q_{pij} \qquad \forall l \tag{4.7}$$

$$q_{pij} \ge 0 \qquad \forall p,i,j \tag{4.8}$$

$$\sum_l ff_{pij} = T_{ij} \quad ,\forall ij \tag{4.9}$$

$$\sum_j T_{ij} = O_i, \quad \forall i \tag{4.10}$$

$$\sum_i T_{ij} = D_j, \quad \forall j \tag{4.11}$$

$$ff_{pij} \ge 0 \quad ,\forall l,i,j \tag{4.12}$$

</td></tr>
</table>

Table 4.2 Notation of Basic Model

N : a set of nodes

L : a set of links

P_{ij} : a set of paths for O-D pair ij

Q_{ij} : traffic volume between O-D pair ij

μ_l : the congestion level can be tolerated

$t_l(0)$: free flow travel time on link l

N : number of demand nodes

M : number of rescue depots

L : a set of links

C_l : capacity flow on link l

γ : dispersion parameter

V_l : traffic flow on link l

Q_{ij} : traffic volume between O-D pair ij

q_{pij} : p_{-th} path flow between O-D pair ij

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

$t_l(V_l)$: travel time on link l

O_i : number of trips from i

D_j : number of trips to j

ff_{pij} : number of trips on p_{-th} path

T_{ij} : number of trips on O-D pair ij

r_{ij1} : if O-D pair ij is involved with 1st regulation, then 1, otherwise 0

r_{ij2} : if O-D pair ij is involved with 2nd regulation, then 1, otherwise 0

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

i : trip origin, $i = 1,2,\cdots I$

j : trip destination, $j = 1,2,\cdots J$

p : path, $p = 1,2,\cdots P$

m : trip origin of emergency vehicle, $m = 1,2,\cdots M$

n : trip destination of emergency vehicle, $n = 1,2,\cdots N$

l : link, $l = 1,2,\cdots L$

Equation 4.4 represents the lower-level objective function to be minimized consisting of the first term for route choice behavior by travelers and of the second term for the most likely O-D trip rate pattern, where symbol γ is a dispersion parameter calibrated from data. It is a function presenting the lower-level goals with the decision variables of link flow (V_l). If the total amounts of traveling costs can be maintained at the lowest level, the road networks will reach a balance point on user perspectives.

Equation 4.5 is the second concern of the lower-level objective, which is to meet the needs of emergency rescue.

Equation 4.6 represents the traffic inflows on path p. The right-hand side of Equation 4.6 composes three items representing traffic flows in the first zone, the second zone and the rest of areas subject to traffic regulation, respectively.

Equation 4.7 represents the traffic flows on every road sections (V_l). It can be measured as the summation of all traffic flows passing link *l* on path p. Parameter r_{pijl} is another dummy variable. If vehicles pass link *l* on path p, it will be marked as 1; otherwise as 0.

Equation 4.8 is to assure that the value of q_{pij} will always be positive.

Equation 4.9 represents the total number of trips passing through path *p*.

Equation 4.10 and **Equation 4.11** represent the total number of starting trips and ending trips. Both are the outcome of trip distribution that should meet the principle of Entropy Model.

Equation 4.12 is to guarantee that the number of trips passing through path *p* will not be negative.

4.4 Properties of Basic Model

The objective of the basic model is to manage the traffic flow and tackle with traffic congestion, and thus satisfy the needs of the victims in the disaster area. The upper-level objective is control the total volume of vehicles entering the disaster areas; while the lower-level objective, applied the combined trip distribution and traffic assignment model, it is hope to more accord with travel behavior analysis. Moreover, in order to select the most rapid path, according to the congestion level of each link, the Min-Max operator is employed to construct another objective function, which is useful for meeting the demand of emergency rescue vehicles and enhancing the efficiency of rescue operation.

4.5 Numerical Example of a Simple Case: Fuzzy Interactive Algorithm

In actual practice, the costs and the capacities of the road network are generally vague or uncertain. Fuzzy set theory appears to be ideally suited to solve such vague aspects. To reduce the complexity of the problem, we employed the possibility of linear programming to handle the vagueness of the parameters and the traditional max-min optimization approach to handle the bi-level aspects. The general multi-level programming problem has been shown to be non-convex and NP-hard. The only effective numerical approach to solving large practical problems appears to be the fuzzy approach proposed by Shih et al.

4.5.1 Applying Fuzzy Approach to Solving the Model

In Chapter 3.1, we had described the fuzzy interactive algorithm. If the scalars α and β are the minimum acceptable degrees of satisfaction for the decision variable x_1 and the upper-level objective $f_1(x)$, respectively, their feasible ranges are constrained by $\mu_{x_1}(x_1)$ and $\mu_{f_1}(f_1(x))$ respectively. The lower-level decision-maker can compare various solutions corresponding to the upper-level decision-maker's satisfactory levels α and β. If the membership function is represented by γ, δ with $0 \le \gamma, \delta \le 1$, it can be considered as the degree of lower-level satisfaction. To satisfy the degrees of satisfaction of both the upper- and the lower-level objectives, the solution must be the minimum of α, β γ and δ, this conclusion can be represented as $\lambda = Min\{\alpha,\ \beta,\ \gamma,\ \delta\}$, where λ is a fuzzy number which obtained from the intersection of the three membership functions. According to the traditional fuzzy approach, λ must be maximized in order to obtain the maximum degree of satisfaction. Therefore, the following multi-objective programming problem needs to be solved.

The study uses the concept of compromise programming for fuzzy optimization to solve the multi-objective programming problem. If the upper-level decision-maker is satisfied with the solution of Equation (4.13), a satisfactory solution is reached. Otherwise, he/she should provide a new membership function for the control variables and objective function and the computation process will continue until a satisfactory solution is reached. Figure 4.4 illustrates the conceptual flow chart of this proposed process, which can be summarized in the following three steps.

$$
\begin{aligned}
&Max \quad \lambda = Max \ \left(\min \ \{\alpha, \beta, \gamma, \delta\}\right) \\
&subject \quad to: \\
&\qquad \mathbf{A}_1\mathbf{x}_1 + \mathbf{A}_2\mathbf{x}_2 \le \mathbf{b} \\
&\qquad \boldsymbol{\mu}_{x_1}(\mathbf{x}_1) \ge \alpha \cdot \mathbf{1} \\
&\qquad \mu_{f_1}(f_1(\mathbf{x})) \ge \beta \\
&\qquad \mu_{f_2}(f_2(\mathbf{x})) \ge \gamma \\
&\qquad \mu_{f_3}(f_3(\mathbf{x})) \ge \delta \\
&\qquad \mathbf{x}_1 \ge \mathbf{0} \\
&\qquad \mathbf{x}_2 \ge \mathbf{0} \\
&\qquad \alpha \in [\mathbf{0{,}1}] \\
&\qquad \beta, \gamma, \delta \in [0,1]
\end{aligned}
\tag{4.13}
$$

Step 1. The decision-makers of the upper and lower levels solve their problems independently by solving Equations 4.1 and Equations 4.4, 4.5. If these three solutions coincide, the optimal or preferred solution of the system is obtained, and then stop. Otherwise, go to Step 2.

Step 2. The upper-level decision-maker decides his/her tolerances on the goal and the decisions in terms of membership functions. Meanwhile, the lower-level decision-maker also decides his/her tolerance on the goal in terms of membership functions. These membership functions will serve as extra constraints in forming the auxiliary problem, Equations 4.13.

Step 3. Solve the auxiliary problem. If the decision-makers at each level are satisfied with the solution, a compromise solution is reached, and then stop. Otherwise, go to Step 2 to obtain newly adjusted membership functions.

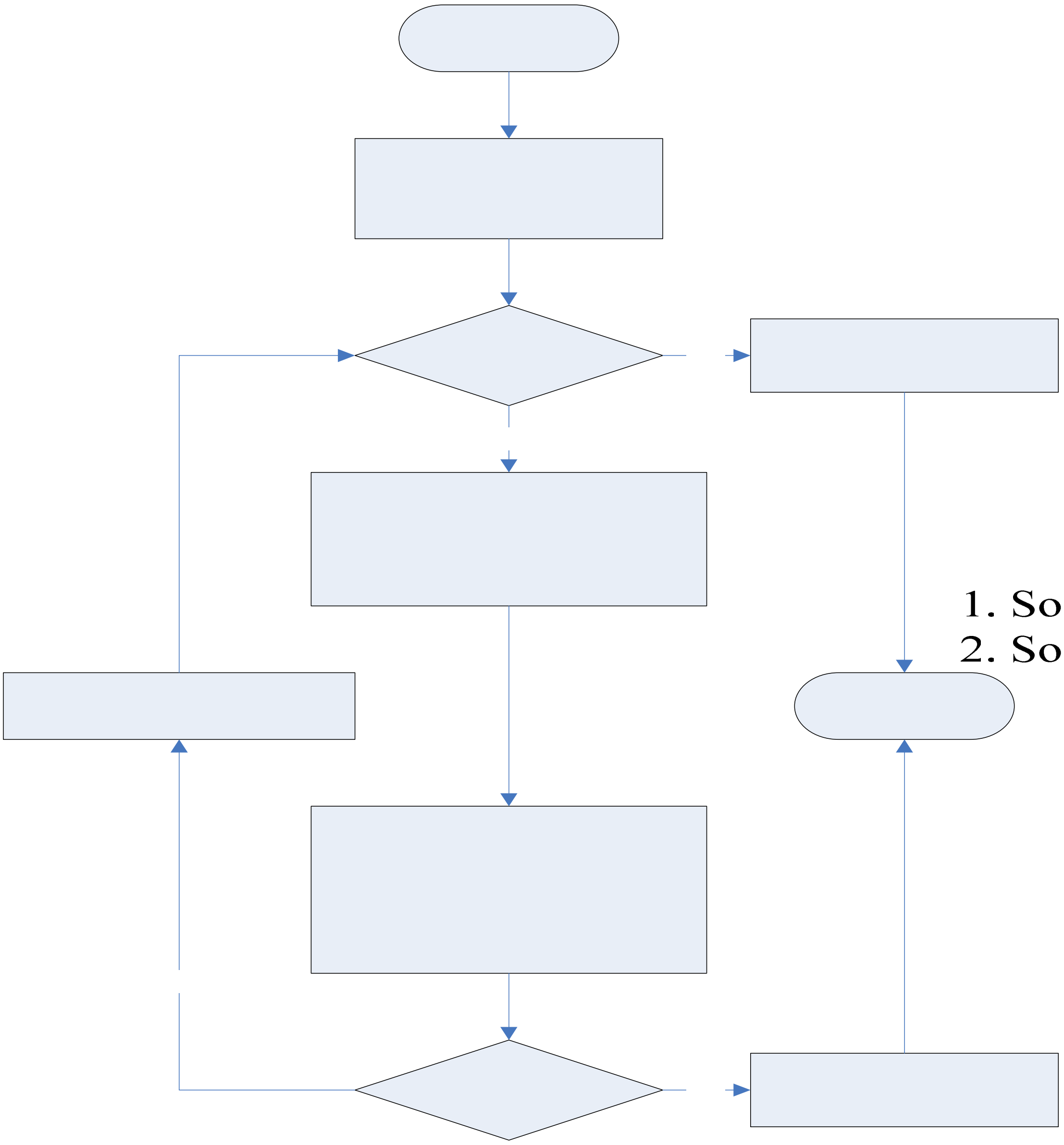


Figure 4.4 Fuzzy Interactive Decision-Making Process

To solve the empirical bi-level mathematical model, the study uses the fuzzy multi-objective approach. The model is solved heuristically to satisfy the time constraint in practical operation instead of finding the global optimization with intolerable computation time.

The basic concept of fuzzy multi-objective optimization is to find the maximal satisfactory degree among conflicting objectives, which is what this study aims to obtain. Let $\mu_{f_1}\left(f_1(\theta_i)\right)$ represent the fuzzy membership function of $f_1(\theta_i)$, $\mu_{f_2}\left(f_2(V_l)\right)$ represent the fuzzy membership function of $f_2(V_l)$, and $\mu_{f_3}\left(f_3(V_l)\right)$ represents the fuzzy membership function of $f_3(V_l)$. By using the λ transformation and $\lambda = Min(\alpha,\beta,\gamma,\delta)$, the multi-objective bi-level programming of the traffic regulation problem in earthquake disaster defined in previous sections can be replaced and formulated as Equation (4.14).

$$
\begin{aligned}
& Max \quad \lambda = Max\left(Min\{\alpha,\beta,\gamma,\delta\}\right) \\
& Subject \quad to: \\
& \qquad f_1(\theta_i) = \theta_1 r_{ij1} Q_{ij} + \theta_2 r_{ij2} Q_{ij} + (1 - r_{ij1} - r_{ij2}) Q_{ij} \\
& \qquad f_2(V_l) = \sum_l \int_0^{V_l} t_l(x)dx + \frac{1}{\gamma}\sum_{i\in N}\sum_{j\in N}\left(T_{ij}\ln T_{ij} - T_{ij}\right) \\
& \qquad f_3(V_l) = \sum_l V_l \cdot t_l(V_l) \Big/ \sum_l V_l \cdot t_l(0) \\
& \qquad \sum_{k\in K_{ij}} q_{kij} = \theta_1 r_{ij1} Q_{ij} + \theta_2 r_{ij2} Q_{ij} + (1 - r_{ij1} - r_{ij2}) Q_{ij} \\
& \qquad V_l = \sum_{i\in N}\sum_{j\in N}\sum_{k\in K_{ij}} r_{kijl} \cdot q_{kij} \\
& \qquad \sum_p ff_{ij}^{\,p} = T_{ij} \qquad \forall_{ij} \\
& \qquad \sum_j T_{ij} = O_i \qquad \forall_i \\
& \qquad \sum_i T_{ij} = D_j \qquad \forall_j \\
& \qquad \mu_{\theta_i}(\theta_i) \ge \alpha \cdot \mathbf{1} \\
& \qquad \mu_{f_1}\left[f_1(\theta_i)\right] \ge \beta \\
& \qquad \mu_{f_2}\left[f_2(V_l)\right] \ge \gamma \\
& \qquad \mu_{f_3}\left[f_3(V_l)\right] \ge \delta \\
& \qquad V_l \ge 0 \qquad \forall_l \\
& \qquad q_{kij} \ge 0 \qquad \forall_{k,i,j} \\
& \qquad ff_{ij}^{\,p} \ge 0 \qquad \forall_{l,i,j} \\
& \qquad \theta_i \in [0,1] \qquad i = 1,\ 2 \\
& \qquad \alpha \in [\mathbf{0},\mathbf{1}] \\
& \qquad \gamma,\beta,\delta \in [0,1]
\end{aligned}
\tag{4.14}
$$

4.5.2 Numerical Examples

A. A Hypothetical Network

We assumed a fuzzy bi-level traffic regulation road network with eight nodes and 26 arcs. There are four centroids of which centroids 6, 3 are inside the disaster area and centroids 1, 8 are outside the disaster area. The fuzzy data are summarized in Table 4.3 and the structure of the network is shown in Figure 4.5.

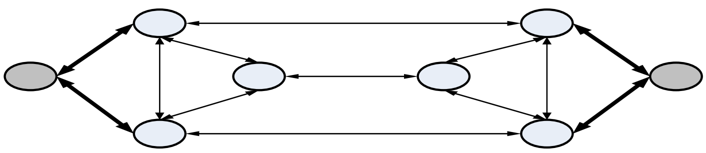


Figure 4.5 Test Road Network

Each link is assumed to have two costs: one in its normal state and the other is in the degraded state. The O-D traffic volume under normal conditions is listed in Table 4.3. Then, the road network capacity under each O-D traffic volume is calculated to be 6600 trips. Calculation of the road network capacity excluding the external-external trips on a degraded road network gives 4940 trips, where the traffic capacity has been decreased by 60% (links 04, 05, 07, 08, 09, 11, 12, 18 of road network), 70% (links 15, 16, 19, 20, 22, 23 of road network) and the other 80% compared with the normal road network. As a result, the degraded road network capacity is less than 75% of the normal network capacity.

Table 4.3 Parameter for Fuzzy Traffic Regulation Problems

Link no.	**From / To**	**Fuzzy Link Capacity(normal)**	**Fuzzy Link Volume(normal)**	**Fuzzy Travel Time(normal)**	**Traffic demand**
01	$1 \to 2$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
02	$1 \to 4$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
03	$2 \to 1$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
04	$2 \to 3$	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
05	$2 \to 4$	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
06	$2 \to 5$	(280, 300, 320)	(200, 220, 240)	(5.21, 5.22, 5.23)	(260, 280, 300)
07	$3 \to 2$	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
08	$3 \to 4$	(90, 100, 110)	(70, 80, 90)	(3.16, 3.18, 3.20)	(90, 100, 110)
09	$3 \to 6$	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
10	$4 \to 1$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
11	$4 \to 2$	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
12	$4 \to 3$	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
13	$4 \to 7$	(280, 300, 320)	(200, 220, 240)	(5.20, 5.22, 5.24)	(260, 280, 300)
14	$5 \to 2$	(280, 300, 320)	(200, 220, 240)	(5.20, 5.22, 5.24)	(260, 280, 300)
15	$5 \to 6$	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
16	$5 \to 7$	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
17	$5 \to 8$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
18	$6 \to 3$	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
19	$6 \to 5$	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
20	$6 \to 7$	(180, 200, 220)	(130, 150, 170)	(2.08, 2.09, 2.10)	(160, 180, 200)
21	$7 \to 4$	(280, 300, 320)	(200, 220, 240)	(5.20, 5.22, 5.24)	(260, 280, 300)
22	$7 \to 5$	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
23	$7 \to 6$	(180, 200, 220)	(130, 150, 170)	(2.08, 2.09, 2.10)	(160, 180, 200)
24	$7 \to 8$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
25	$8 \to 5$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
26	$8 \to 7$	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)

B. Test Results and Discussions

Decision-makers of the upper- and lower-level solve their problems independently by solving Equations 4.1, 4.4 and Equation 4.5 separately subject to its constraints. If these two solutions coincide, the optimal or preferred solution of the system is obtained. Otherwise, the upper-level decision-maker decides his/her tolerances on the goal and the decisions in terms of membership functions.

Meanwhile, the lower-level decision-maker also decides his/her tolerance on the goal in terms of membership functions. In order to satisfy both decision-makers, the interactive approaches are employed to obtain satisfactory membership functions. Since true optimum cannot be defined easily due to the interactions, there is no reason to assume that the optimum is at the corner point. Thus, we consider a compromise solution, which is acceptable to all decision-makers. The proposed approach is very efficient and does not increase the complexity or the size of the original problem. Since the set of our constraints in the model may not be a convex, the uniqueness of the model may not be guaranteed. Moreover, since our purpose is to find a satisfactory compromise solution, even if the current solution obtained is a local optimal solution, it is still acceptable.

The above problem can be solved by LINGO mixed-integer software. The proposed approach first solves the upper- and lower-level decision objectives separately subject to its constraints. The optimal solutions for the upper- and lower-level decision problems are $\left(x_1^U, x_2^U\right)$= (0.23, 0.29) with f_1^U =6600 and $\left(x_1^L, x_2^L\right)$= (0.20, 0.015) with f_{21}^L=6110 and $\left(x_1^L, x_2^L\right)$= (0.20, 0.015) with f_{22}^L=1.04. With solutions serving as reference, and set f_1^U = 6600 and assume $f_1^{'}$=2470, $f_{21}^{'}$=2470 and $f_{22}^{'}$=1.0, let the negative and positive tolerances of the upper-level DM's decision variable x_1 be 0.15 and 0.31, respectively. Using Equations 3.3, 3.4 and 3.5, we obtain the membership functions $\mu_{x_1}(\bullet)$, $\mu_{f_1}(\bullet)$, $\mu_{f_{21}}(\bullet)$ and $\mu_{f_{22}}(\bullet)$ are obtained. The compromise solution is $f^* = \left(f_1^*, f_{21}^*, f_{22}^*\right)$= (2420, 2240, 2.53) with $x^* = \left(\theta_1^*, \theta_2^*\right)$ = (0.21, 0.02). The overall satisfaction of the present solution is $\lambda = 0.45$.

The result indicates that the first-stage regulation rate $(1-\theta_1^*)$ is 0.79, and the second-stage regulation rate $(1-\theta_2^*)$ is 0.98. The value of the ratio for the first-stage regulation implies that it can accept about one fifth of the traffic from outside the regulated area. In contrast, the regulation rate of the second stage indicates that it is almost prohibited into the regulated area completely. That is to say, there remains a certain amount of road network capacity. It is better to give the first priority to emergency rescue vehicles from outside the regulated area, and non-emergency car should be regulated.

In order to deal with the reduction of road network capacity in disaster areas, it is necessary for decision-makers to establish a systematic approach and maintain the physical infrastructures to implement traffic management before and after a major earthquake. It is evident that traffic facilities should be built with the most up-to-date specification for seismic resistance with the countermeasures of contingency plans developed before earthquake. It should be emphasized that the effective traffic management is dependent on reliable traffic data not only during the normal operation, but also after the major earthquake. Through the use of high-quality data, the reliability of traffic regulation throughout the road network will be enhanced.

CHAPTER 5 DEVELOPMENT OF REVISED MODEL

The Basic Model is developed from a two-stage areas traffic regulation concept. The upper-level objective is to allow as much traffic as possible to go through the disaster areas so that victims can feel satisfied. The lower-level objective is to meet the emergency rescue needs by integrating the combined road network assignment and trip distribution concept. However, this model does not consider the different types of O-D trips and traffic patterns. In order to regulate the private vehicles and manage the emergency rescue vehicles for rescue and emergency aid activities, the Revised Model aims at controlling the private vehicle flows which can be generated in and attracted to each traffic regulation zone considering the classification of O-D trips. The problem to be addressed is formulated as a multi-objective, two-modal (private vehicle flows and emergency vehicles) network flow problem according to the concept of network flow theory and bi-level programming.

5.1 Weaknesses of Basic Model

The Basic Model assumes a fixed assignment pattern with the aim of simplifying modular analysis, examines different decision-making perspectives, and follows the trip-analysis approach so as to strengthen the model's applicability and rationality. In this research, the Basic Model regards trip distribution as a dynamic and unknown problem. It is reasonable to assume that the flow between any O-D pair i-j, traffic flow (q_{ij}) will be proportional to the total number of trips leaving the origin O_i, and the total number of trips attracted to the destination D_j. Naturally, the equilibrium O-D flow should also depend on the level of service between the origin and the destination. In other words, traffic flow (q_{ij}) should also depend on $f(t(x))$, where $f(\bullet)$ is some function and $t(x)$ is the O-D travel time.

In the model, trip distribution and road network assignment are integrated together to assign traffic flows into the road networks, so that it can more realistically reflect the true traffic situation. Nevertheless, there are some weaknesses that are described in the following.

A. O-D Traffic Volumes Neglecting Emergency Vehicles

In the Revised Model, vehicles are classified into two categories. One is the private vehicle flows that should be controlled when the travel demand exceeds the capacity of road network and travel for emergency vehicles needed in both rescue and emergency aid activities. The other comprises emergency vehicles carrying supplies and relief personnel that are not controlled during the disaster emergency. Different types of O-D trips and traffic patterns should be considered in order to control the private vehicles and manage the emergency rescue vehicles for rescue and emergency aid activities.

B. Unclassified of Private Vehicle Flows

In the Basic Model, the O-D traffic volume of private vehicle flows is not regarded as the O-D traffic patterns. In the Revised Model, the private vehicle flows are formulated considering the classification of O-D 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 taken as the O-D traffic patterns representing the relative ratio of O-D pairs with origins and/or destinations inside the disaster area.

In particular, the Revised Model deals with the problem of controlling the private vehicle flows, which can be generated in and attracted to each traffic regulation zone considering the classification of O-D trips and determining the location of the emergency vehicles depot.

5.2 Properties of Revised Model

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. As with road network capacity, O-D traffic volume is defined by network characteristics (road network pattern, kink capacity) and flow characteristics. The flow characteristics should include land use pattern, trip distribution (O-D traffic pattern), modal split and traffic assignment.

Analysis of changes in O-D traffic volume for automobiles within road networks of disaster area after the earthquake has revealed that the O-D ratio of short-distance trips increased greatly. The O-D ratio of long-distance trips, which originated outside the disaster area and ordinarily passed through it decreased. The O-D ratio of trips originating inside the disaster area to points outside also decreased. On the contrary, the O-D ratio of trips originating outside the disaster area to points inside increased greatly.

5.3 Formulation of Revised Model

In this research, we discuss the O-D traffic volume according to the classification of private vehicle flows taking into consideration O-D traffic patterns. The O-D trips of vehicle flows are classified into two categories (Masuya, 1999). One is the private vehicle flows that need to be regulated when travel demand exceeds the capacity of a network. The other category is emergency vehicles carrying supplies and relief personnel, which are not regulated during a disaster emergency. The private vehicle flows are also formulated considering the classification of O-D 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 taken as the O-D traffic pattern representing the relative ratio of O-D pairs 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.

The traffic regulation 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 that the command officer of the Emergency Response Center at the county and city governments in earthquake-raided areas is 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 as much traffic as possible to go through the disaster areas without exceeding the reduced roadway capacity, so that victims can feel satisfied. 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 with respect to travel time. Traffic regulation zones are designated by decision makers according to the degrees of damages on the roads. Then the traffic regulation problem of maximizing the total amount of O-D traffic volume (Q_i) taking into consideration both the O-D traffic volume and the emergency vehicles is formulated as follows and the notation is summarized in Table 5.1.:

Upper Level Problem

$$Max \quad Q = \sum_{m=1}^{M}\sum_{n=1}^{N} V_{mn} + \sum_{i=1}^{I}\sum_{j=1}^{J} V_{ij} \tag{5.1}$$

Subject to

$$\sum_{p \in P_{ij}} V_{pij}^{II} = r_{ij} \cdot Q_d \qquad \left(i \in I_i, \quad j \in J_o\right) \tag{5.2}$$

$$\sum_{p \in P_{ij}} V_{pij}^{EI} = s_{ij} \cdot Q_i \qquad \begin{pmatrix} i \in I_i, & j \in J_o \\ i \in I_o, & j \in J_i \end{pmatrix} \tag{5.3}$$

$$V_{ij} = \sum_{p \in P_{ij}} V_{pij}^{II} + \sum_{p \in P_{ij}} V_{pij}^{EI} \qquad \left(i \in I_i, \quad j \in J_o\right) \tag{5.4}$$

$$\sum_{m=1}^{M} V_{mn} \geq V_n \qquad \forall n \tag{5.5}$$

$$\sum_{n=1}^{N} V_{mn} \leq d_m \cdot V_m \qquad \forall m \tag{5.6}$$

$$\sum_{m=1}^{M} d_m \leq D \tag{5.7}$$

$$V_l \leq \mu_l \cdot C_l \tag{5.8}$$

Lower Level Problem

$$Min \quad \sum_{l} \int_{0}^{V_l} t_l(x)dx + \frac{1}{\gamma}\sum_{i=1}^{I}\sum_{j=1}^{J}\left(T_{ij} \ln T_{ij} - T_{ij}\right) \tag{5.9}$$

$$Min \quad Max\left[\frac{\sum_{l} V_l \cdot t_l(V_l)}{\sum_{l} V_l \cdot t_l(0)}\right] \tag{5.10}$$

Subject to

$$\sum_{p \in P_{ij}} q_{pij} = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p \in P_{ij}} \delta_{pij}^{l} \cdot V_{pij}^{II} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p \in P_{ij}} \delta_{pij}^{l} \cdot V_{pij}^{EI} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{p \in E_{mn}} \delta_{pmn}^{l} \cdot V_{pmn} \tag{5.11}$$

$$V_l = \sum_{i \in I}\sum_{j \in J}\sum_{p \in P_{ij}} r_{pij}^{l} \cdot q_{pij} \qquad \forall l \tag{5.12}$$

$$\sum_{p \in P_{ij}} ff_{pij} = T_{ij} \qquad \forall ij \tag{5.13}$$

$$\sum_{j \in J} T_{ij} = O_i \qquad \forall i \tag{5.14}$$

$$\sum_{i \in I} T_{ij} = D_j \qquad \forall j \tag{5.15}$$

$$q_{pij} \geq 0 \qquad \forall p, i, j \tag{5.16}$$

$$ff_{pij} \geq 0 \tag{5.17}$$

$$V_{pij}^{II} \geq 0 \tag{5.18}$$

$$V_{pij}^{EI} \geq 0 \tag{5.19}$$

$$V_{pmn} \geq 0 \qquad \forall p, m, n \tag{5.20}$$

$$V_{mn} \geq 0 \qquad \forall m, n \tag{5.21}$$

Equation 5.1 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 regulation. Adding the two parts together represents the entire traffic flows subject to traffic regulation.

Equation 5.2 represents the origin and destination flow conservation constraint for internal-internal trips.

Equation 5.3 represents the origin and destination flow conservation constraint for internal-external or external-internal trips.

Equation 5.4 represents all the private vehicles between O-D pairs.

Equation 5.5 implies that the constraints with respect to the total number of emergency vehicles necessary for rescue missions at each demand node n.

Equation 5.6 implies that the constraints with respect to the total number of emergency vehicles from the rescue depot m.

Equation 5.7 says that at most D depots can be located.

Equation 5.8 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.

Equation 5.9 illustrates that the first 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.

Equation 5.10 demonstrates the second lower-level objective and depicts that the flow is diverted from congested paths and to less congested ones.

Equation 5.11 represents the link capacity constraints that consider the emergency and private vehicles.

Equation 5.12 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.

Equation 5.13 conserves flows for each O-D pair.

Equation 5.14 represents the total number of starting trips. It is a production constraint that requires summing O-D flows over all destinations, thus yielding trip rates from the origin.

Equation 5.15 represents the total number of ending trips. It is an attraction constraint that requires that summing O-D flows over all destinations, thus yielding trip rates attracted to the destination. Both **Equation 5.14** and **Equation 5.15** are the outcome of trip distribution that should meet the principle of entropy model.

Equation 5.16 is to assure that the volume of p path will always be positive.

Equation 5.17 to **Equation 5.21** is to guarantee that the number of different objective trips passing through path p will not be negative.

Table 5.1 Notation of Revised Model

N : a set of nodes

L : a set of links

P_{ij} : a set of paths for O-D pair ij

μ_l : the congestion level can be tolerated

$t_l(0)$: free flow travel time on link l

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 to demand node n

D : number of depots to locate

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

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

I_i : set of generation zones inside the disaster area

J_i : set of attraction zones inside the disaster area

I_o : set of generation zones outside the disaster area

J_o : set of attraction zones outside the disaster area

N : number of demand nodes

M : number of rescue depots

L : a set of links

E_{mn} : a set of paths for emergency vehicle mn between O-D pair ij

P_{ij} : a set of paths for O-D pair ij

C_l : capacity flow on link l

γ : dispersion parameter

V_l : traffic flow on link l

q_{pij} : p_{-th} path flow between O-D pair ij

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

$t_l(V_l)$: travel time on link l

O_i : number of trips from i

D_j : number of trips to j

ff_{pij} : number of trips on p_{-th} path

T_{ij} : number of trips on O-D pair ij

Q_d : maximum traffic demand of disaster area

Q_i : total amount of O-D traffic volume generated from zone i

V_{ij} : number of private vehicles between O-D pair ij

V_{pij}^{II} : the p_{-th} path traffic volume on an internal-internal O-D pair ij

V_{pij}^{EI} : the p_{-th} path traffic volume on an internal-external or external-internal O-D pair ij

V_{pmn} : the p_{-th} path emergency vehicles between O-D pair ij

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

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

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

δ^l_{pij} : if the p_{-th} path between O-D pair ij is included on link l then 1, otherwise 0

δ^l_{pmn} : if the p_{-th} path between O-D pair mn is included on link l then 1, otherwise 0

r^l_{pij} : if the p_{-th} path between O-D pair ij is included on link l then 1, otherwise 0

5.4 Key Features of Revised Model

In summary, the Revised Model has the following key features in model formulation:

1. With the O-D traffic volume considered as flow characteristics, trip distribution (O-D traffic pattern) and traffic assignment, the O-D trips of private vehicle flows are classified into two categories. One is the trips with origins and/or destinations inside the disaster area and calculated as internal-internal, external-internal and internal-external types of “local trips”. The other category is the trips with origins and destinations outside the disaster area described as “through trips”. In order to balance travel demand and traffic supply when tackling traffic congestion, the Revised Model aims at managing the emergency vehicles and regulating the private vehicle flows in the aftermath of an earthquake disaster.

2. In order to minimize the total travel time from the emergency rescue perspective, the Revised Model sets the second lower-level objective to find the minimum travel time path in terms of congestion level for emergency rescue need. Congestion is measured in terms of *Min* $Max \sum_l V_l \cdot t_l(V_l) / \sum_l V_l \cdot t_l(0)$. In

particular, the model deals with the travel demand according to the passenger car trip purpose set the emergency priority. Then we can manage the emergency vehicles and regulate the private vehicle flows in the aftermath of an earthquake disaster.

5.5 Numerical Example of a Simple Case: Genetic Algorithm

A. A Hypothetical Network

A hypothetical network, shown in Figure 4, is used as the numerical example. The road network has 11 nodes and 28 links, of which there are five centroids (three centroids inside the disaster area and two 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 O-D traffic volumes under normal conditions are listed in Table 5.2. The road network capacity under each O-D traffic volume is 2940 trips. Different scenarios are assumed according to the different road capacity. For example, the capacity is decreased by 60% (links 01, 02, 09, 10, 23, 24 of road network), or 70% (links 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.

The estimated maximum demand of passenger car trips after the seismic disaster within 72 hours is 4000 trips, and the assumed rescue depots of emergency vehicles (such as ambulance, rescue and restoration flows) are located at two centroids (nodes 10, 11) outside the disaster area as illustrated in Figure 5.1. It is assumed that each demand node (nodes 1, 5, 9) needs to have 200 emergency vehicles, and thus, 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 O-D traffic demand is calculated as illustrated in Table 5.2.

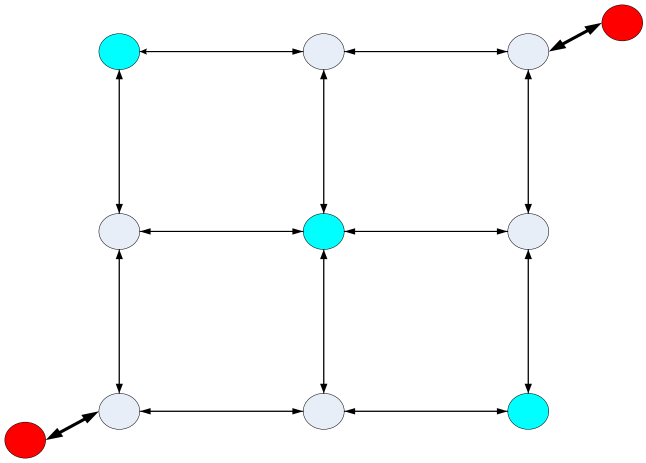


Figure 5.1 Test Road Network. All Links Are Two-Directional.

1 2

The link travel time function adopted from the Federal Highway Administration (FHWA) is the cost function in the user equilibrium model described as follows.

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

4 5

In the example, every reasonable path for the O-D 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.

7 8

11

Table 5.2 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)	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

B. Numerical Results

A computer program coded with Visual Basic.NET was performed on a PentiumⅣ personal computer with 32M RAM. We assumed that each demand node requires 200 emergency vehicles, and the same condition as the previous hypothetical road network. The solution algorithm analysis demo depicts the bi-level traffic regulation problem objectives, test road network, capacity, traffic flow distribution and other assumed initial population data as shown in Figure 5.2.

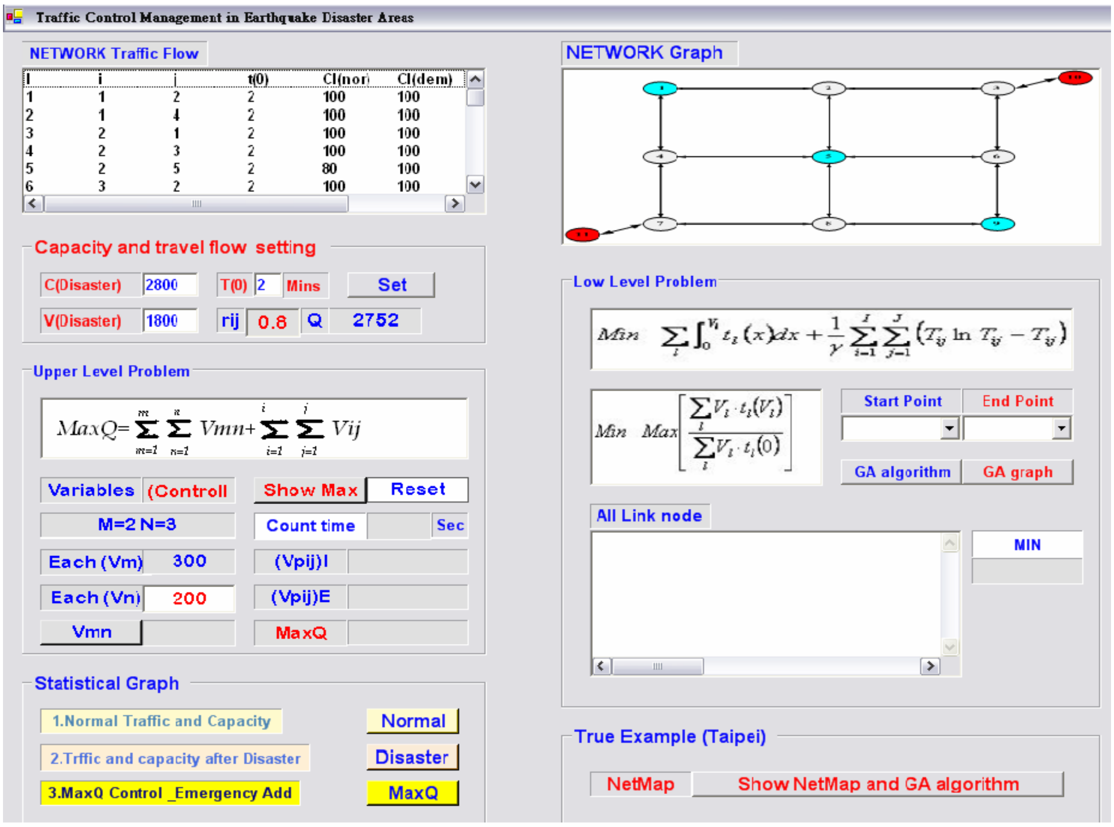


Figure 5.2 Solution Algorithms by Visual Basic.NET Code.

Figure 5.3 presents the results of tests; these tests were performed using Genetic Algorithm with population p =100, mutation rate p_m =0.01 and crossover rate p_c =0.5. In the top of the computer program demo, we can see the assumed traffic flow and capacity of each link, and grid test road network. The middle of the demo show the execution time of 40.20223 seconds achieved by the bi-level programming and user equilibrium assignment, the total number of vehicles on the road network inside the disaster area is 1,408. Although the traffic volumes after traffic regulation indicate that there remains some road network capacity, it is better to give the first priority to accommodate all emergency rescue vehicles from outside into the regulated area. Then the number of passengers cars permitted to enter the regulated area is about 468 with the total maximum traffic vehicles allowed in the disaster area equal 2,476. The lower part of the demo not only shows that the travel time of the shortest path in each generation is 6 minutes, but also reveals the function of the statistical graph depicted as follows.

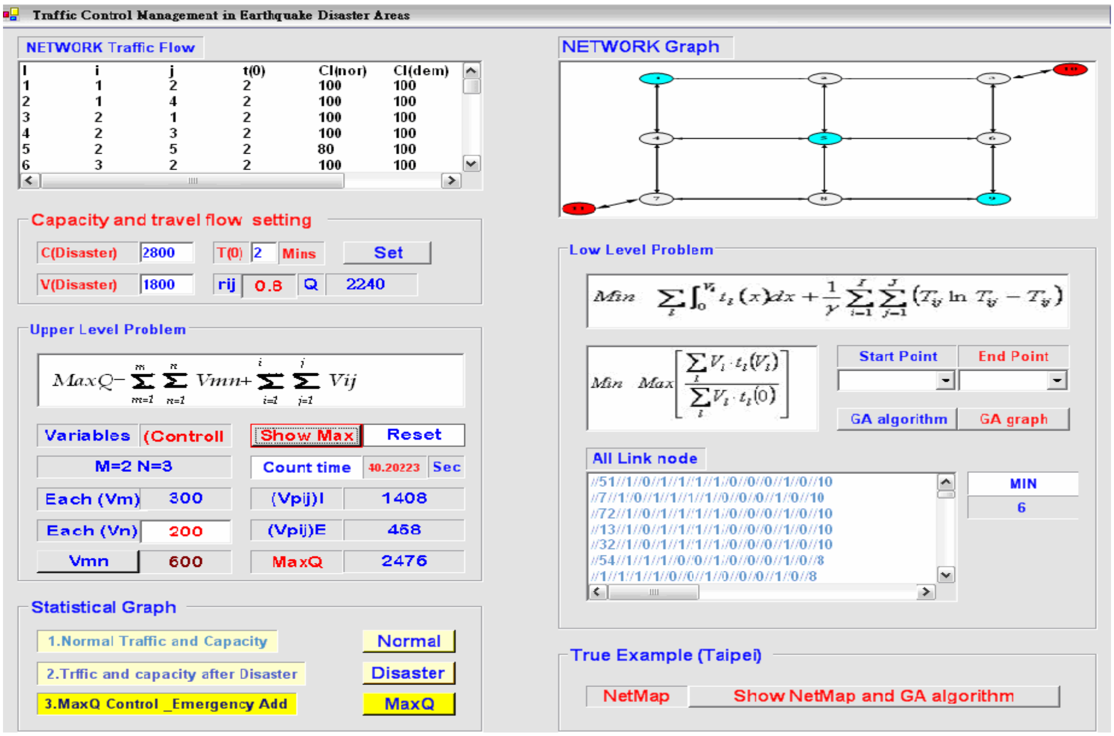


Figure 5.3 Numerical Results by Genetic Algorithm.

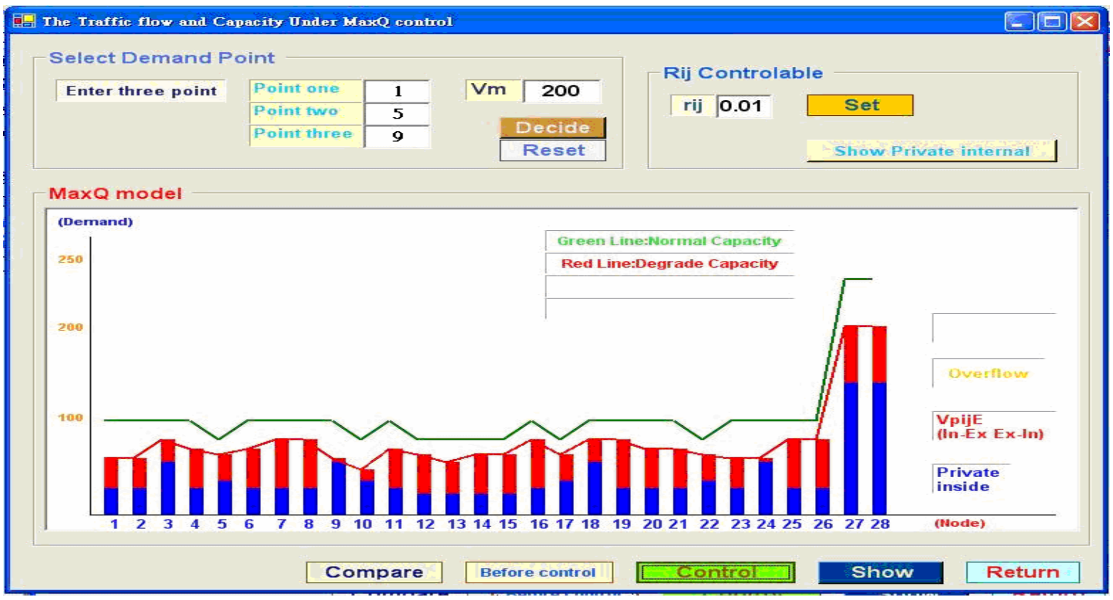


Figure 5.4 Determinations of Allowable Vehicle Flows under Degraded Road Network Capacity

Figure 5.4 indicates that there is still 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 of entering the disaster area in order to first meet the needs of emergency vehicles.

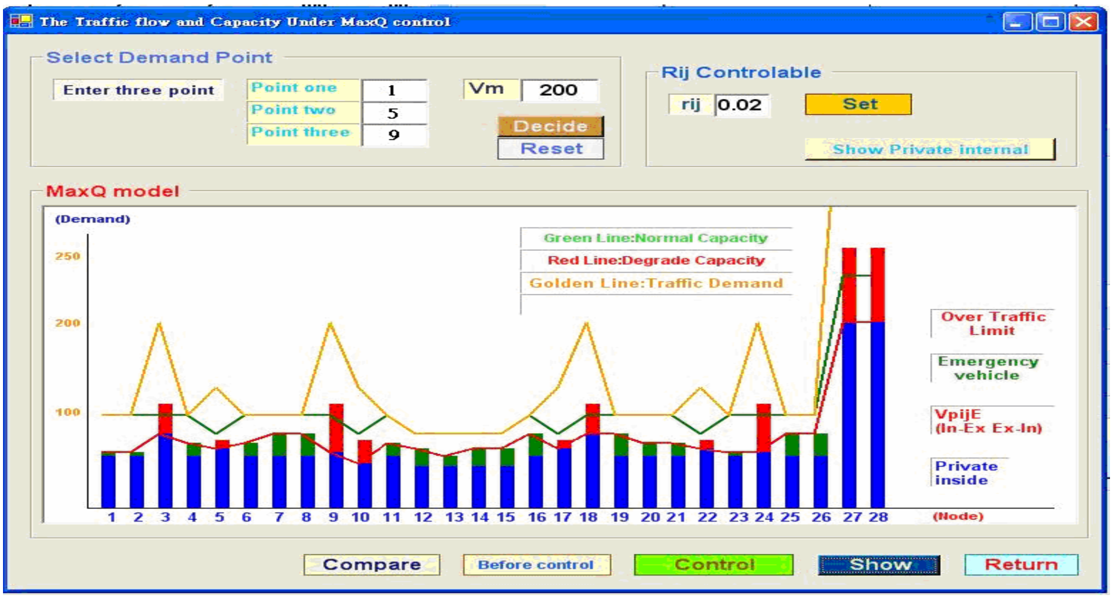


Figure 5.5 Some Emergency Vehicles Exceed Degraded Road Network Capacity

Figure 5.5 indicates that when unit O-D traffic volumes on an O-D pair ij inside the disaster area increase, some emergency vehicles (red bar-chart) exceeding the degraded road network capacity should be regulated. These results imply that the total number of passenger cars entering the regulated area should vary depending on the number of emergency rescue vehicles and location of the rescue depots.

Figure 5.6 shows the traffic flows, road network capacity under normal condition and in the aftermath of the disaster, and the variation in traffic volume variation in each link. The green line of the figure represents the traffic volume of each link under normal condition, and the red line represents the post-quake traffic volume of each link, which is close to the saturated capacity. As can be seen, analyzing the travel behavior by means of genetic algorithm, we can observe that private vehicles (blue bar-chart) travel on most of the links, with few links (red bar-chart) assigned to emergency vehicles. Some of the links (yellow bar-chart) traveled by vehicles into the regulated area from outside can meet the need of both emergency rescue and disaster victims.

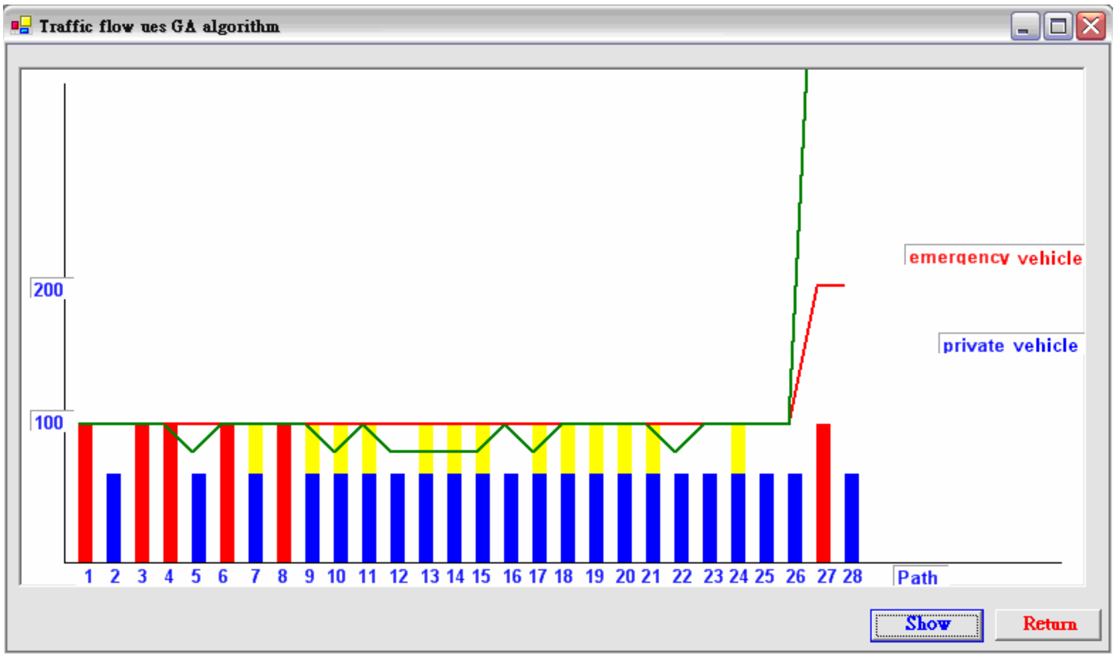


Figure 5.6 Test Result of Traffic Flow by Genetic Algorithm

Figure 5.7 displays that the change in volumes of total traffic in disaster area obtained by genetic algorithm iteration in each generation. The yellow point of the figure in each generation (blue bar-chart) represents the maximum traffic volumes of unconditional state analysis in each population. As can be seen, during the twenty-first generation iteration of genetic algorithm, the approximate optimal solution is reached.

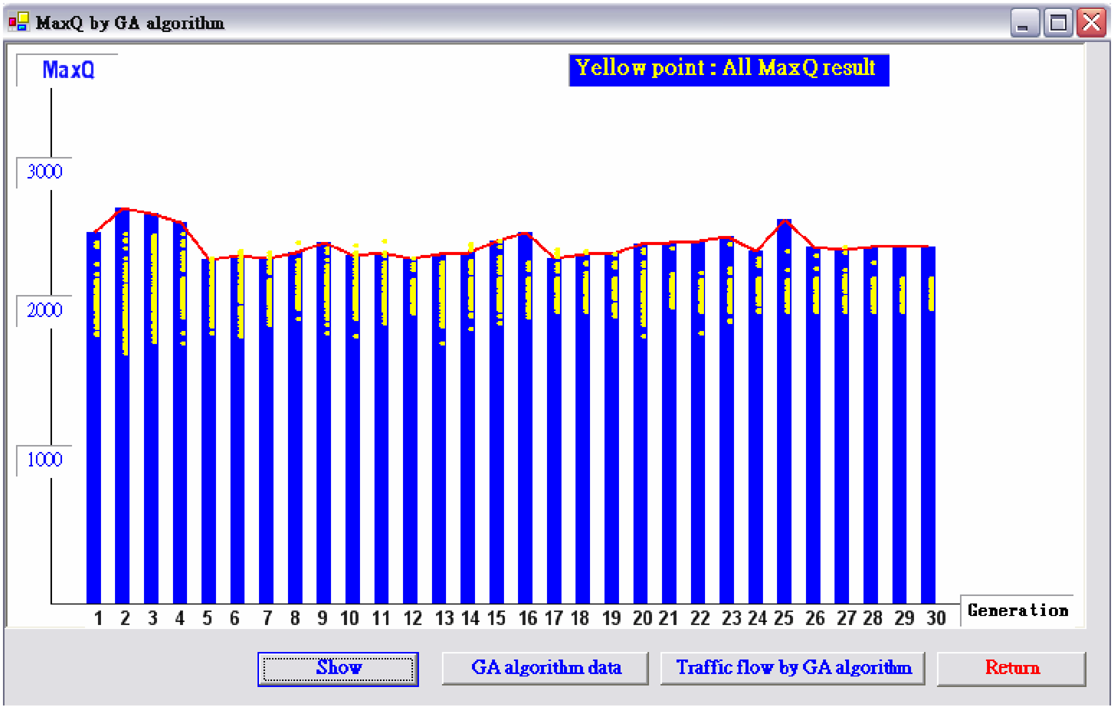
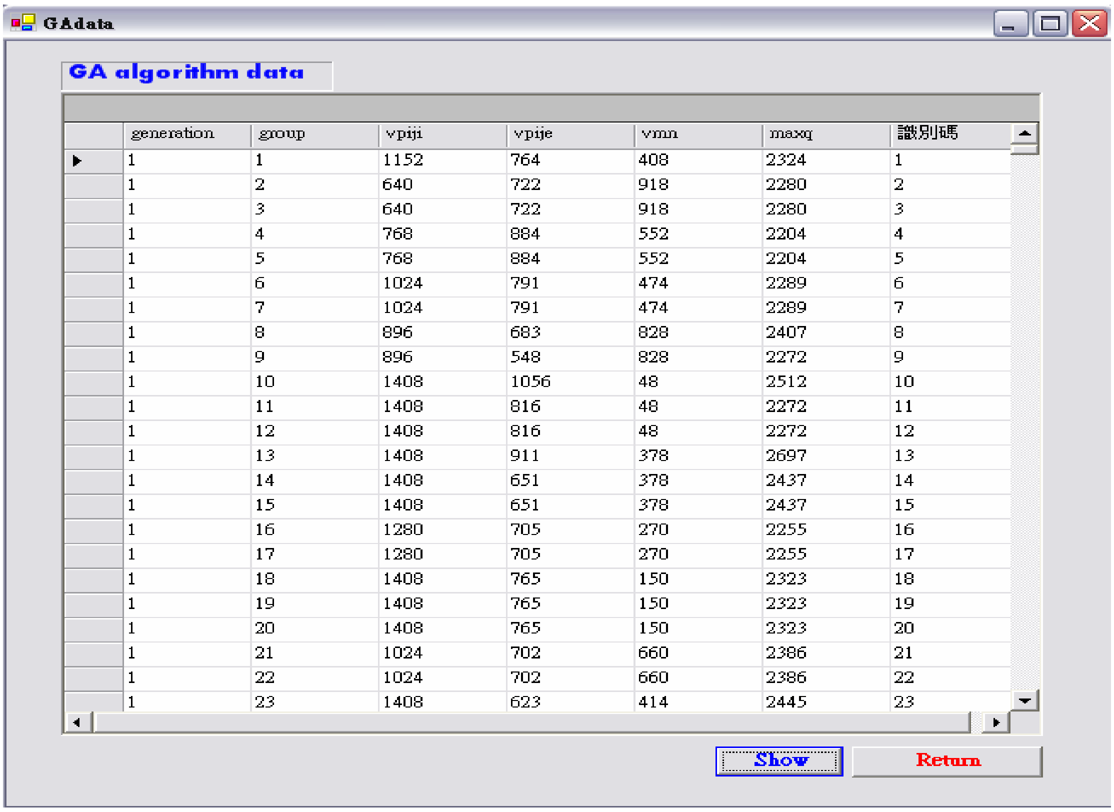


Figure 5.7 The Maximum Traffic Volume in Each Generation



generation	group	vpiji	vpije	vmn	maxq	識別碼
1	1	1152	764	408	2324	1
1	2	640	722	918	2280	2
1	3	640	722	918	2280	3
1	4	768	884	552	2204	4
1	5	768	884	552	2204	5
1	6	1024	791	474	2289	6
1	7	1024	791	474	2289	7
1	8	896	683	828	2407	8
1	9	896	548	828	2272	9
1	10	1408	1056	48	2512	10
1	11	1408	816	48	2272	11
1	12	1408	816	48	2272	12
1	13	1408	911	378	2697	13
1	14	1408	651	378	2437	14
1	15	1408	651	378	2437	15
1	16	1280	705	270	2255	16
1	17	1280	705	270	2255	17
1	18	1408	765	150	2323	18
1	19	1408	765	150	2323	19
1	20	1408	765	150	2323	20
1	21	1024	702	660	2386	21
1	22	1024	702	660	2386	22
1	23	1408	623	414	2445	23

Figure 5.8 Parameters Change in Each Generation by GA

Figure 5.7 also shows the maximum traffic volume of every population in each generation calculated using genetic algorithm. The other parameters, namely the path traffic volume on an internal O-D pair (V_{pij}^{II}), path traffic volume on an internal-external O-D pair (V_{pij}^{EI}), number of emergency vehicles from rescue depot m to demand node n (V_{mn}), and maximum traffic volumes in disaster area, all vary with every individual population in each generation as shown in Figure 5.8.

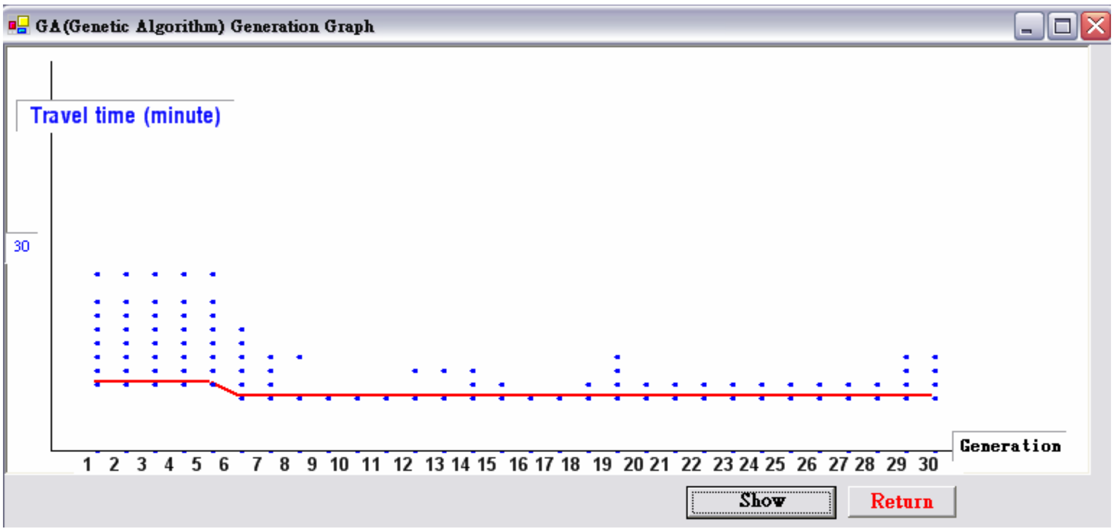


Figure 5.9 The Shortest Path Travel Time of Every Population in Each Generation

Figure 5.9 depicts the result of the shortest path travel time obtained by genetic algorithm. The blue points in the figure represent the various route path travel time in each generation. We select the minimum travel time in each generation denoted by the red line in the figure and demonstrate that the optimum solution to the problem converged at the sixth generation.

Figure 5.10 demonstrates the convergence of genetic algorithm iteration in each generation. As can be seen, the optimal solution is reached after the sixth generation of genetic algorithm.

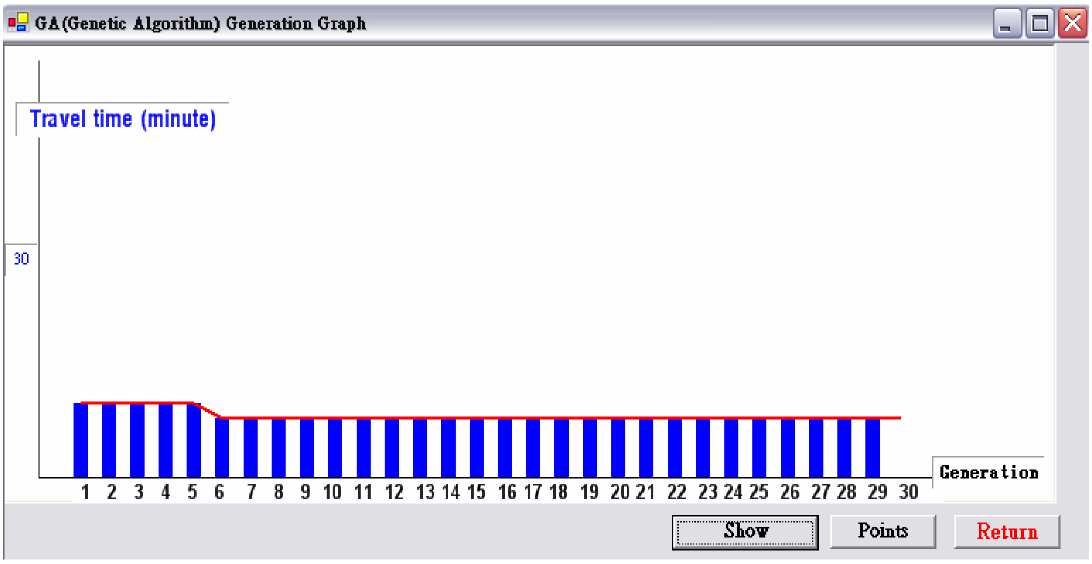


Figure 5.10 The Convergence of Genetic Algorithm Iteration

CHAPTER 6 CASE STUDY

6.1 Problem Descriptions

This study applies the Genetic Algorithm to the problems in order to illustrate the feasibility and realistically of the Revised Model. GA is a stochastic global search method that mimics the metaphor of natural biological evolution. GA operates on a population of potential solutions applying the principle of survival of the fittest to produce (hopefully) better and better approximations to a solution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation. Individuals or current approximations are encoded as strings, *chromosomes*, composed over some alphabets, so that the *genotypes* (chromosome values) are uniquely mapped onto the decision variable (*phenotypic*) domain. The most commonly used representation in GA is the binary alphabet {0, 1}.

Let us consider the real emergency rescue road network in Taipei city to further test which illustrate in Figure 6.1. The road network has 80 nodes and 278 links as depicted in Figure 6.2. According to the TELES simulated data, when a major earthquake is to happen in Taipei city, the Dar-Tong District area will be most seriously affected. We assume that nodes 9, 10, 17 are the origins, nodes 49, 50, 60 are the destination, and the other nodes are intermediate nodes for people in the disaster area to meet the needs of evacuation. The FHWA cost function is adopted throughout this study without loss of generality, the dispersion parameter γ is assumed to be 1. The total production trips at each origin and the attraction trips at each destination are hypothesized as shown in Table 6.1. The O-D traffic volumes under normal and degraded conditions are listed in Table 6.2.

This urban road network is taken from the real network of Taipei city. We assume there are nine O-D pairs: (9, 49), (9, 50), (9, 60), (10, 49), (10, 50), (10, 60), (17, 49), (17, 50) and (17, 60). The different scenarios are assumed according to the different road capacities such as the most serious area destructed by an earthquake in Taipei city, which assumed that the capacity of links in this sub-area are reduced by 50% ($L_2^1, L_3^2, L_8^1, L_9^8, L_9^2, L_{10}^9, L_{16}^8, L_{17}^{16}, L_{17}^9, L_{18}^{17}, L_{18}^{10}, L_{25}^{16}, L_{26}^{25}, L_{26}^{17}, L_{27}^{26}, L_{27}^{18}, L_{31}^{25}, L_{32}^{31}, L_{32}^{26}, L_{33}^{32}, L_{33}^{27}$ of road network). The second seriously affected area are decreased by 60% ($L_{10}^3, L_4^3, L_5^4, L_{11}^4, L_{12}^5, L_{11}^{10}, L_{12}^5, L_{12}^{11}, L_{19}^{18}, L_{19}^{11}, L_{19}^{11}, L_{20}^{19}, L_{20}^{12}, L_{28}^{27}, L_{28}^{19}, L_{29}^{28}, L_{29}^{20}, L_{34}^{33}, L_{34}^{28}, L_{35}^{34}, L_{35}^{29}$ of road network) and the others by 70% or 80% compared with the normal road network demonstrated in Table 6.2. Calculation of the road network capacity on the degraded road network generates 383,220 trips, 72% of the normal network capacity. In this study, the population size of GA is arbitrarily set at 100 while there is no limit on the number of non-dominated solutions. The gene chromosome representation is a binary integer with a fixed length of 20. The value of each gene indicates whether the corresponding link is selected as a traffic regulation measure. The one-point crossover with a crossover rate of 0.5 is adopted. A very low mutation rate of 0.01 is used for this multi-objective integer program. There are 30 generations of GA performed for generating non-dominated solutions.

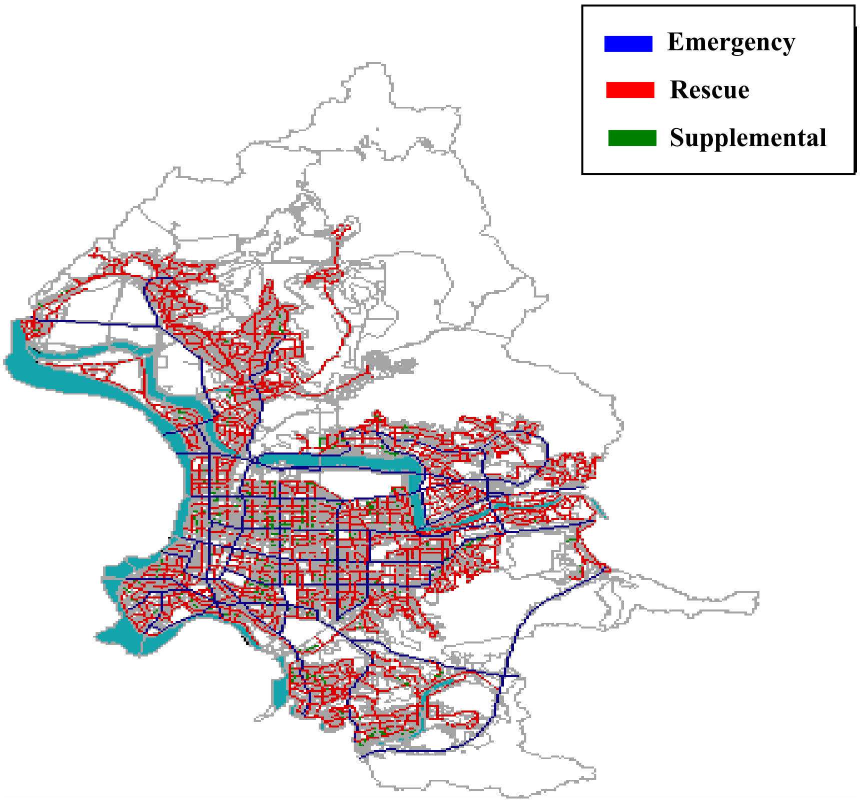


Figure 6.1 Emergency Rescue Road Network of Taipei City

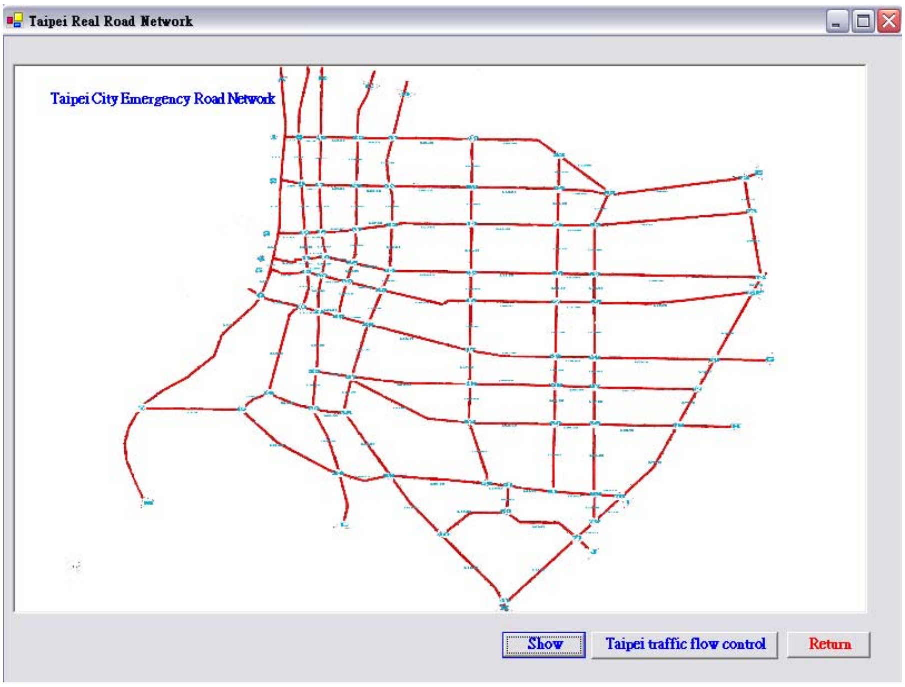


Figure 6.2 Test Road Network of Taipei City

Table 6.1 Production and Attraction Trips

O-D Point	**Origins**			**Destinations**		
	9	**10**	**17**	**49**	**50**	**60**
Trips	5,000	3,500	3,500	3,500	4,500	3,500

Table 6.2 Parameters for Traffic Regulation Problems

Links	**Capacity** normal / abnormal	**Traffic Volume**	**Free-flow Travel Time** (min)	**Links**	**Capacity** normal / abnormal	**Traffic Volume**	**Free-flow Travel Time** (min)
L_{2}^{1}	6000/ 3000	3600	0.612	L_{44}^{33}	5400/ 3780	3240	1.080
L_{3}^{2}	6000/ 3000	3600	0.828	L_{45}^{44}	6000/ 4200	3600	0.720
L_{4}^{3}	6000/ 3600	3600	0.360	L_{45}^{34}	5400/ 3780	3240	1.116
L_{5}^{4}	6000/ 3600	3600	0.216	L_{46}^{45}	6000/ 4200	3600	0.432
L_{6}^{5}	6000/ 4200	3600	0.480	L_{46}^{35}	4800/ 3360	2880	1.260
L_{7}^{6}	4000/ 2800	2400	2.448	L_{47}^{46}	6000/ 4200	3600	0.684
L_{8}^{1}	4000/ 2000	2400	0.216	L_{47}^{36}	6000/ 4200	3600	1.476
L_{9}^{8}	4800/ 2400	2880	0.943	L_{48}^{47}	6000	3600	0.504
L_{9}^{2}	4000/ 2000	2400	0.288	L_{48}^{37}	5400/ 3780	3240	1.608
L_{10}^{9}	4800/ 2400	2880	0.720	L_{49}^{48}	6000	3600	0.540
L_{10}^{3}	4000/ 2000	2400	0.360	L_{49}^{37}	7200/ 5040	4320	1.800
L_{11}^{10}	4800/ 2880	2880	0.360	L_{50}^{49}	6000	3600	0.936
L_{11}^{4}	3600/ 2160	2160	0.468	L_{50}^{39}	5400	3240	1.356
L_{12}^{11}	5400/ 3240	3240	0.216	L_{51}^{50}	5400	3240	0.312
L_{12}^{5}	3600/ 2160	2160	0.540	L_{52}^{51}	6000	3600	0.360
L_{13}^{12}	5400/ 3780	3240	0.540	L_{52}^{40}	4800	2880	1.080
L_{13}^{6}	6000/ 4200	3600	0.540	L_{53}^{42}	4800/ 3360	2880	1.260
L_{14}^{13}	6000/ 4200	3600	1.368	L_{54}^{53}	7200/ 5760	4320	0.504
L_{15}^{14}	5400/ 3780	3240	0.612	L_{54}^{43}	5400/ 3780	3240	1.200
L_{15}^{7}	5400/ 3780	3240	1.368	L_{55}^{54}	7200/ 5760	4320	0.540
L_{16}^{8}	4000/ 2000	2400	0.324	L_{55}^{44}	6000/ 4200	3600	1.200
L_{17}^{16}	6000/ 3000	3600	0.684	L_{56}^{55}	7200/ 5760	4320	0.720
L_{17}^{9}	4000/ 2000	2400	0.276	L_{56}^{45}	6000/ 4200	3600	1.188
L_{18}^{17}	6000/ 3000	3600	0.756	L_{57}^{56}	7200/ 5760	4320	0.420
L_{18}^{10}	4000/ 2000	2400	0.252	L_{57}^{46}	4800/ 3360	2880	1.188
L_{19}^{18}	6000/ 3600	3600	0.360	L_{58}^{57}	7200/ 5760	4320	0.780
L_{19}^{11}	3600/ 2160	2160	0.288	L_{58}^{47}	6000/ 4800	3600	1.188
L_{20}^{19}	6000/ 3600	3600	0.288	L_{59}^{58}	7200	4320	0.432
L_{20}^{12}	3600/ 2160	2160	0.216	L_{59}^{48}	5400	3240	1.188
L_{21}^{20}	4000/ 2800	2400	0.540	L_{60}^{59}	7200	4320	0.540

L_{21}^{13}	6000/4200	3600	0.324	L_{60}^{49}	7200	4320	1.152
L_{22}^{21}	6000/4200	3600	0.900	L_{61}^{60}	7200	4320	0.996
L_{23}^{22}	4000/2800	2400	0.540	L_{61}^{51}	5400	3240	0.612
L_{23}^{14}	6000/4200	3600	0.648	L_{62}^{53}	4800	2880	0.936
L_{24}^{23}	4000/2800	2400	1.080	L_{62}^{54}	5400/4320	3240	0.756
L_{24}^{15}	5400/3780	3240	1.800	L_{63}^{62}	7200/5760	4320	0.504
L_{25}^{16}	4000/2000	2400	0.504	L_{63}^{55}	4800/3840	2880	0.564
L_{26}^{25}	6000/3000	3600	0.684	L_{64}^{63}	7200/5760	4320	0.720
L_{26}^{17}	4000/2000	2400	0.504	L_{64}^{56}	6000/4800	3600	0.564
L_{27}^{26}	6000/3000	3600	0.684	L_{65}^{64}	7200/5760	4320	0.396
L_{27}^{18}	4000/2000	2400	0.492	L_{65}^{57}	4800/3840	2880	0.564
L_{28}^{27}	6000/3600	3600	0.540	L_{66}^{65}	7200/5760	4320	0.792
L_{28}^{19}	3600/2160	2160	0.360	L_{66}^{58}	6000	3600	0.576
L_{29}^{28}	6000/3600	3600	0.288	L_{67}^{66}	7200	4320	0.432
L_{29}^{20}	3600/2160	2160	0.360	L_{67}^{59}	5400	3240	0.576
L_{30}^{29}	6000/4200	3600	0.540	L_{68}^{67}	7200	4320	0.540
L_{30}^{21}	6000/4200	3600	0.288	L_{68}^{60}	7200	4320	0.576
L_{31}^{25}	4800/2400	2880	0.504	L_{69}^{68}	7200	4320	1.008
L_{32}^{31}	6000/3000	3600	0.720	L_{69}^{61}	4800	2880	0.576
L_{32}^{26}	4800/2400	2880	0.504	L_{70}^{69}	7200	4320	0.432
L_{33}^{32}	6000/3000	3600	0.612	L_{71}^{70}	7200	4320	0.360
L_{33}^{27}	4800/2400	2880	0.540	L_{71}^{52}	7200	4320	1.260
L_{34}^{33}	6000/3600	3600	0.684	L_{71}^{41}	5400	3240	1.440
L_{34}^{28}	4800/2880	2880	0.540	L_{72}^{62}	4800	2880	1.944
L_{35}^{34}	6000/3600	3600	0.288	L_{73}^{72}	4800	2880	0.504
L_{35}^{29}	4000/2400	2400	0.504	L_{73}^{63}	4800	2880	2.196
L_{36}^{35}	6000/4200	3600	0.540	L_{74}^{73}	4800	2880	0.972
L_{36}^{30}	6000/4200	3600	0.456	L_{74}^{64}	5400	3240	2.340
L_{37}^{36}	6000/4200	3600	0.792	L_{75}^{74}	4800	2880	0.216
L_{37}^{22}	6000/4200	3600	0.540	L_{75}^{65}	4800	2880	2.232
L_{38}^{37}	6000/4200	3600	0.540	L_{76}^{75}	5400	3240	1.116
L_{38}^{23}	6000/4200	3600	0.468	L_{76}^{66}	6000	3600	1.692
L_{39}^{38}	6000/4200	3600	1.152	L_{77}^{76}	5400	3240	0.468
L_{39}^{24}	5400/3780	3240	0.756	L_{77}^{67}	5400	3240	1.440
L_{40}^{39}	6000	3600	1.152	L_{78}^{77}	5400	3240	0.576
L_{41}^{40}	6000	3600	1.368	L_{78}^{68}	5400	3240	1.188
L_{42}^{31}	4800/3360	2880	1.116	L_{79}^{78}	5400	3240	1.296
L_{43}^{42}	6000/4200	3600	0.504	L_{79}^{69}	5400	3240	0.432
L_{43}^{32}	5400/3780	3240	1.116	L_{79}^{70}	5400	3240	0.540
L_{44}^{43}	6000/4200	3600	0.540				

6.2 Solution by Genetic Algorithm

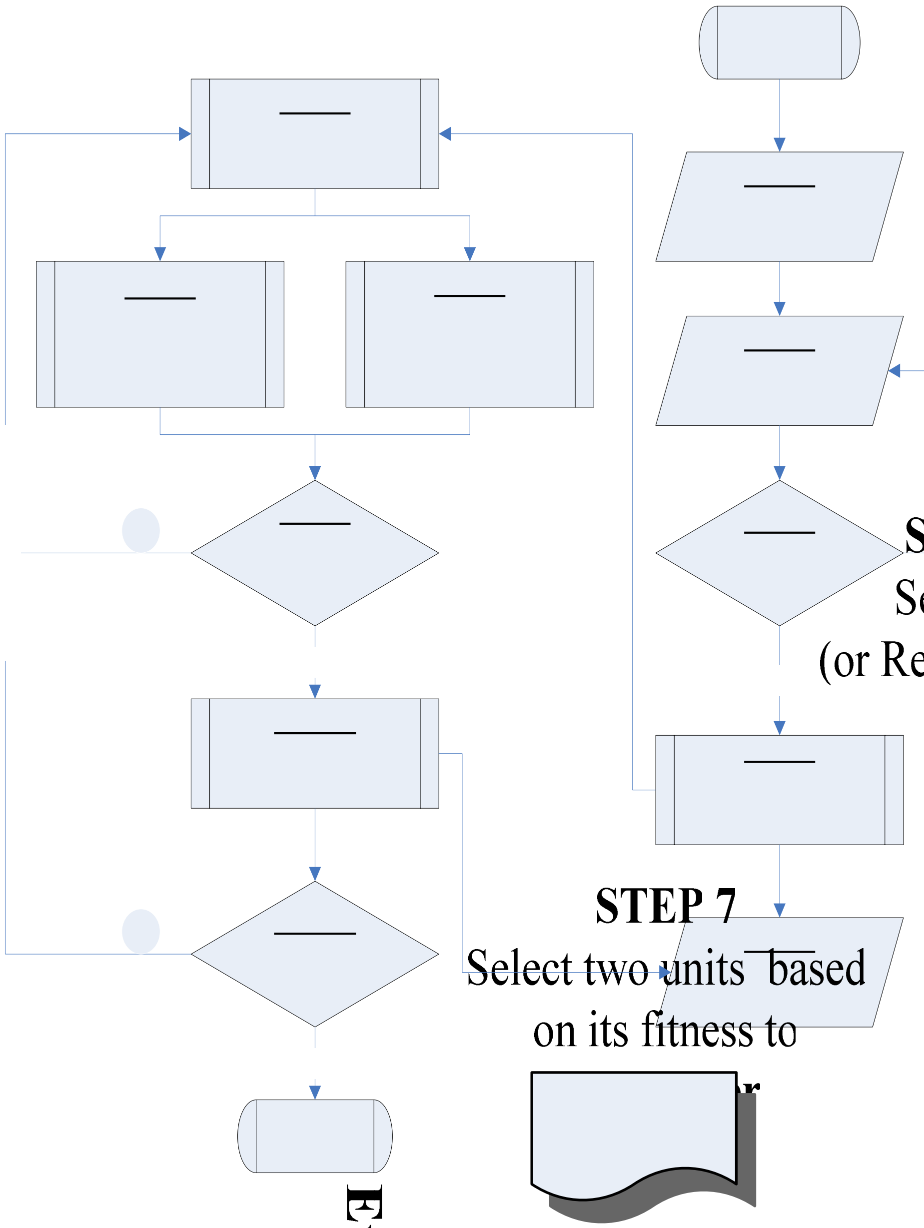


Figure 6.3 Flow-chart of Cumulative Genetic Algorithm Approach

A number of features have made GA a popular tool for applications, and a very easy-to-understand technique for reaching a solution. Rather, the GA can be fully exploited in its parallel structure to gain the required speed for practical uses. While GAs are not perfect, i.e., they do not always obtain the optimal point, they are very efficient in attaining near-optimal solutions significantly faster than conventional point-by-point exhaustive search techniques, especially in large solution spaces. In this research, we apply cumulative genetic algorithm (CGA) that can resolve the multi-objective problem and is capable of handling problem with constraints. The step in this cumulative genetic algorithm approach is shown in Figure 6.3 and the steps involved are described in the following.

STEP 1 Encoding and Parameter Setting

When using genetic algorithm, the solution of problem was decoded as chromosome is the key point of whether the algorithm can implement. There are two critical issues of concern. One is how to handle the phenotype space property of problem mixed together with genotype space; that is, how to introduce the solution of problem represented by genes. The other is the transformation of gene pattern and type when performing genetic algorithm. Therefore, in this problem, we first handle the decision variables using binary encoding. Then the problem is encoded with seven bits (or genes), which represent the different regulation points of road network in the regulated area; with eight bits, which represent the possible pass links of road network in the disaster area; with three bits, which represent the traffic volume of links; and with two bits, which represent the travel time of links. The overall of string named the chromosome that contains 20 bits as illustrated in Figure 6.4. In addition, in this study, the parameters are generation size of 30, population size of 100, mutation rate of 0.01, and crossover rate of 0.9.

n_1	n_2	…	n_6	n_7	l_1	l_2	…	l_7	l_8	v_1	v_2	v_3	t_1	t_2

Regulation Points *Possible pass node (n=1)* *Otherwise (n=0)*

Links of Road Network *Possible pass link (l=1)* *Otherwise (l=0)*

Traffic Volume ***Travel Time*** *Parametric genes*

Figure 6.4 Chromosome Coding

<u>STEP 2</u>   Create Initial Population

The first step of GA is to create an initial population. In this research, the random number generator that distributes uniformly numbers in the desired range is employed to acquire the required number of individuals.

<u>STEP 3</u>   Population Size Checking

The number of individual chromosomes in each evolution is named as population. A larger population represents greater number of chromosomes in parallel searching, which has greater chance of obtaining the optimal solution. Since a large computer memory is required for evolution, the time taken is longer. However, it is harder for smaller population to obtain the optimal solution, and it is easy to fall in the trap of obtaining a local optimal. Therefore, in this study, we set the population size as 100. When the initial population has not reached the setting number of value, and then repeated STEP 2.

<u>STEP 4</u>   Estimate Population Fitness

The objective function is employed to provide a measure of how individuals have performed in the problem domain. Another function, the fitness function, is normally used to transform the objective function value into a measure of relative fitness, thus: $F(x) = g\ (f(x))$ where f is the objective function, g transforms the value of the objective function to a non-negative number and F is the resulting relative fitness. In many cases, the fitness function value corresponds to the number of offspring that an individual can expect to produce in the next generation. A commonly used transformation is that of proportional fitness assignment. The individual fitness, $F(x_i)$, of each individual is computed as the individual's raw performance, $f(x_i)$, relative to the whole population, i.e.,

$$F(x_i) = f(x_i) \Big/ \sum_{i=1}^{N} f(x_i)$$

Where N is the population size and x_i is the phenotypic value of individual i. This fitness assignment ensures that each individual has a probability of reproducing according to its relative fitness.

The selection algorithm selects individuals for expected number of offspring, which is approximately proportional to that individual performance. Baker (Chipperfield, 2003) suggests that by limiting the reproductive range, no individual can generate an excessive number of offspring, thus preventing premature convergence. In this research, individuals are assigned fitness according to their rank in the population rather than their raw performance. A variable V_b is employed to determine the bias or selective pressure, and typically chosen in the interval [1.1, 2.0]. The fittest individuals and the fitness of the others are determined by the following rules:

$$L_B = 2.0 - V_b$$

$$D_f = 2.0 \times (V_b - 1.0) / N_S$$

$$N_T = D_f / 2.0$$

Where L_B is the lower bound, D_f is the difference between the fitness of adjacent individuals, N_T is the expected number of trials (number of times selected) of the least fit individual, and N_S is the population size. The fitness of individuals in the population may also be calculated directly as:

$$F(x_i) = 2 - V_b + 2 \cdot (V_b - 1) \cdot \frac{x_i - 1}{N_s - 1}$$

Where x_i is the position in the ordered population of individual i.

<u>STEP 5</u> **Store Non-inferior Solution**

According to the fitness estimated by STEP 4, if one solution has higher fitness value, it is better than another. Then the expected number of better population fitness in the non-inferior solution set is collected.

<u>STEP 6</u> **Selection (or Reproduction)**

Selection is the process of determining the number of times, or trials, the particular individual are chosen for reproduction, and thus the number of offspring that an individual will produce. The selection of individuals can be viewed as two separate processes:

1. Determining of the number of trials an individual can expect to receive;
2. Converting the expected number of trials into a discrete number of offspring.

The first part is concerned with the transformation of raw fitness values into a real-valued expectation of an individual's probability to reproduce and deals with fitness assignment. The second part is the probabilistic selection of individuals for reproduction according to the fitness of individuals relative to one another and is sometimes known as sampling.

The desire for efficient selection methods is motivated by the need to maintain the overall time complexity of GAs. In this study, we employ a "roulette wheel" mechanism to select individuals probabilistically according to some measure of their performance. The Roulette Wheel Selection is the most common techniques being used for such a proportionate selection mechanism. The selection procedure is depicted in Section 3.3. For example, in Figure 6.5, the circumference of the roulette wheel is F_{sum} for all five chromosomes. Chromosome 1 is the fittest chromosome and occupies the largest interval, where chromosome 3 is the least fit, which corresponds to a smaller interval within the roulette wheel. To select a chromosome, a random number is generated in the interval $[0, F_{sum}]$ and the individual whose segment spans the random number is selected. If the population size is N and each individual's fitness is represented by f_i, then the probability of each individual chromosome selected is $f_i \Big/ \sum_{k=1}^{N} f_k$.

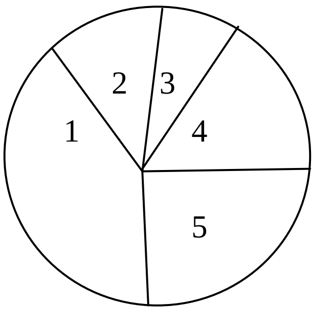


Figure 6.5 Roulette Wheel Selections

<u>STEP 7</u>   Crossover

The crossover procedure implements the exchange mechanism between two parent chromosomes. In this study, we applied the one-point crossover mechanism as illustrated in Section 3.3. A crossover point is randomly set. An operation rate (p_c) is set as 0.5. Crossover between selected chromosomes possibly reproduces fitter chromosomes. Therefore, the fittest chromosomes will be reproduced and their offspring will be added to the next generation.

<u>STEP 8</u>   Mutation

Besides crossover, mutation is another genetic operator. In general, good solutions can usually be obtained by applying the reproduction and crossover operations. However, there may still be a small number of choices that are not explored since they are absent from the initial population. In genetic algorithm, the simplest way of mutation is transmitting inversely the gene (bit), and the mutation process is demonstrated in Section 3.3. It alters each bit randomly with a small probability (p_m). In mutation rate setting, it will set a lower value under normal situation so that it cannot destroy the better chromosomes produced by selection and crossover operations.

From the literature, we learn that there are two kinds of mutation operation. One is the “standard mutation”, where a constant mutation rate is set and the gene is searched step by step using this mutation rate. When the mutation operation occurs, it changes the gene value. The other is the “aggressive mutation”, its operation measure is the same as that of standard mutation, but the mutation rate increases with increasing number of evolution generations. In the initial stage of evolution, the major purpose is to converge to an approximate optimal solution, and thus the mutation rate is set at a lower value. When the chromosome evolution proceeds, concern about the solution being a local optimal arises. In order to look for the missing optimal solution, the mutation rate is set at a higher value. In this study, we employ the “standard mutation” method to search the gene.

STEP 9 **Offspring Checking**

Because the GA is a stochastic search method, it is difficult to formally specify the convergence criteria. As the fitness of a population may remain static for a number of generations before a superior individual is found, the application of conventional termination criteria becomes problematic. In order to avoid long computation, a termination method stops the evolution when the user-specified maximum number of populations is reached.

STEP 10 **Estimate Offspring Fitness**

Each individual fitness value of the offspring is compared with that of the STEP 5 non-inferior solution set. The non-inferior solution set is then updated with newer and non-inferior chromosomes.

STEP 11 **Generation Checking**

Check if the maximum number of generation is reached? If the user-specified maximum number of evolutions has been obtained, then STOP.

6.3 Analysis of Results

A computer program coded with Visual Basic.NET was performed by Genetic Algorithm on a PentiumⅣ personal computer with 32M RAM. We assumed that each demand node requires 600 emergency vehicles, and the same condition as the previous hypothetical road network. The solution algorithm analysis demo depicts the bi-level traffic regulation problem objectives, test road network, capacity and free flow travel time, and other assumed initial population data as shown in Figure 6.6.

Figure 6.6 shows the results of tests performed with 80 nodes and 278 links, and the data are assumed to have a population size of $p_s = 100$, a mutation rate of $p_m = 0.01$, and a crossover rate of $p_c = 0.5$. At the top of this computer program demo, we can see the assumed normal and degraded link capacities in each generation, and the variation in internal-internal trips, internal-external trips and maximum traffic volume in disaster areas. The middle of this figure depicts the original (rescue nodes) and destination (demand nodes) points, and the diagram of statistic analysis implemented by genetic algorithm. This part of the figure shows the execution time of 3306.56 seconds when performing bi-level programming and user equilibrium assignment by genetic algorithm, the total number of trips on the road network inside the disaster area is 327,000. Although the traffic volumes after traffic regulation indicate residual road network capacity, it should be retained to accommodate all emergency rescue trips from outside into the regulated area. Then the number of passengers cars permitted to enter the regulated area is about 186,504 trips and the maximum number of trips allowed in the entire regulated area is 515,304 trips. Moreover, the right-hand side of this figures not only shows that the shortest path travel time is 7.98 minutes in each generation, but also reveals the function of statistical graphs depicted as follows.

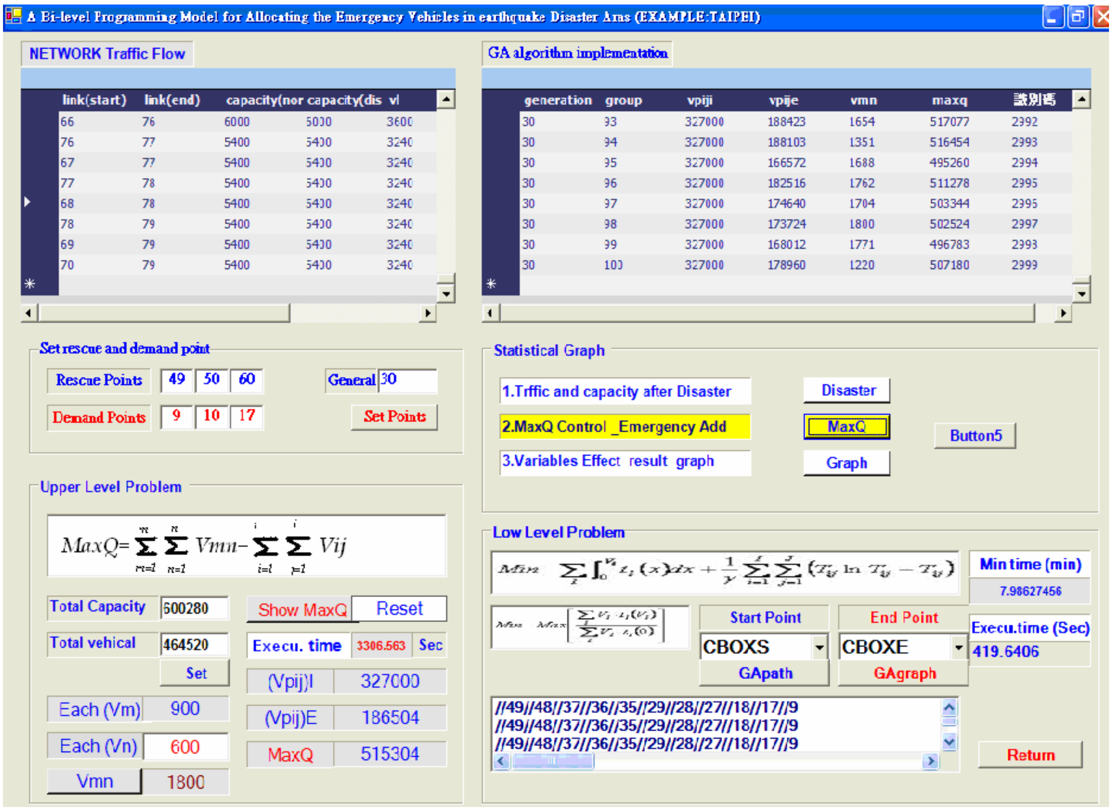


Figure 6.6 Visual Basic.NET Program Execute by Genetic Algorithm

Figure 6.7 shows that the road network capacity (yellow curve) and traffic volume (blue bar-chart) in each links under normal condition. As can be seen, after the earthquake, the road network capacity (red curve) was degraded and the traffic volume (green bar-chart) is increased tremendously approaching close to the full capacity.

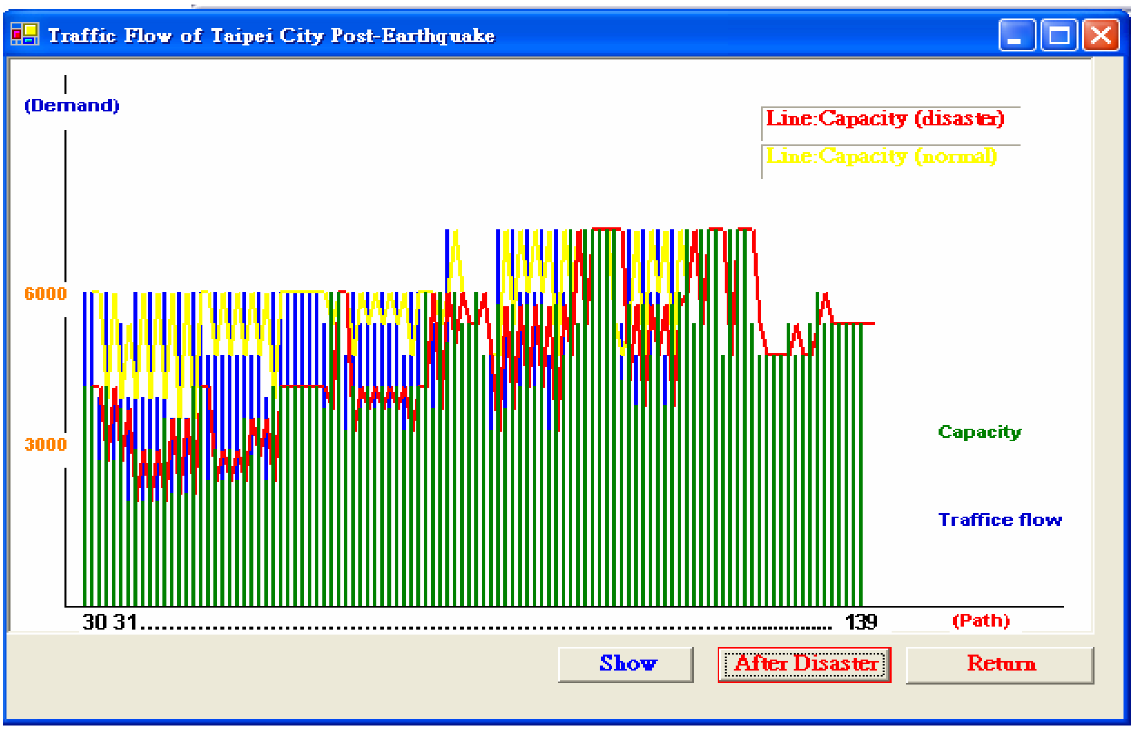


Figure 6.7 Road Network Capacities and Traffic Volumes

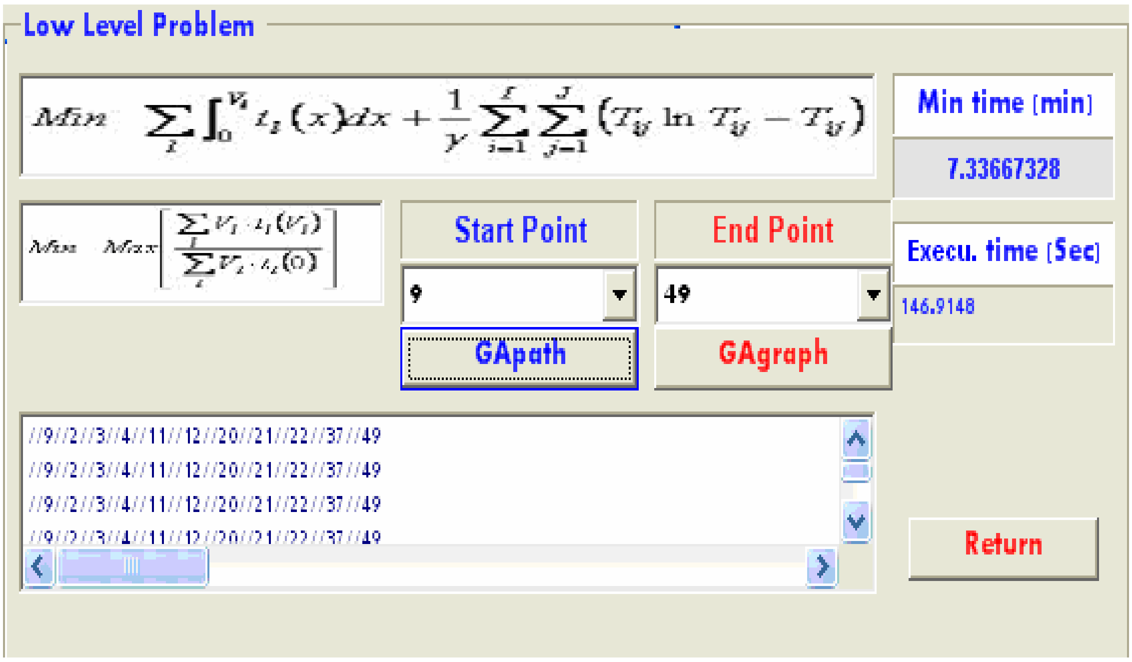


Figure 6.8 Process of Genetic Algorithm Iteration

Figure 6.8 displays the iteration process of the genetic algorithm. According to the TELES simulation data, we take the reference parameters as our traffic regulation model input data. By way of bi-level programming and combine user equilibrium assignment and trip distribution algorithm, the genetic algorithm executes the shortest path analysis and demonstrates the process of iteration. As seen in Figure 7.8, the shortest path is from node 9 to node 49, the execution time is 146.9 seconds, and the travel time of this path is 7.34 minutes.

Figure 6.9 depicts the shortest path travel time of each population obtained by genetic algorithm. The blue points in the figure represent the travel time of various route paths in each generation. The minimum travel time in each generation is selected by genetic algorithm shown as the red line in the figure. As can be seen, the iteration converged at the fourth generation. In other words, after the fourth generation iterated by genetic algorithm, the optimal solution is reached and demonstrated in Figure 6.10.

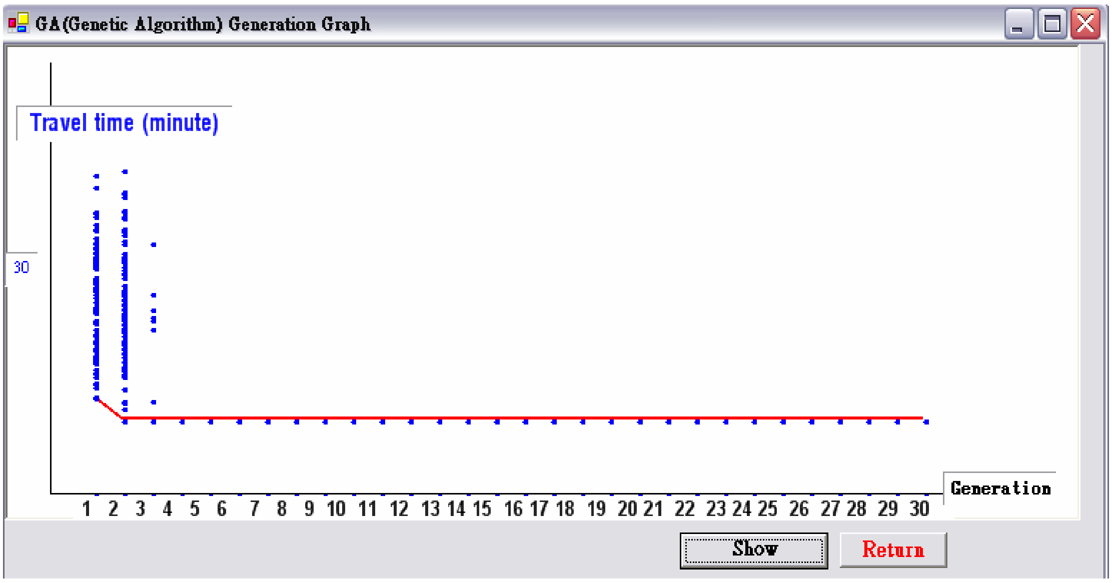


Figure 6.9 The Shortest Path Travel Time of Every Population in Each Generation

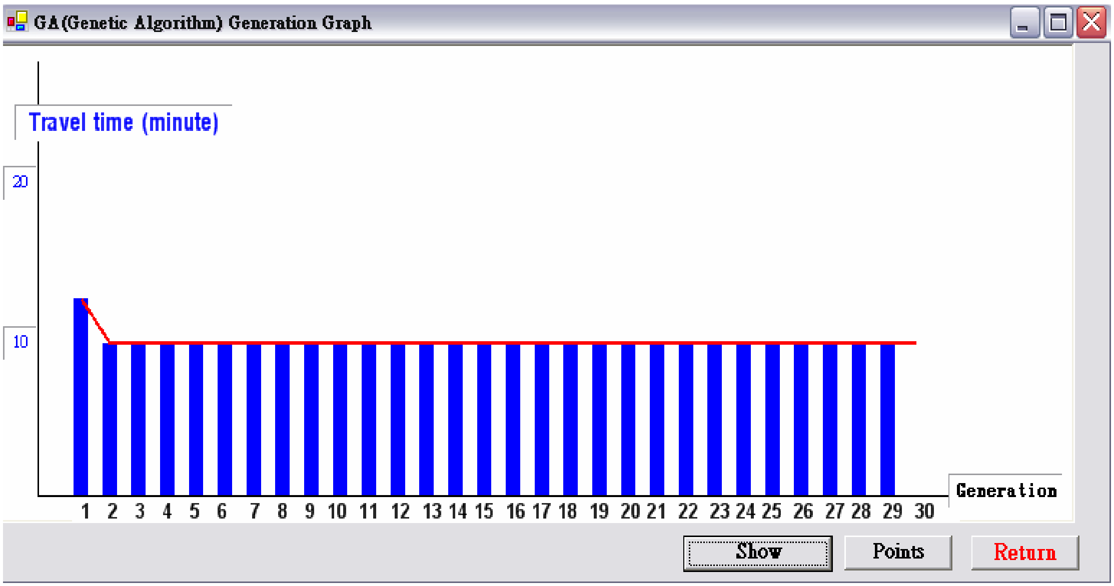


Figure 6.10 The Convergence of Genetic Algorithm Iteration

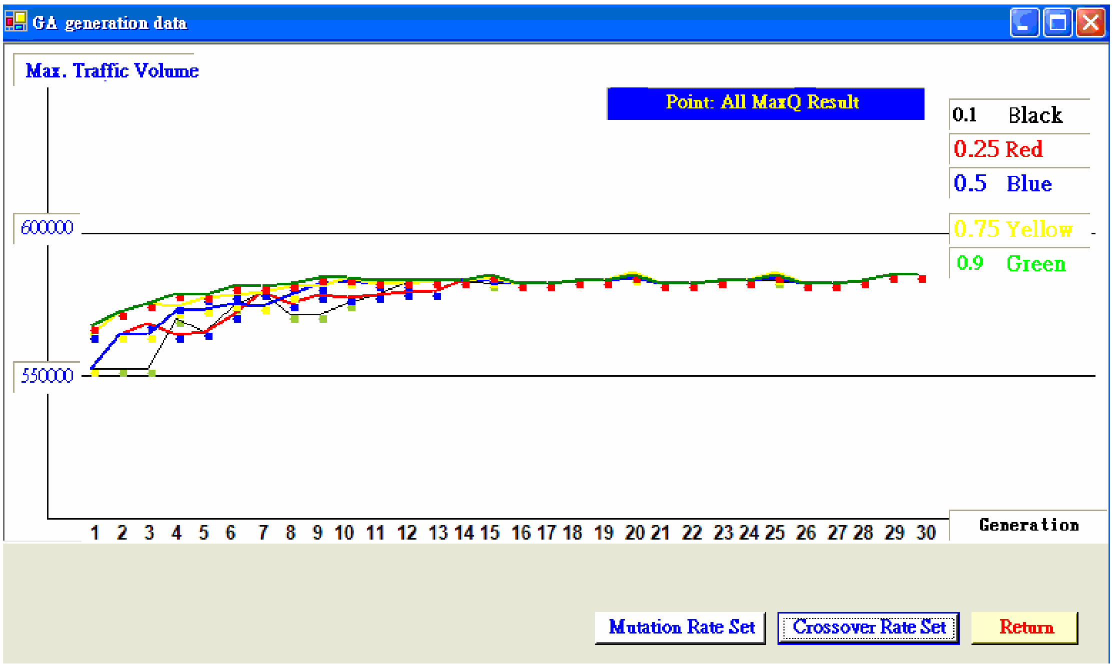


Figure 6.11 Effect of the Different Crossover Probability for Medium-size Network

In Figure 6.11, when we change the crossover probability (P_c) from 0.1 to 0.9, it is easy to find that the higher the crossover probability, the better the solution is. As can be seen, when P_c = 0.75 and P_c = 0.9, the solution is good. Although this is a special case of traffic regulation, then according to the principle, a higher P_c value is more useful than a smaller P_c value for reaching an agreement. The parameters employed are generation size of 30, a population size of 100, a mutation rate of 0.01 and a crossover rate of 0.9. In general, for large population size (100) the crossover probability is 0.6, and for small population size (30), the crossover probability is 0.9. The typical value of crossover probability is 0.9.

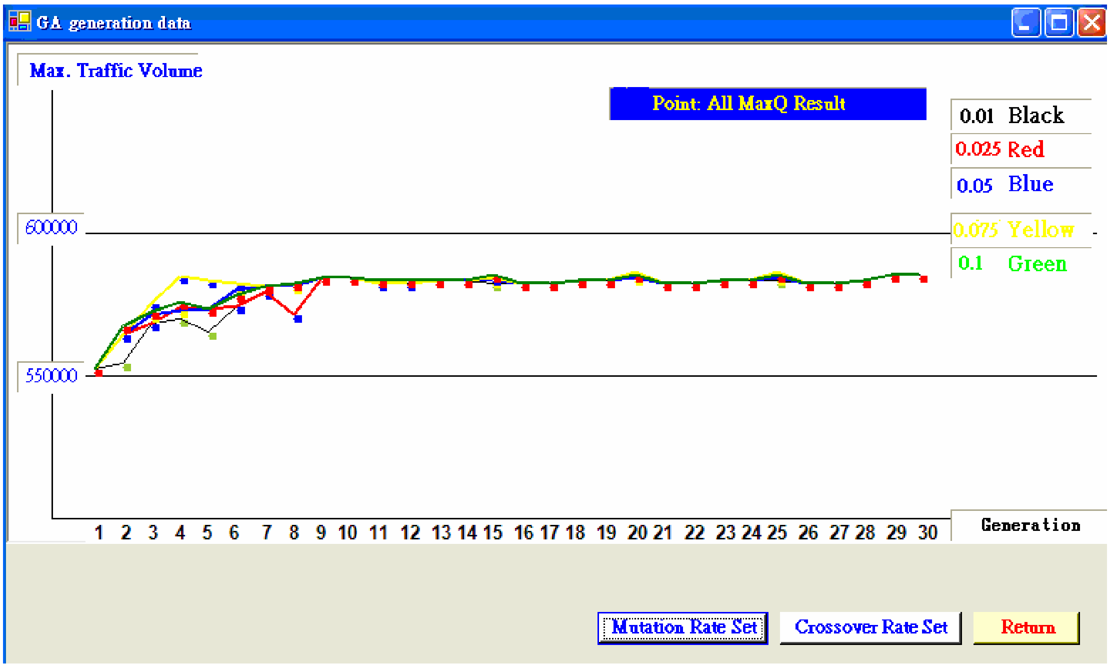


Figure 6.12 Effect of the Different Mutation Probability for Medium-size Network

In Figure 6.12, when we change the mutation probability (P_m) from 0.01 to 0.1, it is easy to find that P_m = 0.075 yields the best solution in few generations, and we can see from the figure that when P_m = 0.05 and P_m = 0.075, the solution obtained is good. The parameters employed are generation size of 30, a population size of 100, a mutation rate of 0.01 and a crossover rate of 0.9. In general, for large population size (100) the mutation probability is 0.001; and for small population size (30) the mutation probability is 0.01. The typical value of mutation probability is 0.01.

Table 6.3 Comparisons of Performance Measures in Revised Model

Network Number / Performance Measure	***Test A Small Grid Network***	***Test A Medium-Size Real Road Network***
Number of Iterations	5-10	30-40
Objective Value	2476 trips	515304 trips
Total Execution Time (sec)	40.2 seconds	3306.5 seconds
Memory Requirement (bytes)	19160 Kbytes	41464 Kbytes

The results of simple grid network and medium-sized real road network obtained by genetic algorithm are compared in terms of four performance measures, i.e., number of iterations, objective value, total execution time, and memory requirement. The results are summarized in Table 6.3. As can be seen, although the results of simple grid network represent the need of lower memory requirement, few numbers of iterations, and shorter execution time for obtaining the optimal objective value, a simply GA has difficulty in tackling complicated, multi-tasking and conflicting problems, and the speed of computation is generally regarded as slow. For a medium-sized real road network with 80 nodes and 278 links, the computation time is increased tremendously. To enhance the capability of GA for practical uses, the intrinsic characteristics of GA should be further exploited and explored.

6.4 Discussions and Summary

In this chapter, we develop a traffic regulation decision-making model (Revised Model) to find an effective post-quake traffic regulation strategy for road network in damage areas. In view of the traffic flow management problem in disaster area, we apply the area regulation strategy and introduce the traffic regulation model concept and genetic algorithm resolution steps. Since the problem is NP-complete, we employ the GA to solve such a combinatorial optimization problem. Although there remain many unanswered questions remaining, it is necessary to experiment with different encoding, crossover and mutation operators. It would be interesting to test with very large size problems (i.e. graphs with thousands of nodes).

When formulating the Revised Model, we change the traditional and subjective regulation concept, which is, prohibiting the private vehicles from entering the damaged area completely. This arouses dissatisfaction from disaster victims and complaints from the general public whose needs for travel cannot be met. In particular, in the aftermath of a major earthquake, the extensive use of privately owned cars not only for evacuation or the procurement of supplies, but for confirming the personal safety of relatives or acquaintances has indicated the importance of managing the travel made with passenger car. Contingency plans are needed for both the area and time for traffic regulation. While total ban on travel in passenger cars is impossible and considering that most of these trips are for very short distance, it is argued that the use of passenger cars should be allowed as much as possible.

In this research, we introduced the parallel paradigm of a Genetic Algorithm and successfully applied it to the UE (or Wardropian) distribution/assignment problem. Despite the lack of a thorough performance analysis of the parallel Genetic Algorithm proposed, the results presented in this study show its utility, versatility, efficiency and potential value in solving NP-complete problems. It indeed provides a powerful means of obtaining global optimal solutions that cannot be obtained by existing methods. We also show that the parameter setting of P_c and P_m are very important. It will have better performance with suitable parameter setting. Different network topologies have different ranges of optimal parameter setting. In principle, P_c cannot be too small and P_m cannot be too large. The typical value of P_c is 0.9 and that of P_m is 0.01.

Finding the shortest path for emergency rescue operations problem involve mathematical optimization. If there are more precise data for our model, a traffic regulation strategy can be scientifically made after a large-scale earthquake. Furthermore, the traffic regulation decision-making model constructed has been proved to be powerful and effective. Not only can it provide training and experience in traffic management, it also has great potential to be installed in regulated areas for emergency vehicles and to be combined with a geographic information system so as to reflect the true reality.

When implementing traffic regulation, the private vehicle flows are controlled when travel demand exceeds the capacity of a network, and the emergency vehicles carrying supplies and relief personnel are managed during a disaster emergency. Effective traffic management is dependant on reliable traffic data not only during normal operation, but also in the aftermath of a large-scale earthquake. In this study, we refer to the TELES simulation data as hypothetical scenarios input data for analysis. In particular, we deal with the problem of controlling the private vehicle flows, which can be generated in and attracted to each zone considering the classification of O-D trips and determining the priority of emergency vehicles to be regulated into disaster areas. The results demonstrate that the execution of a particular disaster scenario not only provides experience in handling traffic management under disaster conditions, but also ensures a capable and reliable response by implementing appropriate traffic management strategies in the event of an actual disaster.

CHAPTER 7 CONCLUSIONS AND SUGGESTIONS

7.1 Conclusions

Using the bi-level programming model, this study attempts to build a dynamic traffic regulation strategy to deal with the needs of emergency rescue operation 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 solved a numerical case using fuzzy interactive algorithm. To solve the model realistically and efficiently, the study has conducted a simple case study and real road network study using the hypothetic scenario analysis with the TELES simulation data, and by applying genetic algorithm. The test results show that this study can formulate an effective traffic regulation strategy for traffic regulation in the aftermath of an earthquake. The contributions of our work are as follows:

1. We have formulated a model for mathematical and interactive decision environment and traffic regulation issues, which is proved to be flexible and effective in solving the traffic regulation problem in earthquake disaster areas;

2. We have shown how a bi-level programming model can be employed to improve existing traffic management systems by controlling rationally the entrance of private vehicles and emergency rescue vehicles in the disaster areas;

3. We have demonstrated that the “Taiwan Earthquake Loss Estimation System” simulation data and the bi-level programming model technique can be utilized to implement an analogous dynamic traffic regulation mechanism for real-time traffic management;

4. The properties of the bi-level traffic regulation problem are much more complicated

than the usual mathematical programming problem and the set of its feasible solution is non-convex and non-unique. We apply the Fuzzy Interactive Algorithm for solving the fuzziness of link performance function. It is found in all the tests that not only the problem is more realistically presented, but the problem is more simplistically solved;

5. Owing to the constraints of computation, we apply the Genetic Algorithm for solving the real large scale road network problems. It is found that the solution algorithm for large network system of the developed traffic regulation model appears to be a powerful approach;

6. The vulnerability of the infrastructure is the major factor of casualties in earthquake disaster areas. It is more likely to have serious damages in the urban area with high density of populations and particularly at the peak-hour periods. Therefore, this study develops a traffic regulation decision-making tool that can potentially maintain a level of road network functionality and thus minimize the loss of life. For the long term disaster preparedness, we must develop a seismic early warning system, elevate seismic-resistant standards of infrastructural and stipulate an anti-earthquake structural code. It is expected that the development of ITS technology will play an important role in disaster mitigation and prevention.

7.2 Suggestions

The bi-level programming model has been proved to be flexible and effective in solving the problem of traffic regulation 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, since the lower-level objectives in the bi-level programming model are analyzed following the “User Equilibrium”, If the problem covers an extensive time period, the problem complexity will increase significantly and the computation efficiency will be a serious concern for the model’s application. Hence, adopting the “System Equilibrium” instead of the “User Equilibrium” should be considered.

Second, obtaining comprehensive data to reflect the true damages in the earthquake-raided areas to verify the feasibility of the models is still a difficult task at this stage. It should be done in the near future, although the data recovery and preservation like the incident itself has a lot of confusion.

Third, this study facing the emergency rescue traffic regulation problem in aftermath of earthquake disaster and formulating the static road-network equilibrium model based on the motorists road choice behavior. When incorporated temporal dimension into the model such that the dynamics of flow variations over time can be better represented.

Fourth, this study assumes that the motorists have the same behavioral facing the disaster to reduce the computational complexity of the bi-level optimization model.

Therefore, variations for traffic mode choice and evacuation behavior of motorists are not considered. It is suggested to take the difference of individual behavior into consideration in the future study could make the model more realistic.

Finally, the study suggests that developing an efficient information and decision support system will be more worthwhile than establishing comprehensive contingency plans for some unexpected disasters. In Particular, it is believed that the development of ITS technology can be of more help in improving existing traffic management systems. In that case, some limitations of the proposed model in application might not be a problem in the future.